Centre for Aerospace & Defence Laws (CADL)
Directorate of Distance Education
NALSAR University of Law, Hyderabad

Course Material

M.A. (SPACE AND TELECOMMUNICATION LAWS)

2.3.10. LAW OF REMOTE SENSING AND GEOSPATIAL DATA

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MODULE-I

INTRODUCTION TO REMOTE SENSING AND GIS

INTRODUCTION TO REMOTE SENSING

The use of remote sensing perhaps goes all the way back to prehistoric times when early man stood on a platform in front of his cave and glanced at the surrounding landscape. These humans were remotely sensing the features in the landscape to determine the best places to gather food and water and how to avoid becoming a food for the other inhabitants of the landscape. The term "photography" is derived from two Greek words meaning "light" (phos) and "writing" (graphein). All cameras and sensors utilize the same concept of light entering a camera or a sensor and being recorded on a film or on a digital media.

The term remote sensing as used for Earth observation has experienced major changes since the 1960s. It was not until the 1960s that "remote sensing" moved beyond black and white aerial photography and began to evolve towards its usage today in the twenty-first century. The past 50 years have seen the development of remote sensing platforms for high-altitude aircraft and satellites and the development of imaging sensors for collecting data from various regions of the electromagnetic spectrum. In concert with these advances in image acquisition capabilities were the developments of image display and processing techniques and algorithms. With the increase in processing power, these image processing software have migrated from mainframe computers to desktops to handheld mobile smart devices.

Along with the advances in technology, there has been a rapid and growing social acceptance of remote sensing. At first, remote sensing was a concern to the public with the "eye in the sky" and "Big Brother" concept. This perception, however, has eroded to a very large extent (but may be returning). Today, a large variety of sensors are deployed on numerous satellites and airborne platforms that collect vast amounts of remotely sensed data around the globe and around the clock. These data of various characteristics in spectral, spatial, radiometric, and temporal resolutions are commonly utilized in the areas of environmental and natural resource management, climate change, disaster management, law enforcement, military, and military intelligence gathering. Remote sensing has permeated our daily lives through Google Earth; global positioning systems (GPS); weather forecasting, wildland fire, hurricane, and disaster management; precision agriculture; and natural resources inventory and monitoring. We cannot live without it.

What Is Remote Sensing, and Why Do It?

Today, the field of remote sensing is a well-recognized interdisciplinary field across the globe. This field is often coupled with the disciplines of image processing (IP), geographic information systems (GIS), and GPS to create the broad field of geospatial science and technologies.

Remote sensing is defined as the acquisition and measurement of information about certain properties of phenomena, objects, or materials by a recording device not in physical contact with the features under surveillance. This is a rather broad definition that encompasses, for instance, medical technologies such as X- rays and magnetic resonance

imaging. In an environmental context, remote sensing typically refers to technologies for recording electromagnetic energy that emanates from areas or objects on (or in) the Earth's land surface, oceans, or atmosphere. Essentially, the properties of these objects or areas, in terms of their associated levels of electromagnetic energy, provide a way to identify, delineate, and distinguish between them. Because the electromagnetic energies of these features are commonly collected by instruments mounted on aircraft or Earth-orbiting spacecraft, remote sensing also gives scientists the opportunity to capture large geographic areas with a single observation or scene.

Another potential advantage of remote sensing, especially when done from satellites, is that geographic areas of interest can be revisited on a regular cycle, facilitating the acquisition of data to reveal changing conditions over time. For a given instrument, or sensor, onboard a satellite, the revisit time depends on the satellite's orbit and the navigational speed as well as the width of the sensor's swath, which is the track the sensor observes as the satellite travels around the Earth. Remotely sensed data are geospatial in nature, meaning that the observed areas and objects are referenced according to their location in a geographic coordinate system, such that they may be located on a map. This allows the remotely sensed data to be analyzed in conjunction with other geospatial data sets, such as data depicting road networks or human population density. Remotely sensed data with sufficient detail can be used to characterize such things as the growth or health status of vegetation, or to identify habitat edges or ecotones (i.e., transition zones between ecological communities) that could not otherwise be discerned effectively from maps created from field observations.

This point illustrates the unique importance of remote sensing as a data source for GIS, which are organized collections of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, and analyze all forms of geographically referenced information. In turn, *geographic information science (geomatics or geoinformatics)* is concerned with conceptual and scientific issues that arise from the use of GIS, or more broadly, with various forms of geographic information. Ultimately, the value of a GIS depends upon the quality of the data it contains. Because remote sensing serves as the primary source of GIS data, it is important for users to understand how these data are generated so they can evaluate subsequent geospatial analyses more critically.

Process in Remote Sensing:

In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved. Note, however that remote sensing also involves the sensing of emitted energy and the use of non-imaging sensors.

1. ***Energy Source or Illumination (A)*** - the first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.

2. ***Radiation and the Atmosphere (B)*** - as the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.

3. ***Interaction with the Target (C)*** - once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.

Fig: An illustration of the remote sensing concept: An instrument (i.e., sensor or scanner) mounted on an aircraft or satellite records information about objects and/or areas on the ground. Typically, these data are spectral in nature, meaning that they document the amount of electro- magnetic energy associated with the targeted objects and/or areas. The extent, or footprint, of the geographic area captured in a single-sensor scene depends on the sensor's design and the altitude of the aircraft or spacecraft on which it is mounted.

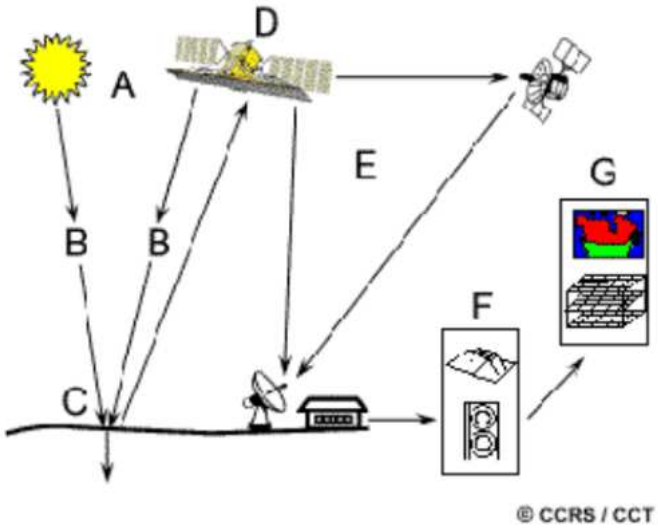
4. ***Recording of Energy by the Sensor (D)*** - after the energy has been scattered by, or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.

5. ***Transmission, Reception, and Processing (E)*** - the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).

6. ***Interpretation and Analysis (F)*** - the processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.

7. ***Application (G)*** - the final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.

These seven elements comprise the remote sensing process from beginning to end.



Electromagnetic Radiation:

As was noted in the previous section, the first requirement for remote sensing is to have an energy source to illuminate the target (unless the sensed energy is being emitted by the target). This energy is in the form of electromagnetic radiation.

All electromagnetic radiation has fundamental properties and behaves in predictable ways according to the basics of wave theory. Electromagnetic radiation consists of an electrical field(E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c).

Two characteristics of electromagnetic radiation are particularly important for understanding remote sensing. These are the wavelength and frequency.

The wavelength is the length of one wave cycle, which can be measured as the distance between successive wave crests. Wavelength is usually represented by the Greek letter lambda (λ). Wavelength is measured in metres (m) or some factor of metres such as nanometres (nm, 10^{-9} metres), micrometres (μm, 10^{-6} metres) (μm, 10^{-6} metres) or centimetres (cm, 10^{-2} metres). Frequency refers to the number of cycles of a wave passing a fixed point per unit of time. Frequency is normally measured in hertz (Hz), equivalent to one cycle per second, and various multiples of hertz.

Wavelength and frequency are related by the following formula:

$$c = \lambda \cdot \nu.$$

Where: λ is the wavelength (m), ν is the frequency (cycles per second, Hz), and c is the speed of light (which is constant at 3×10^8 m/s in a vacuum).

Therefore, the two are inversely related to each other. The shorter the wavelength, the higher the frequency. The longer the wavelength, the lower the frequency. Understanding the characteristics of electromagnetic radiation in terms of their wavelength and frequency is crucial to understanding the information to be extracted from remote sensing data. Next we will be examining the way in which we categorize electromagnetic radiation for just that purpose.

The Electromagnetic Spectrum:

The electromagnetic spectrum ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). There are several regions of the electromagnetic spectrum which are useful for remote sensing.

For most purposes, the ultraviolet or UV portion of the spectrum has the shortest wavelengths which are practical for remote sensing. This radiation is just beyond the violet portion of the visible wavelengths, hence its name. Some Earth surface materials, primarily rocks and minerals, fluoresce or emit visible light when illuminated by UV radiation.

The light which our eyes - our "remote sensors" - can detect is part of the visible spectrum. It is important to recognize how small the visible portion is relative to the rest of the spectrum. There is a lot of radiation around us which is "invisible" to our eyes, but can be detected by other remote sensing instruments and used to our advantage. The visible wavelengths cover a range from approximately 0.4 to 0.7 μm. The longest visible wavelength is red and the shortest is violet. Common wavelengths of what we perceive as particular colours from the visible portion of the spectrum are listed below. It is important to note that this is the only portion of the spectrum we can associate with the concept of colours.

- Violet: 0.4 - 0.446 μm
- Blue: 0.446 - 0.500 μm
- Green: 0.500 - 0.578 μm
- Yellow: 0.578 - 0.592 μm
- Orange: 0.592 - 0.620 μm
- Red: 0.620 - 0.7 μm

Blue, green, and red are the primary colours or wavelengths of the visible spectrum. They are defined as such because no single primary colour can be created from the other two, but all other colours can be formed by combining blue, green, and red in various

proportions. Although we see sunlight as a uniform or homogeneous colour, it is actually composed of various wavelengths of radiation in primarily the ultraviolet, visible and infrared portions of the spectrum. The visible portion of this radiation can be shown in its component colours when sunlight is passed through a prism, which bends the light in differing amounts according to wavelength.

The next portion of the spectrum of interest is the infrared (IR) region which covers the wavelength range from approximately 0.7 μm to 100 μm - more than 100 times as wide as the visible portion! The infrared region can be divided into two categories based on their radiation properties - the reflected IR, and the emitted or thermal IR. Radiation in the reflected IR region is used for remote sensing purposes in ways very similar to radiation in the visible portion. The reflected IR covers wavelengths from approximately 0.7 μm to 3.0 μm. The thermal IR region is quite different than the visible and reflected IR portions, as this energy is essentially the radiation that is emitted from the Earth's surface in the form of heat. The thermal IR covers wavelengths from approximately 3.0 μm to 100 μm.

The portion of the spectrum of more recent interest to remote sensing is the microwave region from about 1 mm to 1 m. This covers the longest wavelengths used for remote sensing. The shorter wavelengths have properties similar to the thermal infrared region while the longer wavelengths approach the wavelengths used for radio broadcasts.

Interactions with the Atmosphere

Before radiation used for remote sensing reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere. Particles and gases in the atmosphere can affect the incoming light and radiation. These effects are caused by the mechanisms of **scattering and absorption.**

Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path. How much scattering takes place depends on several factors including the wavelength of the radiation, the abundance of particles or gases, and the distance the radiation travels through the atmosphere. There are three (3) types of scattering which take place. They are -

Rayleigh scattering occurs when particles are very small compared to the wavelength of the radiation. These could be particles such as small specks of dust or nitrogen and oxygen molecules. Rayleigh scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths. Rayleigh scattering is the dominant scattering mechanism in the upper atmosphere. The fact that the sky appears "blue" during the day is because of this phenomenon. As sunlight passes through the atmosphere, the shorter wavelengths (i.e. blue) of the visible spectrum are scattered more than the other (longer) visible wavelengths. At sunrise and sunset the light has to travel farther through the atmosphere than at midday and the scattering of the shorter wavelengths is more complete; this leaves a greater proportion of the longer wavelengths to penetrate the atmosphere.

Mie scattering occurs when the particles are just about the same size as the wavelength of the radiation. Dust, pollen, smoke and water vapour are common causes of Mie scattering which tends to affect longer wavelengths than those affected by Rayleigh scattering. Mie scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant, and dominates when cloud conditions are overcast.

The final scattering mechanism of importance is called **nonselective scattering**. This occurs when the particles are much larger than the wavelength of the radiation. Water droplets and large dust particles can cause this type of scattering. Nonselective scattering gets its name from the fact that all wavelengths are scattered about equally. This type of scattering causes fog and clouds to appear white to our eyes because blue, green, and red light are all scattered in approximately equal quantities (blue+green+red light = white light).

Absorption is the other main mechanism at work when electromagnetic radiation interacts with the atmosphere. In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths. Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation.

Ozone serves to absorb the harmful (to most living things) ultraviolet radiation from the sun. Without this protective layer in the atmosphere our skin would burn when exposed to sunlight.

You may have heard **carbon dioxide** referred to as a greenhouse gas. This is because it tends to absorb radiation strongly in the far infrared portion of the spectrum - that area associated with thermal heating - which serves to trap this heat inside the atmosphere. Water vapour in the atmosphere absorbs much of the incoming longwave infrared and shortwave microwave radiation (between 22μm and 1m). The presence of water vapour in the lower atmosphere varies greatly from location to location and at different times of the year. For example, the air mass above a desert would have very little water vapour to absorb energy, while the tropics would have high concentrations of water vapour (i.e. high humidity).

Because these gases absorb electromagnetic energy in very specific regions of the spectrum, they influence where (in the spectrum) we can "look" for remote sensing purposes. Those areas of the spectrum which are not severely influenced by atmospheric absorption and thus, are useful to remote sensors, are called **atmospheric windows**. By comparing the characteristics of the two most common energy/radiation sources (the sun and the earth) with the atmospheric windows available to us, we can define those wavelengths that we can use most effectively for remote sensing. The visible portion of the spectrum, to which our eyes are most sensitive, corresponds to both an atmospheric window and the peak energy level of the sun. Note also that heat energy emitted by the Earth corresponds to a window around 10 μm in the thermal IR portion of the spectrum,

while the large window at wavelengths beyond 1 mm is associated with the microwave region.

Now that we understand how electromagnetic energy makes its journey from its source to the surface (and it is a difficult journey, as you can see) we will next examine what happens to that radiation when it does arrive at the Earth's surface.

Radiation - Target Interactions:

Radiation that is not absorbed or scattered in the atmosphere can reach and interact with the Earth's surface. There are three (3) forms of interaction that can take place when energy strikes, or is incident (I) upon the surface. These are: absorption (A); transmission (T); and reflection (R). The total incident energy will interact with the surface in one or more of these three ways. The proportions of each will depend on the wavelength of the energy and the material and condition of the feature.

Absorption (A) occurs when radiation (energy) is absorbed into the target while transmission (T) occurs when radiation passes through a target. Reflection (R) occurs when radiation "bounces" off the target and is redirected. In remote sensing, we are most interested in measuring the radiation reflected from targets. We refer to two types of reflection, which represent the two extreme ends of the way in which energy is reflected from a target: **specular reflection** and **diffuse reflection**.

When a surface is smooth we get **specular** or mirror-like reflection where all (or almost all) of the energy is directed away from the surface in a single direction. **Diffuse** reflection occurs when the surface is rough and the energy is reflected almost uniformly in all directions. Most earth surface features lie somewhere between perfectly specular or perfectly diffuse reflectors. Whether a particular target reflects specularly or diffusely, or somewhere in between, depends on the surface roughness of the feature in comparison to the wavelength of the incoming radiation. If the wavelengths are much smaller than the surface variations or the particle sizes that make up the surface, diffuse reflection will dominate. For example, fine- grained sand would appear fairly smooth to long wavelength microwaves but would appear quite rough to the visible wavelengths.

Let's take a look at a couple of examples of targets at the Earth's surface and how energy at the visible and infrared wavelengths interacts with them.

Leaves: A chemical compound in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelengths. Leaves appear "greenest" to us in the summer, when chlorophyll content is at its maximum. In autumn, there is less chlorophyll in the leaves, so there is less absorption and proportionately more reflection of the red wavelengths, making the leaves appear red or yellow (yellow is a combination of red and green wavelengths). The internal structure of healthy leaves act as excellent diffuse reflectors of near-infrared wavelengths. If our eyes were sensitive to near-infrared, trees would appear extremely bright to us at these wavelengths. In fact, measuring and monitoring the near-IR reflectance is one way that scientists can determine how healthy (or unhealthy) vegetation may be.

Water: Longer wavelength visible and near infrared radiation is absorbed more by water than shorter visible wavelengths. Thus water typically looks blue or blue-green due to stronger reflectance at these shorter wavelengths, and darker if viewed at red or near infrared wavelengths. If there is suspended sediment present in the upper layers of the water body, then this will allow better reflectivity and a brighter appearance of the water. The apparent colour of the water will show a slight shift to longer wavelengths. Suspended sediment (S) can be easily confused with shallow (but clear) water, since these two phenomena appear very similar. Chlorophyll in algae absorbs more of the blue wavelengths and reflects the green, making the water appear more green in colour when algae is present. The topography of the water surface (rough, smooth, floating materials, etc.) can also lead to complications for water-related interpretation due to potential problems of specular reflection and other influences on colour and brightness.

We can see from these examples that, depending on the complex make-up of the target that is being looked at, and the wavelengths of radiation involved, we can observe very different responses to the mechanisms of absorption, transmission, and reflection. By measuring the energy that is reflected (or emitted) by targets on the Earth's surface over a variety of different wavelengths, we can build up a **spectral response** for that object. By comparing the response patterns of different features we may be able to distinguish between them, where we might not be able to, if we only compared them at one wavelength. For example, water and vegetation may reflect somewhat similarly in the visible wavelengths but are almost always separable in the infrared. Spectral response can be quite variable, even for the same target type, and can also vary with time (e.g. "green-ness" of leaves) and location. Knowing where to "look" spectrally and understanding the factors which influence the spectral response of the features of interest are critical to correctly interpreting the interaction of electromagnetic radiation with the surface.

Passive vs. Active Sensing

So far, throughout this chapter, we have made various references to the sun as a source of energy or radiation. The sun provides a very convenient source of energy for remote sensing. The sun's energy is either **reflected**, as it is for visible wavelengths, or absorbed and then **re-emitted**, as it is for thermal infrared wavelengths. Remote sensing systems which measure energy that is naturally available are called **passive sensors**. Passive sensors can only be used to detect energy when the naturally occurring energy is available. For all reflected energy, this can only take place during the time when the sun is illuminating the Earth. There is no reflected energy available from the sun at night. Energy that is naturally emitted (such as thermal infrared) can be detected day or night, as long as the amount of energy is large enough to be recorded.

Active sensors, on the other hand, provide their own energy source for illumination. The sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor. Advantages for active sensors include the ability to obtain measurements anytime, regardless of the time of day or season. Active sensors can be used for examining wavelengths that are not sufficiently

provided by the sun, such as microwaves, or to better control the way a target is illuminated. However, active systems require the generation of a fairly large amount of energy to adequately illuminate targets. Some examples of active sensors are a laser fluorosensor and a synthetic aperture radar (SAR).

Characteristics of Images:

Before we go on to the next chapter, which looks in more detail at sensors and their characteristics, we need to define and understand a few fundamental terms and concepts associated with remote sensing images.

Electromagnetic energy may be detected either photographically or electronically. The photographic process uses chemical reactions on the surface of light-sensitive film to detect and record energy variations. It is important to distinguish between the terms **images** and **photographs** in remote sensing. An image refers to any pictorial representation, regardless of what wavelengths or remote sensing device has been used to detect and record the electromagnetic energy. A **photograph** refers specifically to images that have been detected as well as recorded on photographic film. The black and white photo to the left, of part of the city of Ottawa, Canada was taken in the visible part of the spectrum. Photos are normally recorded over the wavelength range from 0.3 μm to 0.9 μm - the visible and reflected infrared. Based on these definitions, we can say that all photographs are images, but not all images are photographs. Therefore, unless we are talking specifically about an image recorded photographically, we use the term image.

A photograph could also be represented and displayed in a **digital** format by subdividing the image into small equal-sized and shaped areas, called picture elements or **pixels**, and representing the brightness of each area with a numeric value or **digital number**. Indeed, that is exactly what has been done to the photo to the left. In fact, using the definitions we have just discussed, this is actually a **digital image** of the original photograph! The photograph was scanned and subdivided into pixels with each pixel assigned a digital number representing its relative brightness. The computer displays each digital value as different brightness levels. Sensors that record electromagnetic energy, electronically record the energy as an array of numbers in digital format right from the start. These two different ways of representing and displaying remote sensing data, either pictorially or digitally, are interchangeable as they convey the same information (although some detail may be lost when converting back and forth).

In previous sections we described the visible portion of the spectrum and the concept of colours. We see colour because our eyes detect the entire visible range of wavelengths and our brains process the information into separate colours. Can you imagine what the world would look like if we could only see very narrow ranges of wavelengths or colours? That is how many sensors work. The information from a narrow wavelength range is gathered and stored in a **channel**, also sometimes referred to as a **band.** We can combine and display channels of information digitally using the three primary colours (blue, green, and red). The data from each channel is represented as one of the primary

colours and, depending on the relative brightness (i.e. the digital value) of each pixel in each channel, the primary colours combine in different proportions to represent different colours.

When we use this method to display a single channel or range of wavelengths, we are actually displaying that channel through all three primary colours. Because the brightness level of each pixel is the same for each primary colour, they combine to form a **black and white image**, showing various shades of gray from black to white. When we display more than one channel each as a different primary colour, then the brightness levels may be different for each channel/primary colour combination and they will combine to form a **colour image**.

Photo Interpretation, Photogrammetry, and Image Processing:

Prior to the widespread availability of satellite imagery, aerial photography served as the principal foundation for a wide variety of cartographic efforts and geographic analyses. During its period of prominence, analytical techniques emerged that involved mostly nonspectral aspects of aerial photographs. Air photo interpretation uses characteristics such as tone, texture, pattern, shadow, shape, size, and site (location), to identify objects and areas in photographs. In contrast, photogrammetry uses aerial photographs to make reliable spatial measurements of objects. (The word photogrammetry is derived from three Greek roots meaning "light-writing-measurement.") The types of measurements that a photogrammetrist might collect include the distances between features in an area of interest or the heights of particular features. In recent decades, photogrammetric methods have been increasingly applied to digital rather than film-based aerial photographs, and in some cases, to imagery captured by satellite- based sensors.

In particular, digital image processing, which is a concept that encompasses a wide variety of computer algorithms and approaches for visualization, enhancement, and interpretation of remotely sensed images. Pattern recognition is used in digital image processing algorithms with the goal of providing a reasonable answer for all possible inputs and to perform "most likely" matching of the inputs, taking into account the statistical properties of the image data. Key products of digital image processing include thematic maps and color-coded, classified images that depict the spatial pattern of certain characteristics of objects and features, such as the boundaries between the surface water and land. For instance, remote sensing is commonly applied to map the variety and extent of land cover; in turn, these maps serve as critical information for other applications such as ecological studies, urban planning, water resource monitoring, and environmental impact assessment, as well as for policy making.

The Importance of Accuracy Assessment:

A key consideration regarding the use of remotely sensed data is that the resulting outputs must be evaluated appropriately. When the output is a classified map, it is critical to assess its accuracy. A map is an imperfect representation of the phenomena it is meant to portray. In other words, every map contains errors, and it is the responsibility of the

remote sensing analyst to characterize these errors prior to a map's use in subsequent applications. The most widely accepted method for the ac- curacy assessment of remote-sensing-derived maps is by comparison to reference data (also known as "ground truth") collected by visiting an adequate number of sample sites in the field. The key instrument in this comparison is an error matrix, which quantifies the accuracy for each map class of interest as well as the overall map accuracy (i.e., combining all of the classes) and the concepts of Producer's Accuracy and User's Accuracy and the Kappa statistics.

Cost Effectiveness and Reach Versus Richness of Remote Sensing Technology:

Remotely sensed data can be collected over a very large area in a very short period. For example, Landsat collects a scene covering 185 km × 185 km in 26 s. With the advent of sophisticated computing hardware and software and image processing techniques, these data can be transformed into useful digital maps depicting a variety of applications in a geospatial context. However, one needs to be aware of not overselling this technology as a key to most solutions. Remember, all models are wrong, but some are useful. In order for a remote-sensing-derived product to be useful, one must verify the models being used, assess the accuracy of the results, and state the limitations associated with it. Questions such as who controls the data acquisition and distribution become concerns for the use of remotely sensed data.

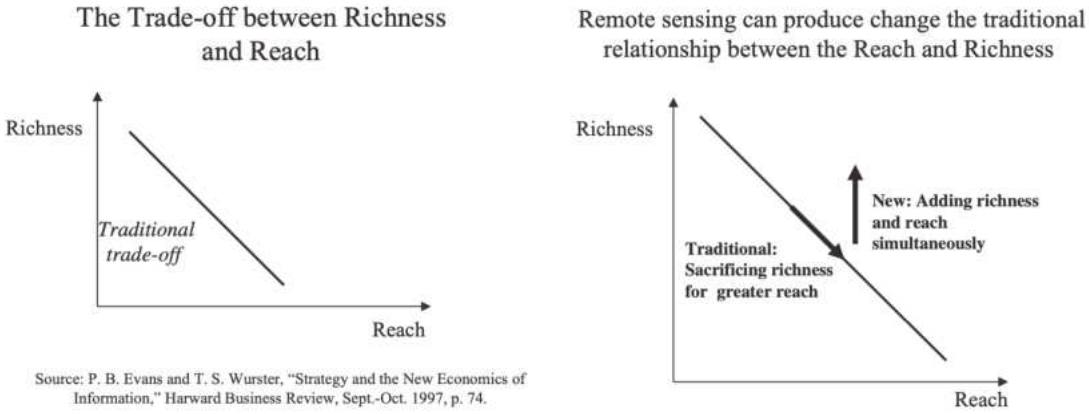


Fig: The availability of rich remote sensing data can blow up the reach/richness trade-off

It is possible to share extremely rich information with a very small number of people, and less rich information with a large number. In a traditional channel of distribution of information, there is a fundamental "trade-off" between "richness" and "reach" (Fig). Reach simply means the number of people exchanging in- formation. Richness can be defined as the amount of information that can be moved from a provider to a user in a given time.

The explosion of connectivity (thanks to open electronic networks), and the adoption of common information standards are now making possible for a very large number of people to exchange very rich information. This is fundamentally altering the traditional

trade-off between richness and reach. Remote sensing provides data with high richness values (high spectral and spatial, spectral, and radiometric resolution) that reach a very broad user community (global). This is another example of disrupting the relationship between the reach and richness.

Data Acquisition

Remotely sensed data are collected by a diverse array of passive and active sensors mounted on aircraft (including airplanes, helicopters, and uninhabited aerial systems) or spacecraft (usually satellites). During the latter half of the twentieth century, large-scale space programs such as National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) were primarily responsible for the development of new remote sensing technologies. Such programs remain key sources of technological innovations, but the expansion of commercial remote sensing has contributed greatly to the proliferation of sensors that provide high-quality data for a variety of applications. The main goal of this chapter is to provide an overview of the types of sensors currently available to analysts, including details about the data they acquire and some of their potential applications. Prior to this discussion, we first introduce the concept of resolution in remote sensing. One common definition of resolution is the ability to discern individual objects or features in a captured image or in the "real world." In this context, it is related to the concept of scale as used by cartographers: a large-scale map—whether constructed from remote sensing imagery or other geospatial data sources—shows more details than a small-scale map, thus making it possible to dis- cern smaller objects or finer features. Nevertheless, the term resolution also relates to several other aspects of remotely sensed data. We illustrate these aspects with examples of commonly used satellite sensors and imagery.

Data Resolution

When we talk about "remotely sensed data," we are usually referring to digital images (i.e., two-dimensional arrays of pixels). These data are typically described by four types of resolution: spatial, spectral, temporal, and radiometric. Spatial resolution, which corresponds most closely to the definition of resolution provided in the preceding paragraph, is a measure of the clarity or fineness of detail of an image. For digital images, this translates to the ground area captured by a single image pixel; because pixels are typically square, resolution is generally expressed as the side length of a pixel. Spectral resolution, represented by the width of the wavelength interval and/or the number of spectral channels (or bands) captured by a sensor, defines the storage of recorded electromagnetic energy and the sensor's ability to detect wavelength differences between objects or areas of interest. The amount of time it takes for a sensor to revisit or reimage a particular geographic location is referred to as its temporal resolution. Finally, the sensitivity of a sensor to incoming electromagnetic energy (i.e., the smallest differences in intensity that the sensor can detect) is known as its radiometric resolution. This metric is usually expressed in terms of binary bit-depth (Jensen 2005), which refers to the number of tonal levels at which data for a given spectral band are recorded by a particular sensor.

Digital images, like other forms of digital data, are stored as bits (i.e., 0 s and 1 s), so a sensor's bit-depth defines the number of unique values, on a binary scale, at which the incoming data can be stored for a pixel. This number is equal to 2n, where n is the stated bit-depth. For example, a bit-depth of 3 means that incoming data can be stored as one of the eight unique values: 000, 001, 010, 011, 100, 101, 110, and 111. The binary bit-depth of most contemporary sensors is at least 8-bit, meaning that image pixels have at least 256 (0–255) possible values.

Each of these resolution types is discussed in subsequent paragraphs. In addition, the different resolution characteristics of some currently operational satellite sensors are presented in Table 2.1. The sensors described in this table are highly variable with respect to resolution. For example, the WorldView-3 satellite's onboard sensor has a spatial resolution of 31 cm for panchromatic (or black-and-white) imagery, while data collected by the "VEGETATION" sensor on the Système Probatoire d'Observation de la Terre (SPOT) 5 satellite are stored in 1150-m pixels. Temporally, the sensors listed in Table 2.1 have resolutions ranging from 15 min to 52 days; in other words, the satellite carrying a particular sensor—or the sensor itself, depending on certain aspects of its configuration—has the capacity to revisit a particular location on the Earth's surface every 15 min (i.e., Geostationary Operational Environmental Satellites, GOES) to every 52 days (i.e., the panchromatic and multispectral camera (PANMUX) sensor on the CBERS-4 satellite).

Spatial Resolution The ability to discern spatial structure is an important element of any remote sensing analysis. It is only in recent years that satellite imagery has supplanted aerial photography as the primary image data source for analyses such as the classification of urban land use. In an urban landscape, surface features such as roads, office buildings, parks, and residential neighborhoods comprise a mosaic, where many small constituent units or pieces are interspersed by a few large ones. Roads and buildings are typically some of the smallest of these units. When viewed from above (e.g., from an airplane), the net visual effect of these units is an aggregate patchwork of various land uses and cover types, but the degree of patchwork detail portrayed by a remotely sensed image, and thus the level of specificity at which it can be classified, depends on its spatial resolution. For example, a 30-m pixel (i.e., the spatial resolution provided by several sensors listed in Table 1) stores one digital number per spectral band of information for any landscape feature smaller than 900 m^2. The pixel could, in fact, accommodate 6 one-story square houses, each having a 1500 ft^2 (139 m^2) footprint. In contrast, an Advanced Very High Resolution Radiometer (AVHRR) pixel, with its 1100-m resolution (see Table 2.1), could incorporate more than 8700 of these houses, if arranged regularly. Increases in spatial resolution have been a persistent trend in sensor innovation. Within a decade of the 1986 launch of the first SPOT satellite, whose 10-m panchromatic spatial resolution opened up new land cover mapping possibilities, space agencies in Japan, India, and Europe had produced satellites with finer spatial resolutions than any of the first five Landsat satellites. The latest generation of commercial satellite ventures, including

Pléiades 1A and 1B, as well as WorldView-2 and WorldView-3, all provide spatial resolutions of 1 m or less.

Table 2.1 (continued)

Sensor (mission)	Organization[a]	Operation period	Swath width (km)	Spatial resolution (m)[b]	Temporal resolution	Radiometric resolution	Spectral resolution (μm)	Spectral bands

[a] *NASA* National Aeronautics and Space Administration, *METI* Ministry of Economy, Trade, and Industry, *NIVR* The Netherlands Agency for Aerospace Programmes, *FMI* Finnish Meteorological Institute, *CNES* Centre National d'Études Spatiales, *NOAA* National Oceanic and Atmospheric Administration, *NESDIS* National Environmental Satellite, Data, and Information Service, *CSA* Canadian Space Agency, *ESA* European Space Agency, *CNSA* China National Space Administration, *CBERS* China-Brazil Earth Resources Satellite Program, *CONAE* Comisión Nacional de Actividades Espaciales, *EUMETSAT* European Organisation for the Exploitation of Meteorological Satellites, *JAXA* Japanese Aerospace Exploration Agency, *ISRO* Indian Space Research Organization, *KARI* Korean Aerospace Research Institute

[b] Acronyms used in describing sensor channels/configurations: *PAN* panchromatic, *MS* multispectral, *VNIR* visible and near-infrared, *SWIR* short-wave infrared *TIR* thermal infrared

[c] The MSS sensor on Landsat 3 had a fifth spectral band for thermal infrared. The MSS sensors on other Landsat missions had four-band configurations

[d] The OMI sensor aboard EOS Aura has one channel recording at 0.27–0.31 μm (in the ultraviolet spectral range) and another recording at 0.306-0.5 μm (ultraviolet and visible spectral range); the pixel size of the former channel is larger (13 × 48 km vs. 13 × 24 km)

[e] Each receiver channel on the CALIOP sensor, a spaceborne LiDAR system, has dual 14-bit digitizers that jointly provide a 22-bit dynamic range

[f] The CALIOP sensor produces simultaneous laser pulses at two wavelengths, 0.532 and 1.064 μm

[g] The NOAA satellite program began in 1978. Currently, NOAA-19 is designated as the program's operational satellite. The AVHRR sensor is also carried as a "heritage" instrument on the Metop-A and Metop-B satellites

[h] While the AVHRR sensor has six spectral channels, only five are transmitted to the ground at any time. The bands designated 3A and 3B are transmitted only during daytime and nighttime, respectively

[i] Although the GOES program has been active since 1975, only GOES-13 through GOES-15 are currently operational. GOES-14 was launched in 2009 but remains in on-orbit storage mode

Table 2.1 (continued)

Sensor (mission)	Organization[a]	Operation period	Swath width (km)	Spatial resolution (m)[b]	Temporal resolution	Radiometric resolution	Spectral resolution (μm)	Spectral bands

[j] Operated as a demonstration instrument, the HICO sensor captured only a single 42 × 92 km scene per orbit. Over its 5-year period of operation, HICO collected > 10,000 scenes worldwide

[k] Collected HICO data have 128 bands spanning the 0.353–1.08 μm range of wavelengths, but the data from outside the 0.4–0.9 μm range are less accurate and therefore only 87 bands are included in the output files made available to users

[l] The radar systems in this table (i.e., SAR/RADARSAT-2, SAR/Sentinel-1 A, and COSI/KOMPSAT-5) operate in a variety of scan modes with different swath widths and spatial resolutions

[m] RADARSAT-2 has a repeat cycle of 24 days, but its left- and right-looking modes may provide more rapid revisits

[n] The spatial resolution of the VEGETATION sensor on Proba-V is 100 m at nadir but 350 m over the full field of view (i.e., at the scene edges)

[o] The VEGETATION sensor provides daily coverage for the following latitudes: 35–75°N and 35–56°S. It offers full global coverage every 2 days

[p] Few details about Gaofen-2 are available, but it is likely similar to Gaofen-1 in terms of spectral resolution and revisit time

[q] The FTS sensor on the GOSAT satellite records 10.5 × 10.5 km images that are spaced 150 km apart in a grid (see Kuze et al. 2009)

[r] Spot Image, a company created by the French Space Agency (CNES), developed and operated the SPOT satellites. Spot Image became a subsidiary of Astrium, a European Aeronautic Defense and Space (EADS) company in 2008. EADS was reorganized as the Airbus Group in 2014

[s] The SPOT satellites have the capacity to record data off-nadir (i.e., to record data in areas that are not directly below the satellite). This may reduce the revisit time to 2–3 days (1 day for the wide-swath VEGETATION sensor), but the images will have different observation geometry, which may affect image processing

[t] Unlike the first five SPOT satellites, SPOT 6 and 7 were developed by the Airbus Group without financial support from the French government. In 2014, SPOT 7 was sold to Azerbaijan's space agency Azercosmos, who renamed it Azersky. Per agreement, Azercosmos has commercial rights to imagery from both satellites for the southern Asia region, while Airbus Group retains the rights elsewhere

[u] The SPOT 6 and 7 satellites are a constellation, operating on the same orbit but phased 180° apart. With the satellites' capacity to record data off-nadir, the constellation can provide 1-day revisit time

[v] GeoEye, the company that originally operated IKONOS and GeoEye-1, merged with DigitalGlobe in 2013

[x] *CAVIS* Clouds, Aerosols, Vapors, Ice, and Snow

[y] The 4-day revisit time of the HiRAIS sensor on Deimos-2 is enabled by a ±45° off-nadir viewing capability

Table 2.1 Characteristics of selected satellite sensors. (Adapted from Rogan and Chen 2004; updated for this publication)

Sensor (mission)	Organization[a]	Operation period	Swath width (km)	Spatial resolution (m)[b]	Temporal resolution	Radiometric resolution	Spectral resolution (μm)	Spectral bands
MSS (Landsat 1–5)	NASA, US	1972–1992	185	80 (MS), 240 (TIR)[c]	16–18 days	8-bit	0.5–1.1, 10.4–12.6[c]	4–5[c]
TM (Landsat 4, 5)	NASA, US	1982–2011	185	30 (MS), 120 (TIR)	16 days	8-bit	0.45–2.35, 10.4–12.5	7
ETM+ (Landsat 7)	NASA, US	1999	185	15 (PAN), 30 (MS), 60 (TIR)	16 days	8-bit	0.52–0.9 (PAN), 0.45–2.35, 10.4–12.5	7+ PAN
OLI (Landsat 8)	NASA, US	2013	185	15 (PAN), 30 (MS)	16 days	12-bit	0.5–0.68 (PAN), 0.433–0.453 (coastal/aerosol), 0.45–2.3, 1.36–1.39 (cirrus)	8+ PAN
TIRS (Landsat 8)	NASA, US	2013	185	100	16 days	12-bit	10.6–11.2, 11.5–12.5	2
MODIS (EOS Terra and Aqua)	NASA, US	1999	2300	250 (PAN), 500 (VNIR), 1000 (SWIR)	1–2 days	12-bit	0.620–2.155, 3.66–14.385	36
ASTER (EOS Terra)	NASA,US; METI, Japan	1999	60	15 (VNIR), 30 (SWIR), 90 (TIR)	4–16 days	8-bit (VNIR/SWIR), 12-bit (TIR)	0.52–0.86, 1.60–2.43, 8.125–11.65	14
Hyperion (EO-1)	NASA, US	2000	7.5	30	16 days	12-bit	0.353–2.577	220
ALI (EO-1)	NASA, US	2000	37	10 (PAN), 30 (MS)	16 days	12-bit	0.48–0.69 (PAN), 0.433–2.35	9+ PAN
OMI (EOS Aura)	NIVR, Netherlands; FMI, Finland; NASA, US	2004	2600	13,000 × 48,000, 13,000 × 24,000[d]	1 day	12-bit	0.27–0.5	740
CALIOP (CALIPSO)	NASA, US; CNES, France	2006	0.1	333	16 days	22-bit[e]	0.532, 1.064	2[f]

Table 2.1 (continued)

Sensor (mission)	Organization[a]	Operation period	Swath width (km)	Spatial resolution (m)[b]	Temporal resolution	Radiometric resolution	Spectral resolution (μm)	Spectral bands
IRSCAM (CBERS-4)	CBERS, China/ Brazil	2014	120	40 (NIR/SWIR), 80 (TIR)	26 days	8-bit	0.77–12.5	4
WFICAM (CBERS-4)	CBERS, China/ Brazil	2014	866	64	5 days	10-bit	0.45–0.89	4
LISS-IV (RESOURCESAT-2)	ISRO, India	2011	70	5.8	24 days	10-bit	0.52–0.86	3
LISS-III (RESOURCESAT-2)	ISRO, India	2011	141	23.5	24 days	10-bit	0.52–1.70	4
AWiFS (RESOURCESAT-2)	ISRO, India	2011	740	56	24 days	12-bit	0.52–1.70	4
TANSO-FTS (GOSAT/Ibuki)	JAXA, Japan	2009	160[q]	10.5	3 days		0.758–14.3	4
Geoton-L1 (Resurs-P No. 1, No. 2)	Roscosmos, Russia	2013, 2014	32 (PAN), 38 (MS)	1 (PAN), 3–4 (MS)	3 days	10-bit	0.58–0.8 (PAN), 0.45–0.80	5+ PAN
KShMSA-VR/SR (Resurs-P No. 1, No. 2)	Roscosmos, Russia	2013, 2014	97 (VR mode), 440 (SR mode)	VR: 12 (PAN), 24 (MS); SR: 60 (PAN), 120 (MS)	3 days	12-bit	0.43–0.7 (PAN), 0.43–0.9	5+ PAN
GSA (Resurs-P No.1, No.2)	Roscosmos, Russia	2013, 2014	25	30	3 days	14-bit	0.4–1.1 nm band width	130
COSI (KOMPSAT-5)	KARI, South Korea	2013	5-100[l]	1–20[l]	28 days		X-band radar	N/A
AEISS-A (KOMPSAT-3 A)	KARI, South Korea	2015	12	0.55 (PAN), 2.2 (MS)	28 days	14-bit	0.45–0.9 (PAN), 0.45–0.9	4+ PAN
IIS (KOMPSAT-3 A)	KARI, South Korea	2015	12	5.5	28 days	14-bit	3.3–5.2	1
HRVIR (SPOT 4)	Airbus Group, France[r]	1998–2013	60	10 (PAN), 20 (MS)	26 days[s]	8-bit	0.61–0.68 (PAN), 0.50–1.75	4+ PAN

Table 2.1 (continued)

Sensor (mission)	Organization[a]	Operation period	Swath width (km)	Spatial resolution (m)[b]	Temporal resolution	Radiometric resolution	Spectral resolution (μm)	Spectral bands
VIIRS (Suomi NPP)	NASA, US; NOAA, US	2011	3000	375 or 750 depending on application	12 h	12-bit	0.41–12.5	21 + Day/Night PAN
Aquarius (SAC-D)	NASA, US; CONAE, Argentina	2011	390	150	7 days		3 L-band microwave radiometer beams + radar	N/A
AVHRR (NOAA 6–19; Metop-A, -B)	NOAA, US; EUMETSAT	1978[g]	2700	1100	12 h	10-bit	0.58–12.5	6[h]
I-M Imager (GOES 12–15)	NESDIS, US	1975[i]	8	1000 (VNIR), 4000 (SWIR), 8000 (moisture), 4000 (TIR)	0.25–3 h	10-bit	0.55–12.5	5
HICO (International Space Station)	Office of Naval Research (ONR), US; NASA, US	2009–2014	42 × 192[j]	90	~3 days	14-bit	0.353–1.08 (0.4–0.9)[k]	128 (87)[k]
SAR (RADARSAT-2)	CSA, Canada	2007	20–500[l]	3-100[l]	24 days[m]		C-band radar	N/A
VEGETATION (Proba-V)	ESA	2013	2250	100/350[n]	1–2 days[o]	12-bit	0.438–1.634	4
SAR (Sentinel-1 A)	ESA	2014	20–250[l]	5–40[l]	12 days		C-band radar	N/A
PMC (Gaofen-1)	CNSA, China	2013	69	2 (PAN), 8 (MS)	4 days	10-bit	0.45–0.9 (PAN), 0.45–0.89	4+ PAN
WFI (Gaofen-1)	CNSA, China	2013	830	16	4 days	10-bit	0.45–0.89	4
HROI (Gaofen-2)	CNSA, China	2014	48	0.8 (PAN), 3.2 (MS)	?[p]	?[p]	?[p]	?[p]
MUXCAM (CBERS-4)	CBERS, China/Brazil	2014	120	20	26 days	8-bit	0.45–0.89	4
PANMUX (CBERS-4)	CBERS, China/Brazil	2014	60	5 (PAN), 10 (MS)	52 days	8-bit	0.51–0.73 (PAN), 0.52–0.89	3+ PAN

Table 2.1 (continued)

Sensor (mission)	Organization[a]	Operation period	Swath width (km)	Spatial resolution (m)[b]	Temporal resolution	Radiometric resolution	Spectral resolution (μm)	Spectral bands
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WFICAM (CBERS-4)	CBERS, China/ Brazil	2014	866	64	5 days	10-bit	0.45–0.89	4
LISS-IV (RESOURCESAT-2)	ISRO, India	2011	70	5.8	24 days	10-bit	0.52–0.86	3
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AWiFS (RESOURCESAT-2)	ISRO, India	2011	740	56	24 days	12-bit	0.52–1.70	4
TANSO-FTS (GOSAT/Ibuki)	JAXA, Japan	2009	160[q]	10.5	3 days		0.758–14.3	4
Geoton-L1 (Resurs-P No. 1, No. 2)	Roscosmos, Russia	2013, 2014	32 (PAN), 38 (MS)	1 (PAN), 3–4 (MS)	3 days	10-bit	0.58–0.8 (PAN), 0.45–0.80	5+ PAN
KShMSA-VR/SR (Resurs-P No. 1, No. 2)	Roscosmos, Russia	2013, 2014	97 (VR mode), 440 (SR mode)	VR: 12 (PAN), 24 (MS); SR: 60 (PAN), 120 (MS)	3 days	12-bit	0.43–0.7 (PAN), 0.43–0.9	5+ PAN
GSA (Resurs-P No.1, No.2)	Roscosmos, Russia	2013, 2014	25	30	3 days	14-bit	0.4–1.1 nm band width	130
COSI (KOMPSAT-5)	KARI, South Korea	2013	5-100[l]	1–20[l]	28 days		X-band radar	N/A
AEISS-A (KOMPSAT-3 A)	KARI, South Korea	2015	12	0.55 (PAN), 2.2 (MS)	28 days	14-bit	0.45–0.9 (PAN), 0.45–0.9	4+ PAN
IIS (KOMPSAT-3 A)	KARI, South Korea	2015	12	5.5	28 days	14-bit	3.3–5.2	1
HRVIR (SPOT 4)	Airbus Group, France[r]	1998–2013	60	10 (PAN), 20 (MS)	26 days[s]	8-bit	0.61–0.68 (PAN), 0.50–1.75	4+ PAN

Spectral Resolution:

The spectral component of remote sensing data is also critical to appropriate data selection. The spectral resolution of a sensor is a description of the range and partitioning of the electromagnetic energy (or reflectance) recorded by the sensor. In this context, sensors can be divided into one of three loose classes of spectral sensitivity: panchromatic (one spectral band), multispectral (multiple spectral bands), or hyperspectral (many, possibly hundreds, of spectral bands). Fundamentally, both multispectral and hyperspectral images can be thought of as "stacks" of identically geo-referenced (i.e., covering the exact same geographic area) panchromatic images, where each image in the stack corresponds to a particular portion of the electromagnetic spectrum. Most satellite-derived remote sensing data are captured in a panchromatic and/or multispectral format (although spaceborne hyperspectral sensors are becoming more commonplace). For example, the Operational Land Imager (OLI) onboard NASA's Landsat-8 satellite records data in nine bands, including one panchromatic band. Each of these bands is sensitive to different wavelengths of visible and infrared radiation. The sensor on the WorldView-2 satellite also records data in nine bands, including a panchromatic band. Most multi-spectral sensors have several bands targeted at the visible-to-near-infrared (VNIR) range (0.4–1.4 μm) of the electromagnetic spectrum, as do OLI (six bands in this range) and WorldView-2 (all eight of its multispectral bands). This is because, in many geographic areas, ambient electromagnetic reflectance is strongly shaped by the distribution and condition of vegetation and water features, particularly in the VNIR range. WorldView-2 is noteworthy for two specialized bands within the VNIR range that are not found on any other spaceborne multispectral sensor: a "yellow" band, aimed at detecting the yellowness of terrestrial and aquatic vegetation, which may help distinguish between vegetation types; and a "red-edge" band, focused on the narrow range of wavelengths where vegetation reflectance transitions from low to high, which may be useful for measuring plant health. While the OLI sensor does not have as many bands in the VNIR range as WorldView-2, it does have two bands in the short-wave infrared (SWIR) portion of the electromagnetic spectrum, as well as a band at the edge of the VNIR range intended specifically for cirrus cloud detection.

Unlike these multispectral sensors, NASA's Hyperion, the first hyperspectral sensor carried aboard a satellite, provides a virtually continuous recording of electromagnetic reflectance across 220 narrow spectral bands in the VNIR and SWIR wavelengths. Although the processing complexity of hyperspectral data has hindered its widespread applicability in many land cover studies, these data provide a great deal of information about the unique reflectance behavior of vegetation stress and diversity. The high spectral resolution also provides an increased ability to dis- criminate between features that have similar response profiles, or signatures, across the electromagnetic spectrum, such as forest stands composed of different deciduous tree species. It is important to note, however, that the first generation of satellite-based, "true" hyperspectral sensors (i.e., sensors with >100 bands), such as Hyperion or the now-defunct Hyperspectral Imager for

the Coastal Ocean (HICO) that operated from the International Space Station, have typically been too coarse in terms of spatial resolution to be used for fine-scale analyses. Such applications remain the purview of airborne hyperspectral sensors, although this trend is likely to change with future advances in hyperspectral imaging technology.

Temporal Resolution:

Temporal resolution, or revisit time, is usually expressed in terms of days. For example, Landsat-8 has a 16-day orbit cycle, meaning that the satellite, and thus the OLI sensor and the thermal infrared sensor (TIRS), returns to a given location on the Earth's surface every 16 days. However, some satellites, such as the GOES, have a revisit cycle of less than an hour in certain locations. The GOES have a coarse, 8-km spatial resolution, which gives them limited utility for local land cover studies, but their temporal resolution makes them highly suitable for meteorological and climatological applications. By contrast, the balance of spatial and temporal resolutions achieved by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS)—with a spatial resolution of 250–1000 m and a temporal resolution of 1–2 days—has made the sensor applicable to a variety of regional- to continental-scale research efforts. MODIS data make it possible to examine land cover changes and patterns affecting environmental quality that may not be obvious unless viewed at the daily or near-daily replication offered by this sensor. In addition, a number of satellites (e.g., SPOT 6 and 7) have the capacity to capture off-nadir imagery (i.e., to record data from areas that are not directly below the satellite sensor). This can reduce their typical revisit time, but it also affects the sensor geometry and subsequent image processing. Furthermore, off-nadir image capture may also alter spatial resolution, particularly for high-resolution sensors; for instance, the spatial resolution of multispectral data from WorldView-3 is 1.38 m at 20° off-nadir versus 1.24 m at nadir.

Radiometric Resolution Many of the current generation of both government and commercial satellites have onboard sensors with high radiometric resolutions. Commonly, these sensors have 10-, 11-, or 12-bit collection depths (also known as their level of "data quantization"), which represents a substantial improvement over the 8-bit resolution typically exhibited by predecessors such as the older Landsat and SPOT sensors. Certain sensors, such as the Advanced Earth Imaging Sensor System-A (AEISS-A) aboard KOMPSAT-5, as well as the Cloud-Aerosol LiDAR with Orthogonal Polarization (CALIOP) instrument aboard NASA's CALIPSO satellite, have even higher radiometric resolutions (14- and 22-bit, respectively). Fundamentally, a sensor's radiometric resolution defines the dynamic range (i.e., the number of possible data values) recorded in each image band, so higher radiometric resolution means that a sensor is more sensitive to variations in electromagnetic reflectance. This increased sensitivity has been shown to be very useful in the land cover classification of complex (e.g., urban and suburban) landscapes.

Ultimately, each of the four resolution types must be considered in light of the intended purpose of the data. For example, except near cities, most terrestrial land- scapes are dominated by vegetation, water, or other natural surfaces, even amid production land uses

such as agriculture or mining. Spatial resolution might be relatively less important for mapping or monitoring efforts in these settings because of high landscape homogeneity. In heavily forested or vegetated environments, data that are high in temporal and spectral resolutions rather than spatial resolution, such as AVHRR imagery, could be a powerful tool for evaluating seasonal or annual change in photosynthetic activity. With respect to other types of analyses, hyperspectral data have demonstrated strong applicability for geological, mineralogical, and soil studies. In addition, radar systems such as the C-band radar on the RADARSAT-2 satellite can be useful for observing sea surface conditions and other aspects of coastal areas, for detecting oil spills, and for monitoring sea ice.

Regardless, in any remote sensing analysis, the appropriate input data should primarily be a function of the individual project objectives. For instance, the level of detail offered by high-spatial-resolution satellite imagery may not be well suited for mapping forested areas because of certain limitations (e.g., the presence of shadows and high spectral variability within forest type classes), but such images have been used successfully in large, homogeneous tracts of rain forest for the assessment of old-growth tree mortality. As this specialized application suggests, there is no one “best” sensor for mapping a particular type of landscape. Although the sensors listed in Table 2.1 are only a sample of the instruments currently producing remotely sensed data for use in scientific applications, they illustrate the wide diversity of options that an analyst should consider before choosing a particular sensor. While that ultimate selection will likely also be a function of other factors, such as budget and processing capabilities, it should be guided foremost by the analyst’s evaluation about which choice will provide the most meaningful information.

Introduction to GIS

Most of the information that concerns our surroundings is called spatial data relating to the surface of the Earth. From the beginning of his existence, the man collected them and made their analysis, enabling the public to specify the conclusions about their surroundings. Over time, the analysis became increasingly complex and included an increasing amount of data. Nowadays, the amount of data is growing dynamically, which makes it impossible to analyse all information. A very good tool for their collection seemed to be various types of IT systems. However, they did not give the opportunity to present in- formation in a spatial way. It was only geographic information systems that allowed man to gather this information, order and store. Data, constantly updated, enabled conducting complex analyses in a shorter time. What once lasted for months can now be done in a few days.

In each of the systems included in the GIS, several characteristic elements can be distinguished. The most important of them are: data, people, hardware, software and data sharing procedures. It should also fulfil appropriate functions, among which one can mention: data collection, their verification and preliminary elaboration, data management, data processing and analysis as well as visualization.

The rapid development of information technology has allowed GIS systems to be widely used in many areas of life, including mining.

CHARACTERISTICS and Definition of GEOGRAPHIC INFORMATION SYSTEMS – GIS

Geographic Information Systems belong to information systems, distinguished by information about the location of objects and spatial relations between them. In addition, they allow for their cartographic presentation and conducting various types of analyses.

The Geographic Information System does not have one definite definition. There are many of them and, above all, they define GIS as an IT system, consisting of various methods of dealing with spatial data, the implementation of which requires hardware and software, as well as people who can operate it.

According to ***CLARKE [1990]***, "GIS is an automated system for collecting, storing, searching, analysing and displaying spatial data".

GAŹDZICKI [1990] defined this system as a system for acquiring, processing, verifying, integrating, manipulating, analysing and presenting data that are spatially referenced to the Earth. It usually includes a spatial database and appropriate software .

According to the definition given at the ***5th Scientific and Technical Conference PTIP*** "GIS is an IT system sup- porting the collection, analysis and sharing of data about objects uniquely spatially located".

The basic functions of Geographic Information Systems include:

- data collection, verification and preliminary elaboration,
- data management,
- data processing and analysis,
- data visualization.

Acquiring data is usually carried out by direct measurements, methods and techniques of photogrammetry and remote sensing, GNSS technology, as a result of transfer from other systems or by using existing documentation in tabular form or in the form of maps. Descriptive data can be entered into the system interactively or by means of a batch. Acquiring and processing into a coherent form of the data model being created is often a long-term, costly process requiring considerable work. It is estimated that in many projects this phase requires up to 80% of time and costs. At the same time, this is the decisive stage for the quality of final results.
Access for digital files, it is possible thanks to the database management system. It allows you to supplement, search, update and organize data. One of the most important tasks in this field is to protect the system against data damage and access by unauthorized persons.
Transformation, analysis, aggregation and generalization can be distinguished among the

processing functions. Some of the processing functions perform only operations on objects without changing them. Another group of processing functions generates (creates) new objects based on existing ones, and yet another can only modify existing objects.

The last group of basic function concerns the output of data in a specific form. This function is aimed at presenting data in an intelligible form to the user and making them available both in the form of paper printouts and in numerical form.

A characteristic feature of Geographic Information Systems is that they consist of five basic elements (Fig. 1).

The organization of spatial data in GIS is based on a layered structure – thematic layers – raster and vector (Fig. 2).

Fig. 1. Components of Geographic Information Systems

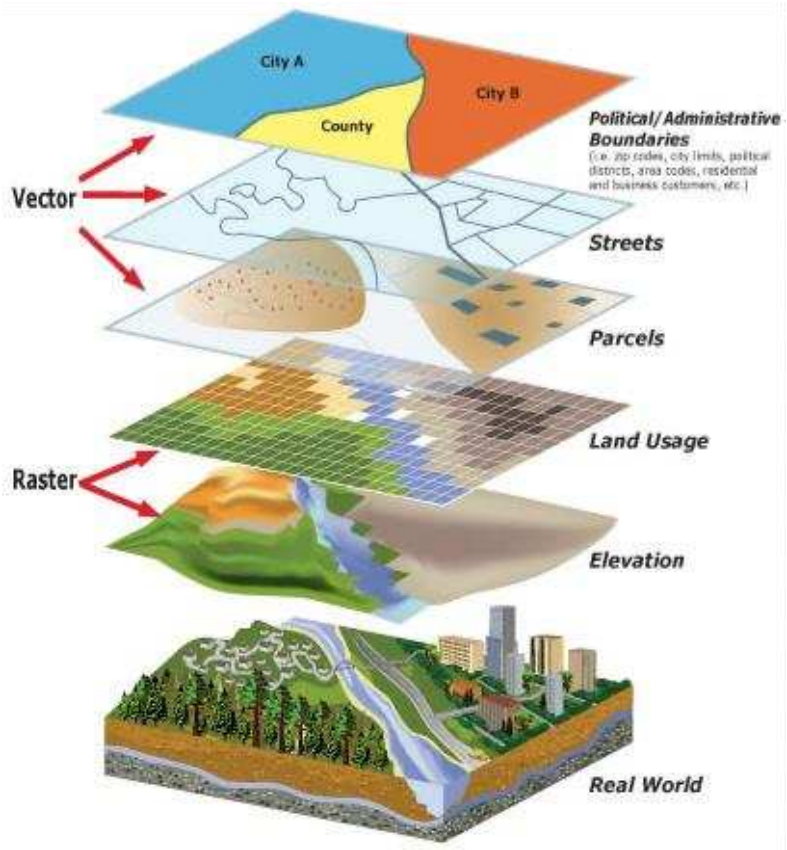


Fig. 2. Exemplary thematic layers in GIS; source: UNC Charlotte [undated]

GIS allows to integrate data from various sources but about the same object or phenomenon. This is possible only when the location is known, hence spatial reference to a specific place on the Earth's surface.

Geographical Information Systems allow to perform various types of spatial analysis, which gives them a universal character and a wide range of applications.

Components of GIS:

A Geographic Information System (GIS) is a system wherein data related to earth, associated phenomena, and events is mapped and analyzed. It is a powerful system that incorporates spatial data, manages it, analyzes it, answers geographic queries and provides great visualization capability. There are five basic GIS components that make it effective.

- Hardware
- Software
- Data
- Methods
- People

Hardware:

Hardware consists of the technical equipment needed to run a GIS efficiently. It includes computer/s (standalone / networked) with good configuration – good processing capability to run the GIS software, enough hard disk space to store large spatial data, and input and output devices such as scanners, printers, etc

Today, GIS runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations. Minimum configuration required to Arc/Info Desktop 9.0 GIS application is as follows:

Product: ArcInfo Desktop 9.0

- Platform: PC-Intel
- Operating System: Windows XP Professional Edition, Home Edition Service Packs/Patches: SP 1
- SP2 (refer to Limitations)
- Shipping/Release Date: May 10, 2004

Hardware Requirements

- CPU Speed: 800 MHz minimum, 1.0 GHz recommended or higher
- Processor: Pentium or higher
- Memory/RAM: 256 MB minumum, 512 MB recommended or higher
- Display Properties: Greater than 256 color depth
- Swap Space: 300 MB minimum
- Disk Space: Typical 605 MB NTFS, Complete 695 MB FAT32 + 50 MB for installation
- Browser: Internet Explorer 6.0 Requirement:
- (Some features of ArcInfo Desktop 9.0 require a minimum installation of Microsoft Internet Explorer Version 6.0.)

Software:

GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are (a) a database management system (DBMS) (b) tools for the input and manipulation of geographic information (c) tools that support geographic query, analysis, and visualization (d) a graphical user interface (GUI) for easy access to tools. GIS software are either commercial software or software developed on Open Source domain, which are available for free. However, the commercial software is copyright protected, can be expensive and is available in terms number of licensees.

Currently available commercial GIS software includes Arc/Info, Intergraph, MapInfo, Gram++ etc. Out of these Arc/Info is the most popular software package. And, the open source software are AMS/MARS etc.

Data:

The most important GIS component is the data – how it is managed and accessed. Data is stored as geographic data (spatial data) and related tabular data (non-spatial data). Data comes in various formats, and GIS integrates such spatial data and non-spatial data by using DBMS. It is the key functionality of GIS that helps in organizing, managing and accessing data.

Methods:

To make a GIS system work properly requires not only the necessary investments in hardware, software and data, but also requires knowledge to utilize the GIS technology. The methods are the procedure followed to answer the question need to be resolved. Method in GIS includes how the data will be accessed, stored, managed, processed, analyzed, and finally presented as output for particular application.

People:

People in GIS are technical persons (GIS managers, database administrators, specialists, analysts, and programmers) who design and maintain the GIS work and those who use it. They are the ones who make GIS work.

People in GIS can be categorized into: viewers – the people who just use GIS for reference; general users – who use GIS for business, services, and making decisions such as planners, scientists, engineers, etc; GIS specialists: who are the backbone of GIS and maintain, process and analyze geographic data. They provide technical support to the users.

What can we do with GIS?

GIS can be used as tool in both problem solving and decision making processes, as well as for visualization of data in a spatial environment. Geospatial data can be analyzed to determine (1) the location of features and relationships to other features, (2) where the most and/or least of some feature exists, (3) the density of features in a given space, (4) what is happening inside an area of interest (AOI), (5) what is happening nearby some feature or phenomenon, and (6) and how a specific area has changed over time (and in what way).

GIS Technology: Advantages and Disadvantages

GIS is a computer-based application for mapping and analyzing geographically referenced data in the form of digitized three-dimensional operations. The use of GIS has become inevitable in almost every geospatial application. The end-user community is interested in exploring the economic and deliberate value of GIS due to the benefits of

this rapidly growing technology. The fundamental advantages of GIS can be generalized as follows:

- It is easy to visualize the spatial information represented by GIS output maps with clear legends and different groups of coloring and patterns. Thus the novice users of GIS could be comfortable with its application. Expert use of the GIS application is highly supportive in all kinds of environment.
- GIS can build various themes and is supportive for database operations such as creation, updating, and manipulation. The map accuracy depends on the quality of input data.
- GIS offers an influential decision-making tool in the education sector for its administration, policy making, and instruction. For administrators, GIS can offer an approach to visualize and manage systems in their entirety, including monitoring campus safety, mapping campus buildings, surveilling cable and other infrastructures, routing school buses, planning school closures and opening new ones, and outlining strategies for recruitment. For policymakers in education, GIS provides them with tools that can present patterns in educational achievement and guide the targeting of new programs.
- Groundwater analysis uses GIS to interpret spatial correlation targeting potential groundwater resources as well as determining water quality. A logical approach can be adapted for the efficient management of water resources, such as surface and subsurface delineations. GIS can be applied to site selection, zoning, planning, and conservation measures.
- Geophysical parameters on the subsurface conditions can be incorporated with spatial data and interpolation techniques can be applied to the exploration, assessment, and prediction of groundwater resources, as well as to the selection of an artificial recharge site. The subsurface flow and pollution model guides how to assess hazards and helps in planning the preventive measures with the help of GIS and geostatistical technologies.
- GIS methods can predict, assess risk, and identify hazardous locations of natural resources. It further integrates the spatial and nonspatial data to enable better understanding of emergency conditions. It also supports analysis and the creation of preventive and mitigating solutions.
- GIS can be used in criminology to identify facts. Some spatial analyses uses underlying social phenomena to identify rates of crime, which necessitates the use of boundary units such as census tracts and police beats. Although some researchers have also recognized that a simple spatial concentration of crime can also be valuable.
- GIS creates employment opportunities in education, administration, research, government, and nonprofit organizations.
- GIS technologies refine datasets, data models, and the relation between attributes. High standards are achieved with the scope for generation of newer objects on an on-demand basis. It also allows existing attributes to be linked with newly defined datasets.

Disadvantages of Geographic Information Systems:

- *Expensive*:

  GIS setup is complex, in addition to the cost of the equipment, there is the cost incurred in training. Frequent updating of datasets or data models may lead to errors in results.

- *Real-time parameters*:

  The handling of growing datasets is an overall challenge to the GIS system. Geographical errors increase with larger-scale data: The quality of the data collected directly affects the accuracy of the end system. Geographic errors will also affect net results since GIS handles large-scale data. Relative loss of resolution: Every technology has negotiable errors when deployed.
  Positional accuracy and precision: Accuracy and precision are the functions of the scale at which a map (paper or digital) is created. The nonspatial data linked to location may also be inaccurate or imprecise. Inaccuracies may result from mistakes of many sorts. Nonspatial data can also vary greatly in precision. Precise attribute information describes phenomena in great detail.

- *Violation of privacy*:

  The user community is not limited to authorized persons. So there is threat in the usage of data displayed from the GIS system.

- Error-prone interpretation could lead to failure of system implementation thus affecting the economic strategy of the implementer.

- There might be failures in initiating or additional effort required in order to fully implement the GIS but there might be large benefits to anticipate as well.

- There is a lack of trained teachers in the domain. Though GIS and remote sensing have been introduced in some universities across the country, still the subjects have not been taught to the fullest extent. Moreover, a link between secondary education and higher education must be established for a wide spread and its continuity in the system. Prior knowledge of GIS is a prerequisite to train the trainers.

Nature of Geographic Information:

This part reviews the basic fundamentals of geographic data and information. The focus is on understanding the basic structure of geographic data, and how issues of accuracy, error, and quality are paramount to properly using GIS technology. The establishment of a robust database is the cornerstone of a successful GIS.

- Maps and Spatial Information
- Characterizing Geographic Features
- Spatial Data Accuracy and Quality

Maps and Spatial Information:

The main method of identifying and representing the location of geographic features on the landscape is a map. A map is a graphic representation of where features are, explicitly

and relative to one another. A map is composed of different geographic features represented as either points, lines, and/or areas. Each feature is defined both by its location in space (with reference to a coordinate system), and by its characteristics (typically referred to as attributes). Quite simply, a map is a model of the real world.

The map legend is the key linking the attributes to the geographic features. Attributes, e.g. such as the species for a forest stand, are typically represented graphically by use of different symbology and/or color. For GIS, attributes need to be coded in a form in which they can be used for data analysis (Burrough, 1986). This implies loading the attribute data into a database system and linking it to the graphic features.

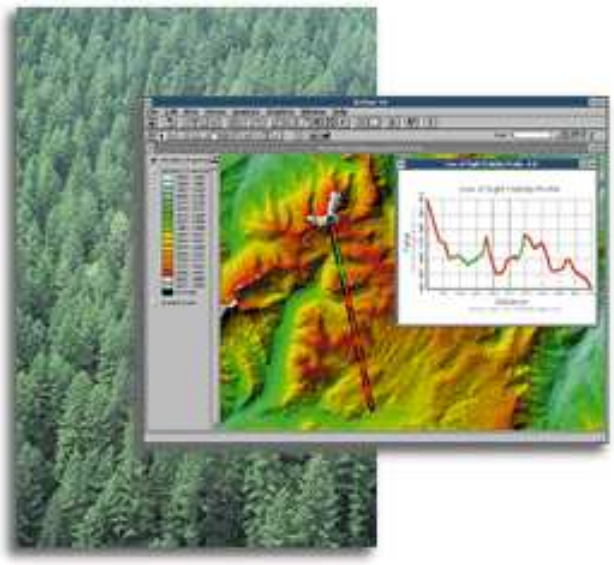


Fig: Maps are simply models of the real world. They represent snapshots of the land at a specific map scale. The map legend is the key identifying which features are represented on a map.

For geographic data, often referred to as spatial data, features are usually referenced in a coordinate system that models a location on the earth's surface. The coordinate system may be of a variety of types. For natural resource applications the most common are:

Geographic coordinates such as latitude and longitude, e.g. 56°27'40" and 116°11’25”. These are usually referred by degrees, minutes, and seconds. Geographic coordinates can also be identified as decimal degrees, e.g. 54.65°.

A map projection, e.g. Universe Transverse Mercator (UTM) where coordinates are measured in metres, e.g. 545,000.000 and 6,453,254.000 normally reference to a central meridian. Eastings refer to X coordinates while Northings refer to Y coordinates.

A legal survey description, e.g. Meridian, Township, Range such as the Alberta Township System, e.g. Township 075 Range 10 West of 4th Meridian.

Geographic data is distinguished from attribute data in that it is referenced spatially by a coordinate system, e.g. it has a spatial extent. Natural resource applications commonly use a Legal Survey system, e.g. the Alberta Township System (ATS), which identifies feature's locations as being a Meridian, Township, and a Range; or a projection such as the UTM coordinate system which identifies features by an Easting coordinate (X) and a Northing coordinate (Y) in a particular UTM zone.

In the UTM projection the area of the earth between 80 degrees North and 80 degrees South latitude is divided into north-south columns 6 degrees of longitude wide called zones. These are numbered 1 to 60 eastward beginning at the 180th meridian. Within each zone the central meridian is given an Easting value of 500,000 metres. The equator is designated as having a Northing value of 0 for northern hemisphere coordinates. Coordinates are recorded relative to the central meridian in metres in a particular zone. The basis of the UTM projection defines that the coordinates are duplicated within each UTM zone. Accordingly, use of the UTM projection is only appropriate for certain spatial extents and scales of data. It is not appropriate to use this projection if your area of interest crosses UTM zone boundaries.

For example, the province of Alberta is located in UTM zones 11 and 12. The central meridian for zone 11 is 117° longitude. The central meridian for zone 12 is 111° longitude. The UTM coordinate system is the most widely used projection in the mapping industry and consequently is becoming an de facto standard for use with geographic information systems. This is particularly true for regional data in Canada. The State Plane coordinate system is widely used in the United States.

Maps are the traditional method of storing and displaying geographic information.

A map portrays 3 kinds of information about geographic features. The:

- Location and extent of the feature
- Attributes (characteristics) of the feature
- Relationship of the feature to other features.

Geography has often been described as the study of why what is where. This description is quite appropriate when considering the three kinds of information that are portrayed by the traditional map;

- The **location and extent** of a feature is identified explicitly by reference to a coordinate system representing the earth's surface. This is **where** a feature is.
- The **attributes** of a feature describe or characterise the feature. This is **what** the feature is.
- The relationship of a feature to other features is implied from the location and attributes of all features. Relationships can be defined explicitly, e.g. roads connecting towns, regions adjacent to one another, or implicitly, e.g. close to, far from, similar to, etc. Implicit relationships are interpreted according to the

knowledge that we have about the natural world. Relationships are described as **how** or **why** a feature is.

The geographic information system distinguishes between the spatial and attribute aspect of geographic features.

Characterizing Geographic Features:

All geographic features on the earth's surface can be characterized and defined as one of three basic feature types. These are points, lines, and areas.

Point data exists when a feature is associated with a single location in space. Examples of point features include a fire lookout tower, an oil well or gas activity site, and a weather station.

Linear data exists when a feature's location is described by a string of spatial coordinates. Examples of linear data include rivers, roads, pipelines, etc.

Areal data exists when a feature is described by a closed string of spatial coordinates. An area feature is commonly referred to as a *polygon*. Polygonal data is the most common type of data in natural resource applications. Examples of polygonal data include forest stands, soil classification areas, administrative boundaries, and climate zones. Most polygon data is considered to be homogeneous in nature and thus is consistent throughout.

Data Accuracy and Quality:

The quality of data sources for GIS processing is becoming an ever increasing concern among GIS application specialists. With the influx of GIS software on the commercial market and the accelerating application of GIS technology to problem solving and decision making roles, the quality and reliability of GIS products is coming under closer scrutiny. Much concern has been raised as to the relative error that may be inherent in GIS processing methodologies. While research is ongoing, and no finite standards have yet been adopted in the commercial GIS marketplace, several practical recommendations have been identified which help to locate possible error sources, and define the quality of data. The following review of data quality focuses on three distinct components, data accuracy, quality, and error.

Accuracy

The fundamental issue with respect to data is accuracy. Accuracy is the closeness of results of observations to the true values or values accepted as being true. This implies that observations of most spatial phenomena are usually only considered to estimates of the true value. The difference between observed and true (or accepted as being true) values indicates the accuracy of the observations.

Basically two types of accuracy exist. These are positional and attribute accuracy. Positional accuracyis the expected deviance in the geographic location of an object from its true ground position. This is what we commonly think of when the term accuracy is discussed. There are two components to positional accuracy. These are relative and

absolute accuracy. Absolute accuracy concerns the accuracy of data elements with respect to a coordinate scheme, e.g. UTM. Relative accuracy concerns the positioning of map features relative to one another.

Often relative accuracy is of greater concern than absolute accuracy. For example, most GIS users can live with the fact that their survey township coordinates do not coincide exactly with the survey fabric, however, the absence of one or two parcels from a tax map can have immediate and costly consequences.

Attribute accuracy is equally as important as positional accuracy. It also reflects estimates of the truth. Interpreting and depicting boundaries and characteristics for forest stands or soil polygons can be exceedingly difficult and subjective. Most resource specialists will attest to this fact. Accordingly, the degree of homogeneity found within such mapped boundaries is not nearly as high in reality as it would appear to be on most maps.

Quality

Quality can simply be defined as the fitness for use for a specific data set. Data that is appropriate for use with one application may not be fit for use with another. It is fully dependant on the scale, accuracy, and extent of the data set, as well as the quality of other data sets to be used. The recent U.S. Spatial Data Transfer Standard (SDTS) identifies five components to data quality definitions. These are :

- Lineage
- Positional Accuracy
- Attribute Accuracy
- Logical Consistency
- Completeness

Lineage:

The lineage of data is concerned with historical and compilation aspects of the data such as the:

- Source of the Data;
- Content of the data;
- Data capture specifications;
- Geographic coverage of the data;
- compilation method of the data, e.g. digitizing versus scanned;
- transformation methods applied to the data; and
- the use of an pertinent algorithms during compilation, e.g. linear simplification, feature generalization.

Positional Accuracy:

The identification of positional accuracy is important. This includes consideration of inherent error (source error) and operational error (introduced error). A more detailed review is provided in the next section.

Attribute Accuracy:

Consideration of the accuracy of attributes also helps to define the quality of the data. This quality component concerns the identification of the reliability, or level of purity (homogeneity), in a data set.

Logical Consistency:

This component is concerned with determining the faithfulness of the data structure for a data set. This typically involves spatial data inconsistencies such as incorrect line intersections, duplicate lines or boundaries, or gaps in lines. These are referred to as spatial or topological errors.

Completeness:

The final quality component involves a statement about the completeness of the data set. This includes consideration of holes in the data, unclassified areas, and any compilation procedures that may have caused data to be eliminated.

Error

Two sources of error, inherent and operational, contribute to the reduction in quality of the products that are generated by geographic information systems. Inherent error is the error present in source documents and data. Operational error is the amount of error produced through the data capture and manipulation functions of a GIS. Possible sources of operational errors include:

- Mis-labelling of areas on thematic maps;
- misplacement of horizontal (positional) boundaries;
- human error in digitizing;
- classification error;
- GIS algorithm inaccuracies; and
- Human bias.

While error will always exist in any scientific process, the aim within GIS processing should be to identify existing error in data sources and minimize the amount of error added during processing. Because of cost constraints it is often more appropriate to manage error than attempt to eliminate it. There is a trade-off between reducing the level of error in a data base and the cost to create and maintain the database.

An awareness of the error status of different data sets will allow user to make a subjective statement on the quality and reliability of a product derived from GIS processing.

The validity of any decisions based on a GIS product is directly related to the quality and reliability rating of the product.

Depending upon the level of error inherent in the source data, and the error operationally produced through data capture and manipulation, GIS products may possess significant amounts of error.

Often because GIS data is in digital form and can be represented with a high precision it is considered to be totally accurate. In reality, a buffer exists around each feature which represents the actual positional location of the feature. For example, data captured at the 1:20,000 scale commonly has a positional accuracy of +/- 20 metres. This means the actual location of features may vary 20 metres in either direction from the identified position of the feature on the map. Considering that the use of GIS commonly involves the integration of several data sets, usually at different scales and quality, one can easily see how errors can be propagated during processing.

Example of areas of uncertainty for overlaying data:

Several comments and guidelines on the recognition and assessment of error in GIS processing have been promoted in papers on the subject. These are summarized below:

- There is a need for developing error statements for data contained within geographic information systems (Vitek et al, 1984).
- The integration of data from different sources and in different original formats (e.g. points, lines, and areas), at different original scales, and possessing inherent errors can yield a product of questionable accuracy (Vitek et al, 1984).
- The accuracy of a GIS-derived product is dependent on characteristics inherent in the source products, and on user requirements, such as scale of the desired output products and the method and resolution of data encoding (Marble, Peuquet, 1983).
- The highest accuracy of any GIS output product can only be as accurate as the least accurate data theme of information involved in the analysis (Newcomer, Szajgin, 1984).
- Accuracy of the data decreases as spatial resolution becomes more coarse (Walsh et al, 1987); and
- As the number of layers in an analysis increases, the number of possible opportunities for error increases (Newcomer, Szajgin, 1984).

MODULE-II

REMOTE SENSING TECHNOLOGIES AND ITS APPLICATION

THE MECHANISM OF REMOTE SENSING

Data is collected through either passive or active instruments, which differ fundamentally in their processes for measurement. Passive instruments detect the radiation reflected off or emitted by the sensed objects from a source other than the instruments, such as sunlight. An example of a passive instrument is an optical sensor. It relies on recording of reflected solar energy; thus, it is only able to take imagery during the day. On the other hand, active instruments transmit energy toward the target and then record the reflected or backscattered energy from the object. Active sensors such as radar, including synthetic aperture radar (SAR), have the advantage over passive remote sensing because they enable monitoring even at night, can penetrate cloud cover and rain, and are largely unaffected by the weather. Furthermore, SARs are particularly well suited for studying geological structures, partly because of their ability to penetrate foliage and view the underlying surface formations. Active sensors are valuable tools for such applications as monitoring forest clearings in very cloudy regions.

Although satellite remote sensing includes those satellites circling around other celestial bodies such as the Moon, this book focuses on the remote sensing of the Earth. Satellites need to be placed in certain orbital trajectories around the Earth to acquire remote sensing data. Remote sensing is conducted principally from two different types of orbits: the geostationary orbit and low-Earth orbit. Satellites in polar orbits can cover the entire surface of the globe over a period of time as the Earth turns below them. The altitude of the orbit determines the size of objects that can be identified: the lower the altitude, the smaller the objects that can be discerned.

The smallest size of an object that can be identifiable in an image is referred to as spatial resolution, which is a major element in determining the capabilities of the satellite. An image with a spatial resolution of 1 metre means that the smallest object that can be discernible in the image is approximately 1m, depending upon such factors as contrast ratio or signal-to-noise ratios; hence the geometrically defined term, Ground Sample Distance (GSD), is more frequently used. Of course, images with higher spatial resolutions give the users enhanced capabilities to assess the specific areas of interest in detail; however, there are other factors that are also important in determining the capability for remote sensing, such as image swath width, spectral resolution, and temporal resolution. Spectral resolution enables objects of similar sizes but different mate- rial to be distinguished, whereas temporal resolution – also referred to as ‘revisit time’ – defines how often a satellite can observe the same location and measure the change in observed phenomena. A temporal resolution/revisit of 16 days means that a satellite passes over the same area for sensing every 16 days, which is suitable for monitoring slowly changing or seasonal phenomena, but insufficient for disaster monitoring, which requires observations of the same location at least daily to monitor the progress of the disaster and its aftermath.

The width of the Earth's surface that a satellite's sensors can observe is called the swath width. Spatial resolution and swath width are typically linked. For a low spatial resolution sensor with the ability to cover a wide swath, high temporal resolution can often be achieved with a single satellite. These satellites are best suited for large-scale environmental measurements. High resolution sensors limit the swath width to tens of kilometres, so a constellation of satellites is needed to achieve the combined capabilities of high spatial resolution and high temporal resolution simultaneously. With the advent of small lower cost satellites, such constellations are increasingly used for different applications.

The operational flow of remote sensing activities includes all of the processes from data collection to data handling activities. The Scientific and Technical Sub-Committee of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) identified the following phases involved in remote sensing:

- Data acquisition;
- Data reception;
- Data pre-processing;
- Data storage;
- Data analysis; and
- Information Utilization.

Wherever data is collected, as the satellite acquires information about the observed phenomena it is transmitted to a ground station, where data is received and processed by computers for human viewing and interpretation. Each receiving station has a set of processes to generate a certified product. Once the data has gone through pre-processing, it is analyzed so as to deliver useful information: the data may simply be enhanced, or further value may be added to create maps. Advanced data analysis and value-adding are the processes that convert data into relevant knowledge ready for immediate use; thus, data goes through various stages of handling operations before it is delivered to the end users.

The Principles Relating to Remote Sensing of the Earth from Outer Space (hereafter: UN Remote Sensing Principles), which is the only international document addressing the sensing activities from space, categorizes three different types of data products: primary data, processed data, and analyzed information. In practice, however, various other terms are used: for instance, 'raw data' or 'unenhanced data' for primary data; 'enhanced data' for processed data; and 'derived products' and 'value added products' for analyzed information. Furthermore, different processing levels are adopted by different entities. No uniformity has yet been achieved for referring to different types of products from different systems, and this generates complexities for both data comparison and data integration by different systems into a final product.

Remote Sensors:

Remote sensing instruments are of two primary types—

- active
- passive.

Active sensors, provide their own source of energy to illuminate the objects they observe. An active sensor emits radiation in the direction of the target to be investigated. The sensor then detects and measures the radiation that is reflected or backscattered from the target. Passive sensors, on the other hand, detect natural energy (radiation) that is emitted or reflected by the object or scene being observed. Reflected sunlight is the most common source of radiation measured by passive sensors.

Active Sensors:

The majority of active sensors operate in the microwave portion of the electromagnetic spectrum, which makes them able to penetrate the atmosphere under most conditions. An active technique views the target from either end of a baseline of known length. The change in apparent view direction (parallax) is related to the absolute distance between the instrument and target.

- *Laser altimeter*—An instrument that uses lidar to measure the height of the platform (spacecraft or aircraft) above the surface. The height of the platform with respect to the mean Earth's surface is used to determine the topography of the underlying surface.
- *Lidar*—A light detection and ranging sensor that uses a laser (light amplification by stimulated emission of radiation) radar to transmit a light pulse and a receiver with sensitive detectors to measure the backscattered or reflected light. Distance to the object is determined by recording the time between transmitted and backscattered pulses and by using the speed of light to calculate the distance traveled.
- *Radar*—An active radio detection and ranging sensor that provides its own source of electromagnetic energy. An active radar sensor, whether airborne or spaceborne, emits microwave radiation in a series of pulses from an antenna. When the energy reaches the target, some of the energy is reflected back toward the sensor. This backscattered microwave radiation is detected, measured, and timed. The time required for the energy to travel to the target and return back to the sensor determines the distance or range to the target. By recording the range and magnitude of the energy reflected from all targets as the system passes by, a two-dimensional image of the surface can be produced.
- *Ranging Instrument*—A device that measures the distance between the instrument and a target object. Radars and altimeters work by determining the time a transmitted pulse (microwaves or light) takes to reflect from a target and return to the instrument. Another technique employs identical microwave instruments on a

pair of platforms. Signals are transmitted from each instrument to the other, with the distance between the two determined from the difference between the received signal phase and transmitted (reference) phase. These are examples of active techniques. An active technique views the target from either end of a baseline of known length. The change in apparent view direction (parallax) is related to the absolute distance between the instrument and target.

- *Scatterometer*—A high-frequency microwave radar designed specifically to measure backscattered radiation. Over ocean surfaces, measurements of backscattered radiation in the microwave spectral region can be used to derive maps of surface wind speed and direction.
- *Sounder*—An instrument that measures vertical distribution of precipitation and other atmospheric characteristics such as temperature, humidity, and cloud composition.

Passive Sensors:

Passive sensors include different types of radiometers and spectrometers. Most passive systems used in remote sensing applications operate in the visible, infrared, thermal infrared, and microwave portions of the electromagnetic spectrum. Passive remote sensors include the following:

- *Accelerometer*—An instrument that measures acceleration (change in velocity per unit time). There are two general types of accelerometers. One measures translational accelerations (changes in linear motions in one or more dimensions), and the other measures angular accelerations (changes in rotation rate per unit time).
- *Hyperspectral radiometer*—An advanced multispectral sensor that detects hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the electromagnetic spectrum. This sensor's very high spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands.
- *Imaging radiometer*—A radiometer that has a scanning capability to provide a two-dimensional array of pixels from which an image may be produced. Scanning can be performed mechanically or electronically by using an array of detectors.
- *Radiometer*—An instrument that quantitatively measures the intensity of electromagnetic radiation in some bands within the spectrum. Usually, a radiometer is further identified by the portion of the spectrum it covers; for example, visible, infrared, or microwave.
- *Sounder*—An instrument that measures vertical distributions of atmospheric parameters such as temperature, pressure, and composition from multispectral information.

- *Spectrometer*—A device that is designed to detect, measure, and analyze the spectral content of incident electromagnetic radiation. Conventional imaging spectrometers use gratings or prisms to disperse the radiation for spectral discrimination.
- *Spectroradiometer*—A radiometer that measures the intensity of radiation in multiple wavelength bands (i.e., multispectral). Many times the bands are of high-spectral resolution, designed for remotely sensing specific geophysical parameters

Remote Sensing Platforms:

Remote sensing means acquiring and measuring information about an object or phenomenon via a device that is not in physical or direct contact with what is being studied.To collect remotely sensed data, a platform – an instrument that carries a remote sensing sensor – is deployed. From the mid 1800's to the early 1900's, various platforms such as balloons, kites, and pigeons carried mounted cameras to collect visual data of the world below. Today, aircraft (both manned and unmanned) and satellites collect the majority of remotely sensed data. The sensors typically deployed on these platforms include film and digital cameras, light-detection and ranging (LiDAR) systems, synthetic aperture radar (SAR) systems, and multi-spectral and hyper-spectral scanners. Many of these instruments can be mounted on land-based platforms, such as vans, trucks, tractors, and tanks. In this part, we will explore the different types of platforms and their resulting remote sensing applications.

Remote Sensing Platforms Today

The period from 1960 to today has experienced some major changes in the field of remote sensing in a variety of ways, including (but not limited to):

- The 1960s and 1970s saw the primary platform used to carry remotely sensed instruments shift from airplanes to satellites. Satellites can cover much more land space than planes, and can monitor areas on a regular basis.
- Also during this time, imagery became digital in format rather than analog. The digital format made it possible to display and analyze imagery using computers, a technology that was also undergoing rapid change during this period. In addition, digital sensors permitted the transmission of imagery from the platform itself to the ground station without a problematic film return system as was used on CORONA and other satellites.
- Sensors were becoming available that recorded the Earth's surface simultaneously in several different portions of the electromagnetic spectrum. One could now view an area by looking at several different images, some in portions of the spectrum beyond what the human eye could view. This technology made it possible to see things occurring on the Earth's surface that one could not detect by simply looking at a visual image.

- The turbulent social movements of the 1960s and 1970s awakened a new and continuing concern about the changes in the Earth's physical environment. Remotely sensed imagery from satellites - analyzed and enhanced with computers - made it possible to detect and monitor these changes. Societal support was and generally continues to remain strong for remote sensing technology.

Modern aerial sensors collect data using film, digital, LiDAR, synthetic aperture radar (SAR), and several other methods. Although satellites are considered primary platforms (collecting much of the data used by governmental and research organizations), other platforms such as ground-based and airborne platforms (including both manned and unmanned aircraft) are quite prevalent and popular. Different platforms can carry different types of sensors depending upon the needs of the user, and each platform offers advantages and disadvantages in terms of range, cost, stability, frequency, scale, and accuracy.

Type of Platforms

Three types of platforms are used to mount the remote sensors –

- Ground Observation Platform
- Airborne Observation Platform, and
- Space-Borne Observation Platform

Ground-based Platforms:

Ground-based platforms include hand held cameras (film or digital), cranes, ground vehicles, tethered balloons, and even towers. Ground-based platforms typically provide up to 50 meters elevated remote sensing data and are useful for acquiring low altitude imagery with frequent coverage for dynamic phenomena. These types of platforms are relatively inexpensive, stable, and due to their low altitude, provide high-resolution data.

Airborne Platforms:

Airborne platforms include airplanes, helicopters, unmanned aerial systems (UAS), high-altitude aircraft, and free-floating balloons. They range from the slow (single engine or light twin engine), low flying (less than 30,000 feet) aircraft to the faster (twin-engine turboprops or jet) that is capable of flying at altitudes above 30,000 feet. Airborne platforms can provide up to 50 km of elevated remote sensing data, and are useful for acquiring atmospheric data, can pin-point locations, and can be used for specific tasks such as precision agriculture, building maintenance, emergency response, mapping, and environmental monitoring.

Advantages	Disadvantages
User can control variables such as altitude	Can be expensive to rent aircraft
Time of coverage can be controlled	Aerial platforms can drift off-course (e.g., balloons)
Easy to mobilize in response to short-term disruptions (e.g., passing clouds)	Turbulent motions can be caused by unexpected altitude changes
Cost of small UAS relatively inexpensive to own and operate	Motion blurring can occur
	Lower atmosphere is heavily subject to airspace regulations that control UAV usage

The National Aerial Photography Program (NAPP) was coordinated by the United States Geological Survey (USGS) as a project to acquire cloud-free aerial photographs at an altitude of 20,000 feet above mean terrain elevation. NAPP photographs were taken with a 6-inch focal length lens at a scale of 1:40,000. Coverage over the conterminous United States includes both black-and-white (BW) and color infrared (CIR) aerial photographs. The NAPP program, which was operational from 1987 to 2007, consists of more than 1.3 million images.

Another aerial imagery program is the National Agriculture Imagery Program (NAIP). NAIP acquires aerial imagery during the agricultural growing seasons in the continental U.S. NAIP is administered by the United States Department of Agriculture's (USDA's) Farm Service Agency (FSA) through the Aerial Photography Field Office in Salt Lake City. Imagery is acquired at a one-meter ground sample distance (GSD) with a horizontal accuracy that matches within six meters of photo-identifiable ground control points, which are used during image inspection. The default spectral resolution is natural color (Red, Green and Blue, or RGB) but beginning in 2007, some states have been delivered with four bands of data: RGB and Near Infrared.

The Remote Sensing Division at the National Oceanic and Atmosphere Administration (NOAA) is responsible for providing data to support the Aeronautical Survey Program (ASP), the Coastal Mapping Program (CMP) and Emergency Response efforts through the use of remotely sensed data. The ASP program collects data using field survey and photogrammetric methods to create runway approach procedures and airport obstruction charts. The CMP program works to provide a regularly updated national shoreline for supporting marine navigation, defining territorial limits, and managing coastal resources. Stereo photogrammetry and LiDAR are used to produce a digital database for a national shoreline. In addition, the Remote Sensing Division often acquires and rapidly disseminates a variety of spatially referenced datasets to federal, state, and local

government agencies, as well as the general public. In its largest response effort, the NOAA collected over 8,000 aerial images of the hardest hit areas in Alabama, Mississippi, and Louisiana after Hurricane Katrina made landfall. These images were made available to emergency personnel and the public on the NOAA/NGS (National Geodetic Survey) website.

Unmanned Aerial Systems or Unmanned Autonomous System (UAS):

UAS is an aircraft without an onboard pilot that is operated autonomously or manually by a remote-control operator. The terms unmanned aerial vehicle (UAV), unmanned aircraft systems/vehicles, remotely piloted aircraft (RPA), and drone, are often used interchangeably. They can be used to collect remotely sensed data for a variety of purposes, including business, agriculture, research, videography, journalism, and numerous others. UAS platforms typically adopted by geospatial researchers are considered small UAS (sUAS), weighing between 0.55 lbs (~0.2 kg) and 55 lbs (~25 kg) as designated by the U.S. Federal Aviation Administration (FAA; weight limits may vary in other countries).

UAS's are revolutionizing how researchers and practitioners model and analyze our world. Compared to traditional remote sensing approaches, UAS provide a largely inexpensive, flexible, and relatively easy-to-use platform to capture high spatial and temporal resolution geospatial data. Capturing imagery is the most common applicaion, and off-the-shelf, point-and-shoot digital cameras are a popular sensor option. Non-imagery applications of UAS include collecting measurements of temperature, pressure, humidity, and wind for atmospheric sampling and meteorology or environmental surveillance using sensors that can detect CO2, methane, and other gases for pipeline monitoring. LiDAR sensors have been employed for terrain and 3D mapping. Please see the DC-24 (Unmanned Aerial Systems) (link is external) for a more indepth discussion of drones and their applications.

Drone:

Drone is a miniature remotely piloted aircraft. It is designed to fulfill requirements for a low cost platform, with long endurance, moderate payload capacity and capability to operate without a runway or small runway. Drone includes equipment of photography, infrared detection, radar observation and TV surveillance. It uses satellite communication link. An onboard computer controls the payload and stores data from different sensors and instruments. The payload computer utilizes a GSM/GPRS (where available) or independent satellite downlink, and can be monitored its position and payload status from anywhere in the world connected to the internet.

Drone was developed in Britain during World War-II, is the short sky spy which was originally conceived as a military reconnaissance. Now it plays important role in remote sensing. The unique advantage is that it could be accurately located above the area for which data was required and capable to provide both night and day data.

High Altitude Sounding Rockets:

High altitude sounding rocket platforms are useful in assessing the reliability of the remote sensing techniques as regards their dependence on the distance from the target is concerned. Balloons have a maximum altitude of approximately 37 km, while satellites cannot orbit below 120 km. High altitude sounding rockets can be used to a moderate altitude above terrain. Imageries with moderate synoptic view can be obtained from such rockets for areas of some 500,000 square kilometers per frame. The high altitude sounding rocket is fired from a mobile launcher. During the flight its scanning work is done from a stable altitude, the payload and the spent motor are returned to the ground gently by parachute enabling the recovery of the data. One most important limitations of this system is to ensure that the descending rocket not going to cause damage.

Aircraft:

Special aircraft with cameras and sensors on vibration less platforms are traditionally used to acquire aerial photographs and images of land surface features. While low altitude aerial photography results in large scale images providing detailed information on the terrain, the high altitude smaller scale images offer advantage to cover a larger study area with low spatial resolution.

The National High Altitude Photography (NHAP) program (1978), coordinated by the US Geological Survey, started to acquire coverage of the United States with a uniform scale and format. Beside aerial photography multi spectral, hyperspectral and microwave imaging is also carried out by aircraft; thereafter multi spectral, hyperspectral and microwave imaging were also initiated.

Aircraft platforms offer an economical method of remote sensing data collection for small to large study areas with cameras, electronic imagers, across- track and along-track scanners, and radar and microwave scanners. AVIRIS hyperspectral imaging is famous aircraft aerial photographic operation of USGS.

Spaceborne platforms:

Spaceborne platforms include the space station as well as both low-level (700 to 1500 km) and high-level (~ 36,000 km) satellites. These types of platforms can acquire large areas of data in a short amount of time, which can be used to monitor Earth resources, atmospheric dynamics, and other applications.

Advantages of spaceborne remote sensing:

Spaceborne remote sensing provides the following advantages:

- Large area coverage;
- Frequent and repetitive coverage of an area of interest;
- Quantitative measurement of ground features using radiometrically calibrated sensors;
- Semi-automated computerised processing and analysis;

- Relatively lower cost per unit area of coverage.

CORONA:

Satellites can trace their origins first back to the CORONA and then the Landsat programs. CORONA was a secret military reconnaissance program that continues in a modified form today, and Landsat (Land Remote Sensing Satellite Platform) was (and is) an open Earth resources program.

From the beginning of the U-2 program, there was concern that the Soviet Union would rapidly develop technology to intercept and down the spy airplane. Thus the United States (in 1956) embarked on developing a reconnaissance system that came to be called CORONA.

From the start, figuring out how to take an aerial image from space, and then bring the film back down to Earth, was a primary challenge. Ultimately, a satellite was designed to release a film canister in a parachute-wearing capsule that was to be recovered in mid-air by a specially equipped aircraft. The capsules were designed to float in water for a short period of time, and then sink if the mid-air recovery failed. On August 19, 1960, the first successful air catch was made of a capsule of exposed film ejected from a photographic reconnaissance satellite. The satellite had made seven passes over the "denied territory" of the Soviet Union, China, and the Eastern Europe, and 17 orbits of Earth. This successful launch started the age of space reconnaissance and revolutionized remote sensing.

Overall, the CORONA Program was extremely successful. Keyhole-1 (KH-1), the first CORONA satellite, carried a single panoramic camera that had a ground resolution of 40 ft by 40 ft. Advances were made with each mission and by 1967 and KH-4, cameras had 5 by 5 ft resolution and the separation angle allowed stereoscopic images to be created. A single CORONA mission could record more photographic coverage than all of the U-2 missions combined. By the time the CORONA Program was completed in 1972, over 800,000 images had been acquired in 121 launches and 156 recoveries. Keyhole reconnaissance satellites, though, continue to be developed today with the present KH-13's.

When CORONA ended in 1972 the United States launched the first Landsat satellite. Landsat is a spaceborne platform used for commercial, academic, and government uses, and has grown dramatically since its first launch.

Polar Orbit (or near-polar orbit):

Polar orbit is an orbit with an inclination angle between 80 and 100 degrees. Such a polar orbit enables observation of virtually the whole globe as the Earth rotates underneath it. It takes approximately 90 minutes for the satellite to complete one orbit. This satellite is typically placed in orbit at 600 km to 1000 km altitude. These satellites have many uses such as measuring ozone concentrations in the stratosphere or measuring temperatures in

the atmosphere. Advantages of polar orbits include: 1) They provide global coverage, and 2) because the orbits are relatively low altitude, they provide fairly high data resolution. The disadvantage of a polar orbit is that they cannot provide continuous viewing of one location.

Sun-Synchronous Orbit:

The Sun-synchronous orbiting satellite passes over any given point on Earth's surface at the same local solar time (Figure 3). Because of the consistent lighting in Sun-synchronous orbits, scientists leverage this in various remote sensing applications, such as change detection monitoring.

Satellites that maintain Sun-synchronous orbits cover each area of the world at a constant local time of day called local Sun time. Therefore, at any given latitude, the position of the Sun in the sky as the satellite passes overhead will be nearly the same within the same season. This ensures consistent illumination conditions when acquiring images in a specific season over successive years, or over a particular area over a series of days. This is an important factor for monitoring changes between images or for mosaicking adjacent images together, as they do not have to be corrected for different illumination conditions. Altitudes of Sun-synchronous orbits are typically around 700 km to 850 km, with orbital periods between 90 to 100 minutes (or, about 14 orbits per day).

Earth resource satellites that are Sun-synchronous include (but are not limited to) Landsat, SPOT, Sentinel, POES, Quickbird, IKONOS, Beijing-1, Terra, Aqua, Aura, Skysat, and ZY-3. More information regarding these different satellites is in the Various Spaceborne Platforms and Their Characteristics section below.

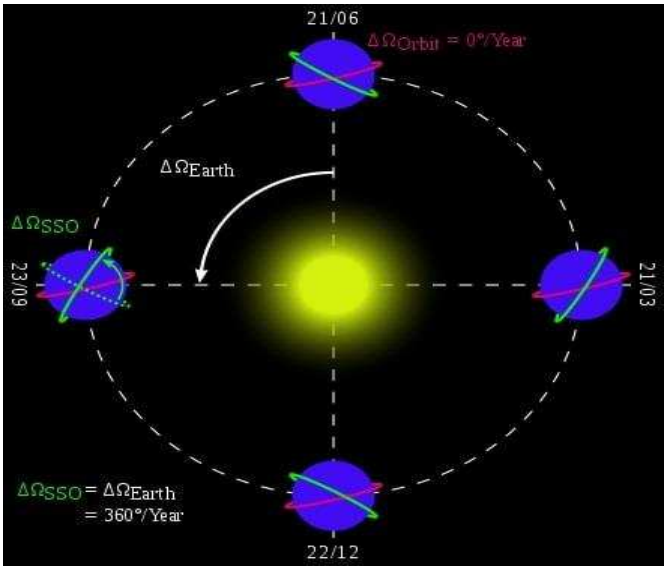


Figure 3: Sun-synchronous orbit. Diagram showing the orientation of a Sun-synchronous orbit (green) at four points in the year. A non-Sun-synchronous orbit (magenta) is shown for reference.

Geostationary Orbit:

Geostationary orbits are located at a distance of 36,000 km above the Equator (inclination angle of 0 degrees) (Figure 4). At this distance, the orbital period of the satellite is equal to the rotational period of the Earth. The result is that the satellite is at a fixed position relative to the Earth. Geostationary orbits fall in the same category as geosynchronous orbits, but with that one special quality of being parked over the Equator.

Geostationary satellites are positioned at different longitudes in order to increase global coverage. Benefits of a geostationary platform include: 1) They can make repeated observations over a given area, and 2) one can achieve high temporal resolution data. For example, the GOES (Geostationary Operational Environmental Satellites) satellites provide a temporal resolution of 1 minute, effectively monitoring severe weather environments in real time. The disadvantage of geostationary platforms is that -- due to the high orbit -- the spatial resolution of the data is much lower than polar-orbiting satellites. Today's meteorological weather satellite systems use a combination of geostationary satellites and polar orbiters. The geostationary satellites offer a continuous hemispherical view of almost half the Earth while the polar orbiters offer a higher spatial resolution.

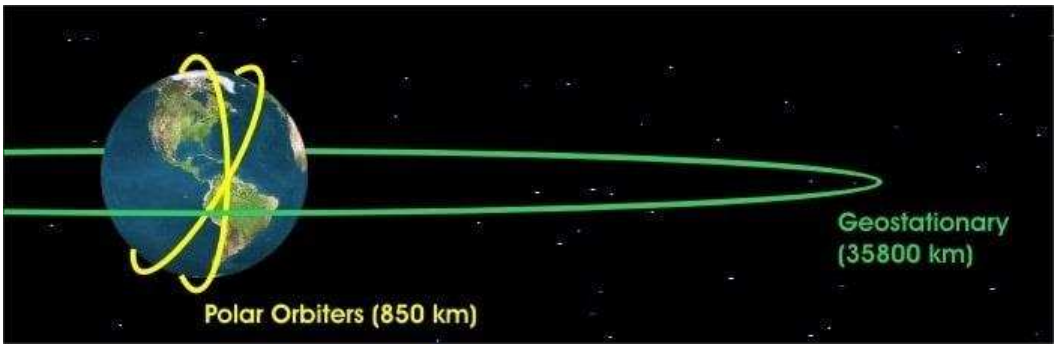


Figure 4. Geostationary versus polar orbiters.

<u>Various Spaceborne Platforms and their Characteristics:</u>

Landsat

In 1972, the National Aeronautics and Space Administration (NASA) began the Earth Resources Technology Satellite (ERTS-1), which later became Landsat-1. Each Landsat mission has been named in numerical order, with different sensor platforms defining what data is collected by its sensors. The Landsat-1 mission was a "proof-of-concept" that Earth orbiting satellites could effectively monitor natural and cultural resources. To date, there have been eight Landsat missions, with the 9th planned for launch in 2020 (Table 2).

Table 2. Characteristics of Landsat Missions

Satellite	Launched	Retired	Orbit (minutes)	Orbit Cycle (days)	Alt (km)	TM* Bands	MSS *** Bands	RBV**** *Bands
Landsat 1	23 July 1972	1 June 1978	103	18	900	--	4,5,6,7	1,2,3
Landsat 2	22 January 1975	25 February 1982	103	18	900	--	4,5,6,7	1,2,3
Landsat 3	5 March 1978	31 March 1983	103	18	900	--	4,5,6,7, 8	--
Landsat 4	16 July 1982	15 June 2001	99	16	705	1 to 7	4,5,6,7	--
Landsat 5	1 March 1984	5 June 2013	99	16	705	1 to 7	4,5,6,7	--
Landsat 6	5 October 1993	Failed Launch						
Landsat 7	15 April 1999	still active	99	16	705	1 to 8**	--	--
Landsat 8	11 February 2013	still active	99	16	705	OLI and TIRS ***	--	--
Landsat 9	December 2020	yet to launch	99	16	705	OLI-2 and TIRS-2	--	--

* TM = Thematic Mapper (30m resolution, 120m resolution thermal).

** TM+ (30m resolution, 60m resolution thermal; 30m resolution for band 8 = panchromatic = 0.5-0.9mm).

*** MSS = Multispectral Scanner (80m resolution). 4=green, 5=red, 6=NIR, 7=NIR, 8=thermal

**** RBV = Return Beam Vidicon (80m resolution). 1=blue-green (475-575nm); 2=orange-red (580-680nm); 3=red-NIR (690-830nm)

***** OLI = Operational Land Imager (link is external); TIRS = Thermal Infrared Sensor (link is external)

Landsat provides a unique historical resource to assist a broad range of specialists in managing the world's food, water, forests, and other natural resources for a growing world population. Open access to its full image collection has been made possible via several online interfaces and this has enabled many geospatial applications.

SPOT

SPOT is the Système Pour l'Observation de la Terre, initiated by the French space agency in the late 1970's. SPOT was designed to improve the knowledge and management of Earth by exploring Earth's resources, detecting and forecasting phenomena involving climatology and oceanography, and monitoring human activities and natural phenomena. SPOT's off-nadir viewing gives the possibility to create stereo views of the landscape.

ZY-3A

China's first civilian high-resolution surveying and resource satellite, Zi Yuan-3A or ZY-3A, was launched in September 2012. The satellite sensors provide panchromatic imagery at 2.1m resolution and 3.6 m resolution for its forward- and backward-looking sensors. It also collects multi-spectral imagery at 5.8 m resolution. It is a near-polar, Sun synchronous satellite, flying at an altitude of 506 km, with a repeat orbital cycle of 5 days.

POES (Polar Operational Environmental Satellites):

The POES satellite system offers the advantage of daily global coverage, by making nearly polar orbits 14 times per day at approximately 832 km above the surface of the Earth. The Earth's rotation allows the satellite to see a different view with each orbit, and each satellite provides two complete views of weather around the world each day. The National Oceanic and Atmosphere Administration (NOAA) partners with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) to constantly operate two polar-orbiting satellites: one POES and one European polar-orbiting satellite called Metop. The POES instruments include the Advanced Very High Resolution Radiometer (AVHRR) instrument (Table 3 and the Advanced TIROS Operational Vertical Sounder (ATOVS) suite. Data from the POES satellites supports a broad range of environmental monitoring applications including weather analysis and forecasting, climate research and prediction, global sea surface temperature measurements, atmospheric soundings of temperature and humidity, ocean dynamics research, volcanic eruption monitoring, forest fire detection, global vegetation analysis, search and rescue, and many other applications.

Table 3. Advanced Very High Resolution Radiometer (AVHRR) Bands

Band	Wavelength (µm)	Principle Applications
1	0.58 - 0.68	Daytime cloud and surface mapping, snow and ice extent.
2	0.725 - 1.0	Land-water boundaries, snow and ice extent.
3A	1.58 - 1.64	Vegetation and soil moisture. Delineate snow from clouds.
3B	3.55 - 3.93	Detecting hot targets such as forest fires, night cloud mapping, sea surface temperature.
4	10.30 - 11.30	Determining cloud and surface temperatures, day or night cloud mapping.
5	11.50 - 12.50	Determining cloud and surface temperatures, day or night cloud mapping, water vapor correction.

GOES (Geostationary Operational Environmental Satellites)

The first GOES satellite launched in 1974. GOES satellites (GOES-13, -14, -15, and -16), operated by the NOAA, orbit the Earth in geosynchronous orbits. Because GOES satellites stay above a fixed spot on the surface, they provide constant monitoring of any atmospheric "triggers" that would cause severe weather conditions such as tornadoes, flash floods, hail storms, and hurricanes. When these conditions develop, the GOES satellites are able to monitor storm development and track their movements. GOES satellite imagery is also used to estimate rainfall during thunderstorms and hurricanes, as well as estimate snowfall accumulations and overall extent of snow cover. Satellite sensors also detect ice fields and map the movements of sea and lake ice.

Sentinel:

The European Space Agency (ESA) is developing a new family of missions called Sentinels (Figure 5). Each Sentinel mission is based on a constellation of two polar-orbiting satellites that carry a range of technologies such as radar and multi-spectral imaging instruments for land, ocean, and atmospheric monitoring.

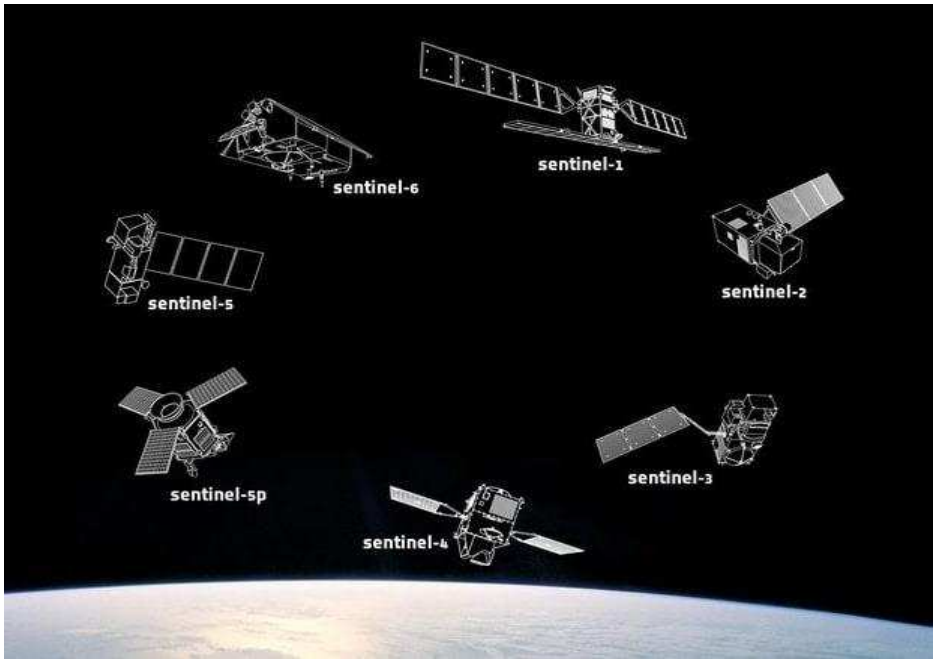


Figure 5: Sentinel family of satellites.

Commercial and Small Satellites

Commercial, small satellites are those satellites with low orbits and less mass compared to major satellites. They usually collect high-resolution data, are relatively low cost, and are flexible to launch. They can be designed, manufactured and launched by private companies, research institutions, or universities, and they are generally designed for special purposes.

In 1984, Congress established the legal framework for licensing and regulating a private satellite industry, but no industry emerged until 1993, when WorldView Inc. became the first U.S. company licensed to operate a commercial land observation satellite. NOAA (under the umbrella of the U. S. Department of Commerce) maintains information (link is external) on the Licensing of Private Remote Sensing Space Systems. The site is intended to provide U.S. laws, regulations, policies, and related information pertaining to the operation of private and commercial remote sensing satellite systems. The Mission of the NOAA Commercial Remote Sensing Regulatory Affairs (CRSRA) is to "regulate the operation of private Earth remote sensing space systems, subject to the jurisdiction or control of the United States, while preserving essential national security interests, foreign policy and international obligations. Its Vision is to balance commercial viability of private Earth remote sensing space systems and sound regulatory practices and policies while protecting national security, foreign policy and international obligations."

In 2014, the U.S. Department of Commerce (with support from the U.S. Departments of Defense and State), relaxed regulations regarding the distribution and sale of high-resolution imagery. Consumers can now purchase imagery at up to 0.25 m (25 cm) panchromatic and 1.0 m multispectral resolution. Prior to 2014, the U.S. federal

government prevented companies from selling imagery with resolutions sharper than 0.50 m (50 cm).

The companies in the satellite imaging market sell images to businesses such as Google Maps and Apple Maps and governments by licensing the images to them. Consumers of remote-sensing data also include farmers, city planners, map-makers, environmentalists, emergency response teams, news organizations, surveyors, geologists, mining and oil companies, timber harvesters, and domestic as well as foreign military planners and intelligence organizations. The rising demand for high resolution and advanced satellite imagery across these various fields has led to the increased use of commercial satellites.

Some examples of commercial satellites include:

IKONOS

IKONOS was the first commercial Earth observation satellite to collect publicly available high-resolution imagery at 1m panchromatic resolution and 4m multispectral resolution. IKONOS (launched by a company called GeoEye) orbits at an altitude of 681km (with a revisit frequency of 3-5 days off nadir, and 144 days for true nadir). IKONOS brought imagery rivaling that of military spy satellites to the commercial market. IKONOS imagery began being sold on 1 January 2000. The spacecraft was retired in 2015, but the imagery is available in the DigitalGlobe library.

Digital Globe

Digital Globe is one of the bigger companies in the commercial satellite image collection industry. DigitalGlobe was founded in 1992 under the name WorldView Imaging Corporation (in 2013, DigitalGlobe combined with GeoEye). Today, DigitalGlobe owns and operates a sophisticated constellation of high-resolution commercial Earth imaging satellites. Together, WorldView-1, GeoEye-1, WorldView-2, WorldView-3 and WorldView-4 are capable of collecting well over one billion square kilometers of quality imagery per year and offering intraday revisits around the globe. Table 4 below highlights some of the major characteristics of presently operational DigitalGlobe satellites.

Table 4. DigitalGlobe Constellation of Commercial Satellites

Feature	WorldView-1	GeoEye-1	WorldView-2	WorldView-3	WorldVIew-4
Operational Altitude	496 km	681 km	770 km	617 km	617 km
Spectral Characteristics	Panchromatic	Panchromatic + 4 multispec	Panchromatic + 8 multispec	Panchromatic + 8 multispec + 8 shortwave/IR	Panchromatic + 4 multispec
Panchromatic Resolution (nadir)	0.50 m	0.41 m	0.46 m	0.31 m	0.31 m
Multispectral Resolution	NA	1.64 m	1.85 m	1.24 m	1.24 m
Average Revisit at 40ºN Lat.	1.7 days	< 3 days	1.1 days	1.0 day	1.0 day

QuickBird:

QuickBird is a high-resolution commercial Earth observation satellite owned by DigitalGlobe that launched in 2001 (and decayed in 2015). The satellite collected panchromatic imagery at 61 cm resolution and multispectral imagery at 2.44 m - 1.63 m resolution (at 450 km and 300 km altitude, respectively). The orbit altitude lowered during the end of its mission life. At this resolution, details such as buildings and other infrastructure were easily visible.

Beijing-1

Beijing-1 is a low-cost Earth observation satellite established by a private company (BLMIT) to manage commercial data distribution and services. The platform carries two payloads that provide high-resolution (4 m) panchromatic images alongside medium-resolution (32 m) multi-spectral images. Beijing-1 provides the Chinese government and commercial users with information on agriculture, water resources, environmental, and disaster monitoring throughout China. The satellite is also used for monitoring urban development and pollution. Beijing-1 is capable of continuously imaging Chinese territory even at the longest landmass track (3000 km) and transmits images to the groundstation in Beijing in real-time. Beijing-1 orbits at an altitude of 699 km, and is a member of the Disaster Monitoring Constellation.

SkySat

SkySat is a constellation of sub-meter resolution Earth observation satellites owned by Planet Labs that provide high-resolution panchromatic and multispectral imagery, high-definition video, and analytics services. Planet Labs acquired the satellites with their purchase of Terra Bella (formerly Skybox Imaging) from Google in 2017. The resolution of the SkySat satellite imagery and videos is high enough to observe objects that impact the global economy such as terrain, cars and shipping containers. The satellites can capture video clips lasting up to 90 seconds at 30 frames per second. When Skybox originally developed the satellites, they planned to "change the nature" of the satellite industry by building satellites with "off-the-shelf" electronics that cost under $50 million. The SkySat satellites are based on the CubeSat concept, using inexpensive automotive grade electronics and fast commercially available processors, but scaled up to approximately the size of a minifridge. CubeSat is a type of miniaturized satellite that is made up of multiples of 10x10x10 cm cubic units, having a mass of no more than 1.33 kg per unit. SkySat satellites are approximately 80cm long and weigh 220 lbs. The satellites operate in a polar inclined, circular orbit at approximately 450 km above the earth.

EROS

EROS is a series of Israeli commercial Earth observation satellites, designed and manufactured by Israel Aircraft Industries (IAI). The satellites are owned and operated by ImageSat International, another Israeli company. EROS A was launched on December 5, 2000 to an altitude of 480 km. The satellite provides commercial images with an optical resolution (link is external) of 1.8 m. The satellite orbits Earth in a Sun-synchronous orbit, so that its imaged target is always in daylight. EROS A always crosses the equator (link is external) at 9:45am local time. EROS A has a height of 2.3 m and a diameter of 1.2 m. It weighs 250 kg. EROS B was launched on April 25, 2006. The satellite offers an optical resolution of 70 cm (about two feet).

NASA's Earth Observing System (EOS):

NASA's Earth Observing System (EOS) is a coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans (Figure 6). The satellite component of the program was launched in 1997. Table 5 shows some of the active platforms of the EOS system, their launch date, and their mission description.

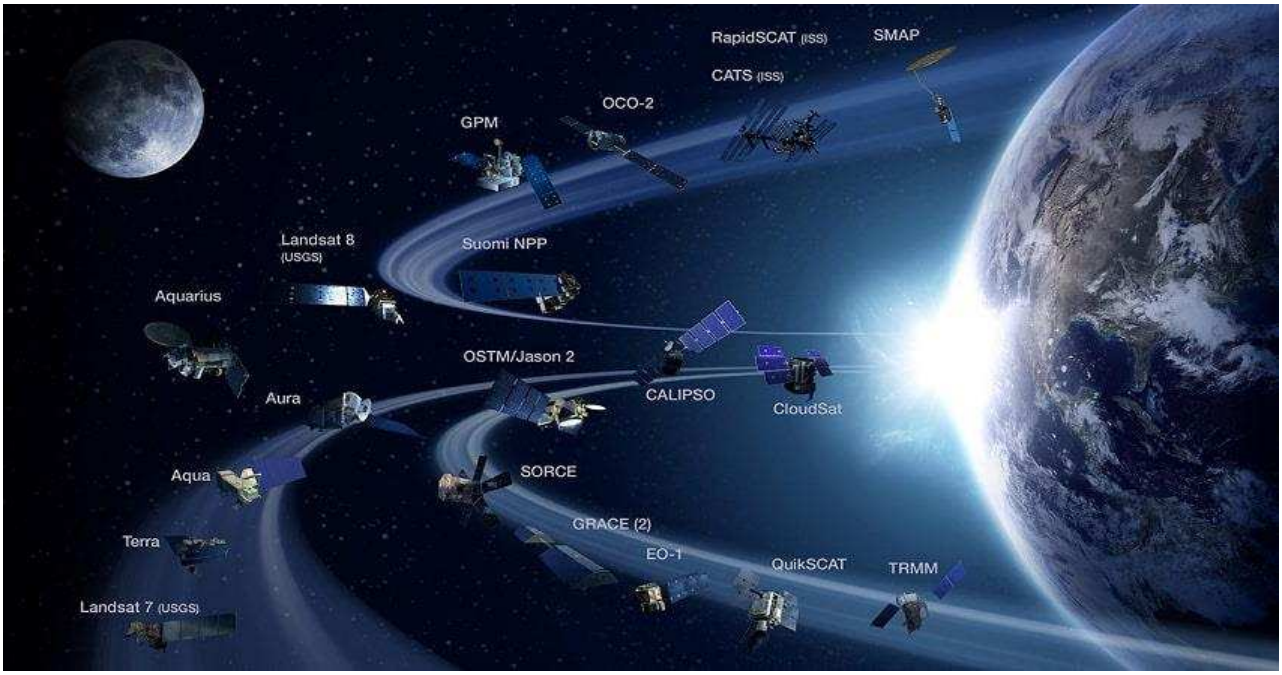


Figure 6. NASA's Earth Observing Satellites (EOS) and their Mission Descriptions

Table 5. Earth Observing Satellites (EOS) and their Mission Description

Satellite	Launch Date	Mission Description
Landsat-7	15 April 1999	Supply the world with global land surface images
Terra (“Earth”)	18 December 1999	Monitor the state of Earth's environment and ongoing changes in its climate system
Aqua (“Water”)	4 May 2002	Study the precipitation, evaporation, and cycling of water
Aura (“Air”)	15 July 2004	Study the Earth's ozone layer, air quality, and climate
CloudSat	28 April 2006	Provide the first direct global survey of the vertical structure and overlap of cloud systems and their liquid and ice-water contents
Landsat-8	11 February 2013	Supply the world with global land surface images
OCO-2	2 July 2014	Provide space-based global measurements of atmospheric carbon dioxide
SMAP	31 January 2015	Measure surface soil moisture and freeze-thaw state

REMOTE SENSING APPLICATIONS

Once data or derived products are delivered to the users, they are utilized for a wide range of applications. Applications include, but are not limited to: map making, land use, crop monitoring, natural resource management, registry of lands, urban planning, studies of environment, and verification of claims. Amongst other uses, satellite remote sensing is suited for monitoring and protection of the environment. This book focuses on the environmental and disaster management applications.

The Earth's environment includes the atmosphere, land, and oceans. Environmental applications include the assessment of land mass (including forests), and air and marine pollution. Global warming is an imminent environmental problem; satellite remote sensing is useful in monitoring the oceans, ice, atmosphere, and forests to provide key information on the environmental components, as well as evidence of global warming. Present data and past data can be compared to assess the extent and rate of deforestation, desertification, and loss of polar ice. Deforestation in the Amazon, for instance, has been the subject of many studies. Satellite images are also used for verification of environmental harm in specific areas of interest. Many lawsuits centre on the presence of toxic material in the air, water, or soil and satellite data is an effective tool to verify such claims. In particular, detection of oil slicks is a major application for verification purposes.

Satellites have provided data on earthquakes, floods, landslides, and fires. Satellites can monitor the progress of hurricanes and fires as well as measure the extent of damage from earthquakes and floods in the aftermath. The data becomes a vital tool to identify the damaged areas for an effective disaster response. Indeed, following the 2004 Indian Ocean Tsunami, a number of satellite images were provided and used to assess the location and the extent of the devastation, and to direct relief services and aid agencies most effectively by comparing these images with those taken before the tsunami. Critical decisions were made based on the satellite images to identify the overall extent of the disaster, as well as to conduct street level damage assessment to give the necessary direction for aid.

Some Remote sensing applications and uses:

- Determining soil moisture content using active and passive sensors from space
- Mapping with laser precision using Light Detection and Ranging technology
- Catching tax-evaders red-handed by locating new construction and building alterations
- Spinning the globe with mapping services like Google Earth, Bing Maps and OpenStreetMaps
- Predicting retail earnings and market share by counting cars in parking lot
- Snapping aerial photos for military surveillance using messenger pigeons in World War II
- Charging higher insurance premiums in flood-prone areas using radar

- Doing the detective work for fraudulent crop insurance claims
- Searching for aircrafts and saving lives after fatal crashes
- Detecting oil spills for marine life and environmental preservation
- Counting polar bears to ensure sustainable population levels
- Uncovering habitat suitability and fragmentation for panda bears in protected areas
- Identifying forest stands and tallying their area to estimate forest supplies
- Navigating ships safely with the most optimal route
- Measuring wind speed and direction for wind farms, weather forecasting and surfers
- Spying on enemies with reconnaissance satellites
- Delineating and assessing the health of riparian zones to conserve lakes and rivers
- Estimating surface elevation with the Shuttle Radar Topography Mission
- Extracting mineral deposits with hyperspectral remote sensing
- Watching algae grow as an indicator of environmental health
- Forecasting weather to warn about natural disasters
- Detecting land cover/use types for decision making
- Monitoring the environment with the ESA's Copernicus Program
- Mapping soil types for agriculture planning
- Preventing the spread of forest disease types
- Fighting wildfires by planning firefighter dispatch
- Monitoring air quality in the lower atmosphere
- Assessing terrain stability using interferometry in the oil and gas sector
- Unearthing ancient archaeological sites like the Mayans and ancient Egypt
- Pinpointing your position on Earth with Global Positioning Satellites
- Optimizing solar panel energy output with global horizontal irradiance
- Finding the driving factors that contribute to poverty
- Observing the flow of ocean currents and circulation
- Studying glacier melts and effects on sea levels
- Providing a base map for visual reference and assisting orient the map reader
- Snorkeling in an oasis of marine vegetation with the coastal channel
- Tracking hazards for better response and recovery
- Keeping tabs on the shift from rural to urban growth
- Quantifying crop conditions with Normalized Difference Vegetation Index (NDVI)
- Preventing the degradation and loss of wetland ecosystems
- Tracking sediment transport into rivers and lakes
- Saving money and time on the farm with precision farming

- Reversing illegal rainforest cutting in Brazil
- Putting illegal boat dumping under the microscope
- Inventorying and assessing rural road conditions with UAVs
- Driving with no hands (autonomous vehicles)
- Measuring gravity with the GRACE satellites
- Deriving elevation and contours using photogrammetry
- Watching the aurora borealis from another angle
- Comparing the past and present with human impact change
- Planning an optimal telecom network capacity
- Tracking displaced refugees to help deliver aid and services
- Keeping a watchful eye to prevent future atrocities from happening
- Designing a lift irrigation system to supply water in India
- Measuring the volume difference at a uranium enrichment site using 3D mapping

Terrestrial Applications of Remote Sensing:

Each day, millions of individual images and observations collect an enormous variety of information about the Earth's surface and subsurface. This routine surveillance enables the monitoring and modeling of ecosystem health, detecting seismic activity, identifying surface vegetation, promoting sustainable agriculture, and characterizing the physical and social vulnerability of human settlements.

Continuous advances in satellite remote sensing and geospatial technology have dramatically accelerated our understanding of environmental phenomena— extracting data which is often invisible (or less visible) from the ground—allowing us to develop innovative solutions to ever more complex social, environ- mental, and economic challenges. Decreasing costs of computing technology and satellite imagery; increasingly robust proprietary and open source software; rapid availability of geospatial data easily acquired online; higher quality image resolutions (e.g., under 1 m); and the ever-greater number of satellite sensors have all contributed to transformational changes in every field of study and professional practice.

Terrestrial applications of remote sensing include mapping, change detection, monitoring, modeling, and other observations of land uses stemming from human activities. For example, remote sensing has shown great promise to map and monitor land use and land cover change (LULCC) in an efficiently and cost-effective manner. Utilizing remotely sensed data may be the only viable mechanism for tracking LULCC changes at the subregional, regional, and global scales. An exhaustive review of terrestrial remote sensing applications is beyond the scope of this chapter. However, this chapter does provide examples of demonstrative case studies of the diverse and exciting ways that remote sensing has been put into use in tackling difficult local, regional, and global challenges.

Classifying Land Use and Land Cover:

One of the most frequently used applications of remote sensing is in the creation of land use and land cover (LULC) maps. LULC maps are created by taking an image and categorizing natural and artificial features into representative groups or "classes". Resource managers and researchers use LULC maps to study everything from plant composition to human settlement patterns, as well as to answer questions such as "how is vegetation changing and why?" Several large- scale LULC studies include the European Environmental Agency's classification of 25 European Union member states and other European countries and the UN Food and Agricultural Organization's (UNFAO) LULC mapping of the Sahel region of West Africa. In addition, new initiatives are increasingly being taken by agencies acting at national, regional, or global level in an effort to establish a base data layer for LULC to enable the monitoring of LULCC at all scales.

In 2010, China initiated the Global Land Cover (GLC) mapping project, the aim of which was to produce a 30 m GLC data product (GlobeLand30) with ten land cover classes for the years 2000 and 2010 within a 4-year period. Over 10,000 Landsat-like satellite images were combined to cover the entire Earth at 30 m resolution. The project thus far has produced many interesting datasets relating to various aspects of land cover and its relation with the availability of water and other natural resources. As always, accuracy is an important consideration. According to Gong et al. (2013), the first attempt to conduct an accuracy assessment on the GLC dataset was an experimental evaluation on the usability of existing automated classification techniques. Four classifiers, that is, Maximum Likelihood Classifier (MLC), J4.8 Decision Tree Classifier (DT), Random Forest Classifier (RF), and Support Vector Machine (SVM) were tested with more than 8000 images captured during the year 2000. It was found that the highest overall classification accuracy (OCA) was produced by SVM, at 64.9 %.

There are other major programs of interest at national level in the US involving LULCC mapping. A good example is the Multi-Resolution Land Characteristics (MRLC) Consortium involving a number of the US Federal agencies. Starting in the mid-1990s, MRLC has grown into a group of ten agencies that coordinate the production of five different products, including the National Land Cover Database (NLCD), the Coastal Change Analysis Program (C-CAP), the Cropland Data Layer (CDL), the Gap Analysis Program (GAP), and the Landscape Fire and Resource Management Planning Tools (LANDFIRE). As described by Wickham et al. (2014), these products include almost every aspect of land cover from impervious surface to detailed crop and vegetation types to fire fuel classes. Some products can be used for land cover change assessments because they cover multiple time periods. The MRLC Consortium has become a collaborative forum, where members share research, methodological approaches, and data to produce products using established protocols, and we believe it is a model for the production of integrated land cover products at national to continental scales.

Another example is the North American Landscape Characterization (NALC) project that has produced LULC data for the entire US. The NALC project was sponsored by the US

Environmental Protection Agency's (EPA) and the US Geological Survey, EROS Data Center. This project is a component of the National Aeronautics and Space Administration's (NASA) Landsat Pathfinder program of experiments to study global change issues.

At the regional scale, monitoring urban growth is one of the questions social scientists, urban planners, and decision makers deal with most frequently. The direct impacts of urban expansion on physical, ecological, and social resources have made research on urban sprawl an issue of increased interest. Traditional census sources are extremely useful in that they capture changes in the socioeconomic and demographic structure of cities, but they lack spatial details and are not frequently updated.

Remote sensing, in contrast, makes available a vast amount of data with continuous temporal and spatial coverage and can, therefore, provide a successful means for monitoring urban growth and changes. Current research is oriented toward the use of remotely sensed data in conjunction with demographic and socioeconomic data to study urban change dynamics or to better understand the spatial distribution of population and socioeconomic phenomena.

This has been particularly important in developing countries where many cities are experiencing a rapid increase in population and consequential urban expansion, and where remote sensing may provide fundamental observations of urban growth that are not available from other sources.

Most of the research on urban growth is still based on traditional land cover classifications and change detection methodologies, but recently there has been a shift toward the development of integrated datasets that can be used in planning and urban monitoring efforts. Such relatively new trends include, for example, the development of urban environmental quality and quality-of-life indices to monitor physical and social changes in cities.

Turning to the local scale, Hester et al. (2009) produced LULC maps from high-resolution satellite (Quickbird) data of an area in Raleigh, North Carolina that was subsequently used for impervious area estimation, land use change detection, and water quality studies.

Understanding and Protecting Biodiversity Through Wildlife Tracking:

Our understanding of large animal movement, migration patterns, and habitat utilization patterns are largely tied to the landscape. As these animals move over large geographic areas, our understanding of their movement patterns can often be quite limited. Common approaches have involved tagging and recapturing animals in different locations, whereas more modern approaches involve monitoring active animal movement with radio telemetry applications. Newer approaches include the process of "bio-logging". Bio-logging, which uses small animal-attached tags for recording and/or relaying of data about an animal's movements, behavior, physiology, and/or environment, has led to important new discoveries about migratory patterns, habitats, breeding and wintering

grounds, speed of migration, orientation, the influence of weather conditions and climate change, and an enormous host of other factors.

Studies conducted in the field offer unique opportunities to observe natural phenomena; however, there are many challenges—from being prohibitively expensive to logistically difficult. Wildlife biology has advanced through an influx of technology in which audio and video recordings, GPS, and satellite remote sensing are important aids in gaining biological and physical information from free-ranging species. The ARGOS satellite system, created in 1978 by the French Space Agency (CNES) to collect and relay meteorologic and oceanographic data, is one of the most established satellite-based systems used to track mammals, marine animals, and birds across the globe.

Direct remote sensing from aerial platforms has also been applied to larger animal movement studies. Often, all of these approaches are limited to observing only a few animals at a time, and within a manageable/limited spatial scale, due to cost, the labor involved, and the time necessary to complete the study. Satellite remote sensing, despite its potential to provide data over a large spatial scale and at a relatively low cost, has been applied a lot less to larger animal inventories and tracking animal movement studies. However, large, region-scale, satellite imagery has been useful in monitoring associated vegetation and landscape usage of animals.

Verlinden and Masogo (1997) used Normalized Difference Vegetation Index (NDVI) data products generated from the Advanced Very-High-Resolution Radiometer (AVHRR-NOAA) sensor to correlate habitat greenness estimates with species density distributions of ostrich populations (*Struthio camelus*) and large, grazing herbivores: wildebeest (*Connochaetes taurinus*), hartebeest (*Alcelaphus buselaphus*), eland (*Taurotragus oryx*), and gemsbok (*Oryx gazella*). This study was carried out in the semi-arid region of the Kalahari Desert, Africa. The Kalahari Desert comprises an area of over 900,000 km^2 and encompasses much of Botswana, and parts of Namibia and South Africa. Larger animal species in this region must travel over large distances in search of grass "greenness" patches in order to fulfill their water and nutrient requirements. The green patches of grasses result from rainfall, which may be highly variable both temporally and spatially. For this study computer-generated density and distribution models were developed for each species, coupled with rainfall data and field observations made from aircraft. The generated density and distribution estimates were compared to NDVI data. The NDVI data used consisted of 10-day composite data and were derived from corrected and georeferenced Global Area Coverage (GAC) data with a resolution of approximately 4 × 4 km. The GAC dataset is comprised of a reduced resolution image data that is processed while onboard the AVHRR satellite platform. The AVHRR-GAC data are resampled by extracting one line out of every three captured and averaging four of five adjacent samples along the sensor's scan line. This process results in a reduced resolution image apart from the original 1.1 km resolution image data.

The Verlinden and Masogo (1997) NDVI model results showed low, but significant, correlations to aerial survey greenness scores (Spearman rank correlation was 0.43,

p<0.001). NDVI model results also showed low, but significant, correlations to ground-sampled greenness scores (Spearman rank correlation was 0.33, $p < 0.001$). These significant positive relationships between NDVI and grass greenness (both aerial survey and ground sampled) suggested that, with some caution, NDVI estimates could be used in this area to monitor greenness. Relationships between NDVI and animal distribution proved more difficult to determine. However, the NDVI-greenness correlations may show a means of assessing habitat suitability, on a regional scale in the Kalahari, for a few of the species examined (i.e., wildebeest, hartebeest, and ostrich).

Researchers and environmental managers may be beginning to view image analysis applications derived from remote sensing as an efficient and promising means of confronting data gaps in inventory challenges, status and trend monitoring, recovery planning, and predictive assessments of species biodiversity and wildlife population management. Current limitations of spaceborne remote sensing and the development of effective management approaches in tracking and monitoring animal movement include identifying an appropriate scale of study, as well as the availability and appropriateness of the type and resolution of the remotely sensed data or remotely sensed data product required. However, with the continuing evolution of sensor technologies ever expanding, as well as higher sensor ground spatial resolutions becoming more commonly available, the ability to use spaceborne sensors may provide an efficient means of investigating animal movements over larger spatial scales. The potential of integrating remote sensing and geospatially derived data-driven analyses may additionally have a huge impact on the public, as well as on professionals within the field, and further increase the possibility for the use of these technologies to create opportunities for greater public and scientific discussion.

Water Resources:

Surface water supply, reservoir mapping and monitoring, water quality mapping and modeling, runoff forecast modeling, drainage network mapping, hydrologic research, watershed characterization, and surface water impairment are all water-resources-related candidates for remotely sensed data applications.

Changes in land use and land cover may have severe impacts on aquatic ecosystems. Activities such as agriculture, urbanization, and erosion are primary sources of sediment and nutrient input into water bodies. A few examples of the consequences of increased sediment and nutrient loading on water bodies include the loss of littoral or coastal zone habitat, eutrophication, depletion of oxygen, and changes in food webs dynamics.

Nonpoint source pollution (NPS) is the term used to describe loadings to water bodies from diffuse sources within the landscape. These sources make up nutrient and chemical pollutants from developed areas, construction sites, paved surfaces, cultivated fields and pasture lands, and atmospheric deposition. However, despite the variety of pollutants classified as NPS, sediments are the largest amounts of material transported to surface

waters. Approximately 60 % of all sediment and sediment-associated contaminants delivered to the US's rivers, lakes, and coastal regions are from agricultural soil loss.

Remote sensing provides a unique technological advantage in monitoring aquatic systems due to its ability to capture data over large areas, and assorted spatial and temporal resolutions. However, satellite remote sensing of aquatic systems has been less studied as a result of the difficulties inherent in interpreting reflectance values of water. Clear water provides little spectral reflectance because longer wavelengths are absorbed and the reflected shorter wavelengths, which sensors rely on for surface feature detection, are subject to higher atmospheric scattering. Due to the absorption of longer wavelengths, most deep and clear water bodies appear dark on unclassified satellite imagery. Sensors, such as the Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM), were primarily designed for land studies, and thus are not completely applicable to aquatic studies. Recent improvements in sensor technologies have allowed for better spatial and spectral resolutions than previously available, which may improve their usefulness to aquatic studies.

In a study by Nelson et al. (2003), Landsat-7 data were used to investigate the relationship between spectral values extracted from Landsat Enhanced Thematic Mapper (ETM+) data and water clarity using Secchi disk transparency (SDT) measurements The SDT measurements incorporated the range of SDT values found within a geographic region comparable to 80 % of the lakes within the lower peninsula of Michigan, US. The Secchi depth is inversely proportional to the absorbance of light by water and dissolved or particulate substances, such as algal biomass.

This study represented an assessment of water clarity on a regional scale using remotely sensed data and identified an important consideration necessary for modeling water clarity on such a large scale—models developed for large regions must incorporate the full range of lake SDT values found throughout the region in the model calibration. Models that incorporate this complete range of SDT values, such as the one developed in this study, may not produce statistical relationship results as high as models that are developed for groups of lakes that do not incorporate the full regional range of SDT values. In addition, these results suggest that Landsat may be better suited for predicting shallow SDT values (i.e., eutrophic- higher algal biomass) than clearer water containing deeper SDT values. These types of models, based on remotely sensed data, have the capacity to provide managers with a method to inventory shallow SDT lakes across the entire state where in situ data are difficult to obtain. In particular, regulatory and management agencies would be able to monitor private lakes without spending resources on these lakes and without requiring the permission of the property owner. Additionally, models developed from remotely sensed data may be useful in the historical analysis of watershed changes that may have caused lake eutrophication to occur over time. This application is a very attractive use of remote sensing since historical imagery may be obtained for aquatic systems that have become eutrophic over time.

Beyond this specific study, despite current limitations, remote sensing does possess the potential to provide a valuable tool for monitoring freshwater systems. Several studies have successfully used remote sensing to measure characteristics of aquatic systems such as chlorophyll and SDT suspended sediments, and dissolved organic matter. Other studies have used remote sensing to map aquatic plant abundance in large areas of homogenous cover or for species detection in smaller areas they have used high-resolution hand or aircraft sensors. While remote sensing has been used in large-scale land change studies for many years, few studies have used currently available remotely sensed data to develop standardized methods for measuring water quality parameters across a wide range of aquatic environments, over large regions, or covering multiple images.

Accessing water quality parameters on a regional scale provides a challenge in that regional remote sensing requires that multiple remotely sensed images be combined from multiple dates or regions of varying atmospheric influences (i.e., haze, cloud cover, etc.). Multitemporal image-to-image differences are a result of atmospheric absorption and light scattering, which can be highly variable from one period of time to the next (Moore 1980). This difference can have a pronounced effect on the interpretation of imagery for trend analyses when using multiple images that are collected on different days, months, or years. Song et al. (2001) found that atmosphere corrections are necessary when using two or more satellite images collected on different dates, such as imagery used in land use/cover change studies. For example, for aquatic studies, Brivio et al. (2001) found that without the appropriate corrections for atmospheric scattering and transmittance effects, successful remote sensing of water quality parameters could not be accurately achieved from four Landsat TM images. Brivio et al. (2001) were able to develop two image-based rectification models which were used to correct regional atmospheric effects in multi-seasoned Landsat images of Lake Lseo and Lake Garda, Italy. However, accurate and simple procedures to correct for these effects are still an area of future research.

These atmospheric limitations may be reduced by many recent technological advances. A few of the newest sensors include IKONOS, the Earth-Observing System (EOS) Terra sensors, and the Landsat ETM+. These sensors will ultimately employ more advanced data calibrations than was possible with some of the older sensors. However, the advantage of the older Landsat platforms is that they provide consistent historical data not yet available from new sensors, and the temporal and spatial resolutions provided by Landsat MSS and TM are still more effective in monitoring landscape changes. For example, since the early 1980s, remote sensing techniques have become commonly used to detect wetland change. However, few studies have taken advantage of the wealth of historical data available from the satellite platforms that have been operating across several decades, and that are becoming widely available and inexpensive. Images obtained using the Landsat MSS sensor presently represent our longest, continuous satellite remotely sensed historic record.

The availability of newer data will, however, allow for the integration of cross-platform data in developing band and image sharpening algorithms which will serve to fill in the

gaps present in the older system data acquisitions (clouds, haze, etc.) and enhance the ability to develop multi-image calibrations for cross referencing. Furthermore, three of the main Terra sensors (MODIS—Moderate Resolution Imaging Spectrometer, ASTER—Advanced Spaceborne Thermal Emission and Reflectance Radiometer, and MISR—Multi-angle Imaging Spectroradiometer) have been identified as being particularly useful in the remote sensing of large-area land cover and land use changes and vegetation dynamics studies. However, aquatic remote sensors have yet to see the production of sensors specifically designed to monitor aquatic environments.

Currently, Landsat provides one of our richest data sources for the remote sensing of historical changes in large areas of wetlands, water quality, and aquatic plants. This is evident from the high revisit cycle, spatial resolutions, and 30 years of operation provided by these sensors.

Forest Resources:

Applications of remotely sensed data to forest resources and environmental management are numerous. Examples may include any of the following applications:

- Forest canopy extent and structure mapping
- Forest health mapping and monitoring
- Timber inventory
- Forest-type mapping
- Timber stand conditions assessment
- Harvesting and procurement priority implementation
- Reforestation
- Deforestation

Deforestation, the clear-cutting of forests for subsequent conversion to other land uses, is common throughout much of the world, especially in tropical regions. During the past decade, the five countries with the highest rates of forest loss (Brazil, Papua New Guinea, Gabon, Indonesia, and Peru) lost a combined 3.6 million hectares of primary forest each year. Large-scale deforestation has major implications for ecosystem function and biodiversity, as well as climate change, since it affects regional carbon storage and sequestration. In addition, selective logging is widespread in rapidly deforesting areas such as the Amazon, further exacerbating the ecological impacts.

Deforestation is typically driven by economic pressure (i.e., a perceived economic incentive for forest conversion rather than conservation) and is usually facilitated by limited governmental oversight in the affected regions. Because of the lack of regulatory enforcement, illegal logging is often rampant, encroaching upon (and reaching into) supposedly protected forest areas. Unfortunately, governments in those world regions with the highest deforestation rates typically lack resources for monitoring or predicting patterns of forest conversion. However, a number of recent studies have shown that remote sensing can be a cost-effective approach for monitoring deforestation (due to both

legal and illegal logging) and for identifying management priority areas. The typical remote-sensing-based strategy is to analyze a time series of Landsat images (or similar moderate-resolution imagery) captured over a period of many years. Time series analyses of moderate-resolution satellite images have been used to study deforestation in many regions of the world: Southeast Asia, the Amazon, Central Africa, and Eastern Europe. Below, we highlight a few such applications.

Instead of focusing on actual changes in forest cover, Laporte et al. (2007) mapped the expansion of logging roads over a 27-year period (1976–2003) in the humid forests of Central Africa. Despite the persistence of cloud cover in this region (an estimated 1.6% of which was completely obscured by cloud cover), the researchers typically had multiple images available to delineate an area; in total, they used more than 300 Landsat images to map their four-million-square-kilometer study area. The images were contrast stretched to optimize road detection, and then the roads were manually digitized. Basically, the researchers found that this manual approach outperformed semiautomated approaches, particularly when delineating older roads or working from older imagery. The researchers also used IKONOS imagery of a 25 km2 area in the northern Republic of Congo to examine the finer-scale impacts of logging activities, finding that canopy gaps in logged areas were five to six times larger than gaps in adjacent unlogged areas.

Laporte et al. (2007) mapped nearly 52,000 km of road in the study region. Overall, logging roads accounted for 38% of the length of all roads. The most rapidly changing region was the northern Republic of Congo, where the rate of road construction increased from 156 km per year for 1976–1990 to 660 km per year after 2000. The researchers estimated that approximately 5 % of the total forested area was disturbed. In summary, this effort yielded the first comprehensive dataset on the status of logging in Central Africa, and so will serve as a key resource for future planning and management.

Deforestation in the Amazon region of South America is a well-known problem, but actually less than 1 % of the region was deforested prior to 1975. Deforestation rates increased exponentially in subsequent decades because of economic incentives for conversion to agriculture (e.g., favorable credit policies for cattle ranchers). The state of Rondônia in western Brazil has become one of the most rapidly deforested parts of the Amazon. Many migrants have been brought to the state through government colonization projects, placing a huge burden on the state's remaining forests. While only 4200 km2 of forest had been cleared in Rondônia in 1978, by 2003 the amount of cleared forest had increased to nearly 68,000 km^2.

The 2000 and 2010 MODIS true-color-composite images from the remote north- western corner of Rondônia. The time series illustrates the typical pattern of initial deforestation along (both legal and illegal) roads, which permits small farmers to colonize previously inaccessible areas (NASA 2011). Over time, this leads to the establishment of large settlements and the clearing of most forest parcels.

Like the state of Rondônia, the southeastern Asian nation of Papua New Guinea has similarly seen a large population increase in recent decades, combined with an increased demand for timber and other resources. A team of researchers from the University of Papua New Guinea and Australian National University analyzed deforestation and forest degradation in the nation—home to the world's third largest rain forest (BBC 2008)—over a 30-year period. They used Landsat, Spot 4, and Spot 5 imagery to create a map of land cover as of 2002, which they then compared to a 1972 land cover map created by the Australian Army. The researchers found that 15% of Papua New Guinea's forest had been cleared over the 30-year period, while an additional 9% was severely degraded by logging. They also found that the rate of forest conversion had generally risen since 1990; by 2001, the estimated deforestation rate was just over 3600 km2 per year. The current rate of conversion could result in the loss of more than half the nation's forest cover by 2021.

Two satellite images from Papua New Guinea's Gulf Province, the first captured in 1988 and the second in 2002. Because Papua New Guinea is a mountainous island country, logging has mostly been limited to accessible areas (i.e., valleys and coastal lowlands). However, Shearman et al. (2009) estimated that 13 % of upper montane forests were also lost between 1972 and 2002.

Forest Health

In recent years, disturbances from extensive wildfire, drought, nonnative insect/pest species invasions, and climate change have threatened the health of forest throughout the globe. These threats, which can stretch across periods of time that last many years, may result in shifts in the dominant forest tree and animal species, as well as extensive forest mortality. Satellite and aircraft remote sensing techniques have relied on the capture of spectral color and infrared data to access forest health. From acquired remotely sensed data, the NDVI has been used as a traditional tool for forest vegetation health assessments. The NDVI is an essential index of vegetation greenness that results from light interacting with the vegetation canopy. Chlorophyll pigments found in the leaves of healthy vegetation, that make up the forest canopy, interact with incoming solar radiation by strongly absorbing visible light in the blue (0.45 μm) and red range (0.67 μm) of the electromagnetic spectrum, which is primarily used for the process of photosynthesis. Alternatively, light is reflected within the green range (0.5 μm) and even more so strongly reflected in the near-infrared portion (0.7–1.3 μm) of the electromagnetic spectrum. This strong reflection of light in the near-infrared portion of the electromagnetic spectrum is largely due to the leaf's internal structure. The response of the absorption and refection regions within the electromagnetic spectrum of the vegetation depicts the typical spectral signature curve for healthy vegetation when comparing the relationship of wavelength with percent reflectance.

The spectral signature response curve for healthy vegetation may vary slightly over time as a plant canopy changes from early spring growth to late-season maturity and senescence. However, when vegetation becomes stressed as a result of disturbances,

reflectance in the infrared range of the electromagnetic spectrum may also change, becoming significantly lower. In fact, stressed vegetation will typically reflect more light in the visible range of the spectrum, since less is being taken up for photosynthesis, and reflect less light in the near-infrared range. Thus assessing these differences (i.e., healthy vegetation vs. stressed vegetation) remote-sensing- derived NDVI results can reveal where vegetation is thriving and where it is under stress.

The US Forest Service, in collaboration with NASA-Stennis Space Center, DOE Oak Ridge National Laboratory, and the USGS EROS Data Center, developed a near-real-time regional monitoring system for forest disturbances. This system is known as ForWarn and was developed in response to the 2003 US Healthy Forest Restoration Act, which mandated that a national forest threat Early Warning System (EWS) be enacted due to the increased extent and threat of forest disturbances across the country. ForWarn started online operations in 2010. This system uses multiple historical baseline datasets and satellite-derived NDVI values from the MODIS Aqua and Terra satellites (232 m ground spatial resolution) to derive weekly forest change products across the lower 48 United States.

Data products are accessed through the ForWarn website, and ForWarn's geospatial data viewer provides user access to forest disturbance dynamics throughout the year of interest. ForWarn products have also been used to identify and track regional disturbances, including defoliation and mortality from insects, to drought, to wildfire, to severe storm events, and to human deforestation activities. Disturbance maps are available online through the ForWarn Change Assessment Viewer.

Biomass Estimation:

The term biomass in the terrestrial environment, from an ecological perspective, often refers to the numbers, weight, or mass of living organisms. For vegetation, the term biomass typically refers to a dry weight calculation of the aboveground components of larger vegetation, such as grasses, shrubs, and trees, whereas smaller algae and fungi species are often less considered, particularly in satellite remote sensing studies. For animals, few studies capture carnivores and herbivores with remote sensing. Thus, satellite remotely sensed estimates of terrestrial biomass largely include studies of the latter, macro-vegetation. However, estimates of vegetative terrestrial biomass can be ecologically very important and provide great capacities for assessing ecosystem biodiversity and implications for management strategies. The definition of biomass typically implies the measurement of the mass of living biological organisms in a given area at a given time. This measurement may come in the form of weights, or even less commonly referred to as an in situ value, or natural state, such as standard vegetation indices (e.g., NDVI, etc.) as previously discussed. However, traditional methods of estimating of terrestrial biomass are usually made from field-based measurements collected over extremely small areas and usually nonrepresentative of a larger region in which synoptic sampling would be prohibitive. Satellite remote sensing offers advantage

in vegetative terrestrial biomass inventorying, monitoring, and analyses in that the platform's sensors have the unique ability for large-area, repetitive sampling.

The NDVI (a ratio of red to near-infrared), a leaf area index (or LAI—a vegetation biophysical parameter that consists of a dimensionless variable and a ratio of leaf area to per unit ground surface area), and the fraction of vegetation cover (fCOVER) were used to evaluate the performance of SPOT imagery in estimating grassland biomass in a study by Dusseux et al. (2015). Linear regression models applied to 15 samples were developed to determine relationships between bio- mass measurements and variables estimated from SPOT sensor imagery. Biomass measurements were taken in the field from nine agricultural sites in the region of Brittany, in northwestern France, throughout the 2011 growing season. The remote sensing variables were developed from five cloud-free SPOT 4 images (20 m ground spatial resolution) that were acquired throughout the 2011 growing season. The image acquisition dates and field samples varied by a range of 2–11 days, with the imagery being corrected for both radiometric and atmospheric effects. The results of this study suggested that significant statistical relationships were possible between the observed biomass measurements and the remote-sensing-derived measurements (NDVI and LAI values; R2 values of 0.30 and 0.68, respectively, at a level of significance $p < 0.01$), thus providing improved estimates of grassland productivity corresponding to varying climate conditions.

Remote-sensing-derived estimates of aboveground biomass have also been implemented by other recent studies. Latifi et al. (2015) developed biomass estimate of stratified and non-stratified forest stands using a combination of data from Li- DAR (2 m height threshold) and an airborne hyperspectral data scene (4 m pixel size, 125 spectral bands). For further details on the use of hyperspectral data and combined LiDAR data. Finally, Barrachina et al. (2015) also used linear regression analyses based on field samples and vegetation indices (vegetation wetness index/VWI and NDVI) derived from Landsat-5 TM to estimate grass aboveground biomass in mountain meadows and pasture lands of the Pyrenees region of southwest France. Linear regression results (R2) ranged between 0.76 (2008 and 2009 mid-summer) and 0.74 (2008 and 2009 end of summer), respectively, at a level of significance $p < 0.01$.

Estimates of aboveground biomass are critically important to enhance our understanding of biodiversity, species richness, and primary productivity. More recently, remotely sensed data, both airborne and satellite, are increasing in popularity and are contributing to improved biomass estimates for modeling the dynamics of carbon fluxes occurring between the atmosphere and the terrestrial ecosystem. As more sophisticated models of global carbon balance are being developed, researchers need synoptic and conterminous estimates of aboveground terrestrial biomass that are limited by local-area field samples that may only provide estimates relative to a specific local. Remote sensing provides a larger regional capacity for sampling larger areas within certain geographic and temporal windows. As presented in this discussion, remote-sensing-derived estimates of terrestrial biomass have been used in combination with routinely applied vegetation indices, such as

NDVI and statistical regression modeling, and have been found to produce promising results. Although the results produced from these types of studies are not perfect, newer methods involving emerging sensor technologies (e.g., LiDAR, hyperspectral data, higher resolution multispectral data, and interferometry synthetic aperture radar data, etc.) may help to improve current methodologies.

Carbon Estimation:

Forests worldwide contain a large portion of terrestrial carbon stocks and depending on the decisions humans make in the face of continued climate and land use change, forests will be either net carbon sinks or sources. However, the exact amount of carbon contained in the earth's forests is not known to even one significant figure, ranging from 385 to 650 PgC. Furthermore, there are unacceptably large variations and uncertainties in the estimates of terrestrial emissions, with a northern terrestrial uptake ranging from 0.5 to 4 Pg C year−1, and tropical terrestrial emissions of − 1 to + 4 Pg C year−1. At least half of the uncertainty in carbon emission estimates from land use change results from uncertain estimates of biomass.

Recent multinational initiatives, such as the United Nations Reducing Emissions from Deforestation and Degradation (REDD+), are seeking to decrease tropical forest emissions and turning them from net carbon sources to net carbon sinks. In the Sierra Nevada forests of California, strategic placement of treatments (SPLATS) areas across the landscape are being implemented as part of the Sierra Nevada Forest Plan Amendment to interrupt potential wildland fire spread, to reduce the extent and severity of these fires, and to improve the continuity and distribution of old forests across landscapes. The United Nations Blue Carbon Program aims to increase carbon storage from coastal ecosystems by producing credits for mangrove and wetland conservation.

The success of these new policy initiatives requires accurately quantifying and detecting changes in forest structure, biomass, and carbon stocks at spatio-temporal scales that are simultaneously relevant from an ecological, policy, and management perspective. Utilizing remote-sensed data provides the best path forward. Currently, three complementary remote-sensed technologies: (i) Terrestrial Laser/LiDAR Scanning (TLS), (ii) Airborne Laser/LiDAR Scanning, and (iii) Synthetic Aperture Radar (SAR) are being used in conjunction with field data to estimate forest structure, biomass, and carbon.

Necessity of ground truthing None of the remote sensing technologies discussed below directly measure biomass or forest carbon. Rather they all measure a variety of structural parameters of vegetation (e.g., canopy height, canopy volume, stem diameter) that can then be used with field-derived allometric equations to estimate vegetation volume, biomass, and carbon. Allometric relationships or allometry are mathematical equations describing the relationship between one or more parameters of an object and its shape. In the case of biomass estimation, information on wood specific density is needed and in the case of carbon both the wood-specific density and carbon content of tissue are needed. With regards to biomass and carbon estimation, most allometric equations estimate these

using tree diameter and/or height. Chave et al. (2004) reviewed the literature on the use of allometric equations to estimate forest biomass and carbon. They found four types of uncertainty that could affect biomass estimates: (i) errors related to tree parameter estimates; (ii) errors related to the selection of allometric equations; (iii) sampling error due to sample plot size; and (iv) how representative the study plots were of the entire ecosystem. Overall, they concluded that the choice of allometric equations was the most important source of uncertainty. These findings point to the care that must be taken when using remote-sensed data to estimate forest biomass and carbon. Significant uncertainty can enter into the estimates both from the measurement uncertainty in the sensor and from the uncertainty embedded in the allometric measurements.

Terrestrial laser/LiDAR scanning (TLS) TLS is a relatively new technology that uses a rotating laser scanner to produce 3-D maps of various structures. It has seen widespread application in a diversity of disciplines, including archaeology, criminology, engineering, geology, and forestry. TLS is capable of giving the coordinates (x, y, z) of any object with high resolution (mm level) and accuracy. The technology has been applied to vegetation structure characterization and monitoring since the mid-2000s. TLS datasets provide high- resolution reconstructions (point clouds) of trunks, branches, and leafs distributions. Furthermore, tree biomass can be estimated by multiplying the volume of its structure by its respective wood density.

Airborne laser/LiDAR scanning Airborne LiDAR systems are able to provide canopy height measurements over fairly large areas. It fills the gap between high-resolution below the canopy data provided by TLS (discussed above) and coarser satellite-based SAR measurements (discussed below). The current airborne LiDAR system can estimate vegetation height with an accuracy of ~ 1 m.

From a technical perspective, airborne LiDAR is similar to TLS in that the scanner emits a laser pulse that is reflected back from target objects and recorded by the scanner. In the case of airborne LiDAR the sensor is mounted on an aircraft with an Inertia Measurement Unit (IMU) and Global Position System (GPS). The IMU gives the precise orientation of the scanner and the GPS gives the precise location.

Synthetic aperture radar (SAR) Although airborne biomass and 3-D structure measurement methods (e.g., LiDAR) have significantly improved over the past decade, they are still too expensive to be conducted routinely on a global scale. Thus, the only current and near future available remote sensing technology capable of monitoring global vegetation structure, biomass, and carbon stocks is from the new generation of multiband and multi-polarization SAR satellites (TerraSAR-X, TanDEM-X, RADARSAT-2, ALOS-PALSAR). This method works because the SAR signal interacts with different vegetation structures depending on the signal wavelength. A short wavelength signal (X-band) interacts mainly with canopies, an intermediate wavelength signal (C-band) penetrates deeper into the vegetation and interacts also with branches, and a long wavelength signal (L-band) can penetrate throughout the vegetation and interact also with tree trunks. Thus, multiwavelength observations can provide useful estimates of vegetation structure and

forest biomass. Another important advantage of SAR observations is the ability to acquire data in all weather conditions, which is extremely helpful in overcast tropical regions.

While promising early uses of SAR monitoring has been only partially successful mainly due to signal saturation problems. SAR-based biomass estimations are valid up to a certain threshold where saturation occurs. The X- and C-band backscatter saturates at low biomass levels (30–50 Mg/ ha), although a more recent study suggests the C-band estimate at a higher saturation level such as 250 Mg/ha. An estimate for the L-band saturation level ranges from 40 to 600 Mg/ha. Most of the wide variation in biomass saturation estimates reflects different estimation methods as well as a different number of ground validation sites. A recent study by Englhart et al. (2011) that used both L-band ALOS and X-band TerraSAR-X data to measure aboveground biomass in tropical forests used about 400 validation points and obtained good biomass estimates up to 600 Mg/ha.

SAR data provide two main observables: amplitude and phase. Moving forward, we expect to see greater use of the Interferometric SAR (InSAR) technique to mea- sure vegetation biomass and carbon. The InSAR technique is currently widely used to quantify changes and deformation of the earth due to earthquakes, volcanic activity, subsidence, and water level changes. The InSAR technique uses information on phase differences through the creation of an interferogram between two SAR acquisitions of the same area. This may be done using either a repeat-pass (two-pass) or a single-pass bistatic acquisition (one-pass). For vegetation applications, single-pass bistatic InSAR is preferable as it avoids problems associated with coherence loss, temporal decorrelation, and wind decorrelation.

Wildland Fire Risk Assessment:

Wildland fire, defined as the relatively fast spreading of unintentional fire across a large areal extent of forested land, remains one of the greatest potentials to alter or disrupt ecosystem patterns and processes across the globe. These altered patterns and processes include terrestrial vegetation distribution and structure, LULCC dynamics, deforestation and desertification, global carbon cycle, and global climate change. Whether this fire is caused by natural forces or human activity, the ecological consequences can be tremendous. Wildland fire is a significant source of harmful emissions worldwide with important implications for human health and carbon budget estimation. Many federal agencies have come to recognize the need for a unified approach to managing lands for prescribed and wildfires (Wildland Fire Executive Council 2009). However, the estimation of fire emissions is often based on the total replacement of forest or other ecosystems that, if the burn area is correctly estimated, undoubtedly overestimates the amount of emissions. In most circumstances, burn severity is not quantitatively estimated. The relative probability of wildland fire in California is shown as an example. Other parts of the US and most regions of the world also have significant fire risk.

Recent estimates suggest that wildland fires contribute to global greenhouse gas emissions at an alarming rate (approximately 6 % of global carbon emissions). The

current threat is changes in climate may be altering fire regimes and increasing wildfire contributions to global greenhouse gas emissions, further limiting humans' and the natural environment's capacity to reduce these impacts.

Advanced fire modeling for calculating wildland fire risk has relied on vegetation, weather, and meteorological inputs to calculate fire spread, fuel loads, and smoke production. However, despite numerous technological advances, our ability to manage fire and fire threat has been relatively limited. Additionally, the quantification of global greenhouse gas emissions as a result of fire is still poorly understood and inadequately represented in global emission models. However, remote sensing, beyond the commonly applied meteorological and weather applications, provides greater capacity to model fire characteristics in that both aerial and spaceborne sensors have the ability to overcome costly field-collected data, which is often labor and time consuming, as well as requires lengthy processing intervals, thus minimizing the possibility of real-time model development.

(Khorram et al. 2014) have shown the applicability of airborne synthetic aperture (Unmanned Air Vehicle Synthetic Aperture Radar;UAVSAR) and Landsat TM multispectral data for modeling smoke emissions from wildland fires in northern California. The following images illustrate the utilization of the Berkeley Emission Estimation System (EES), which is used by several resource agencies as a decision support tool for their wildland fire management decision-making activities. The EES uses First Order Fire Effects Model (FOFEM) as a framework and is based on the spatially specific inputs. The EES is based on a number of parameters, many of which can be estimated from remote sensing data.

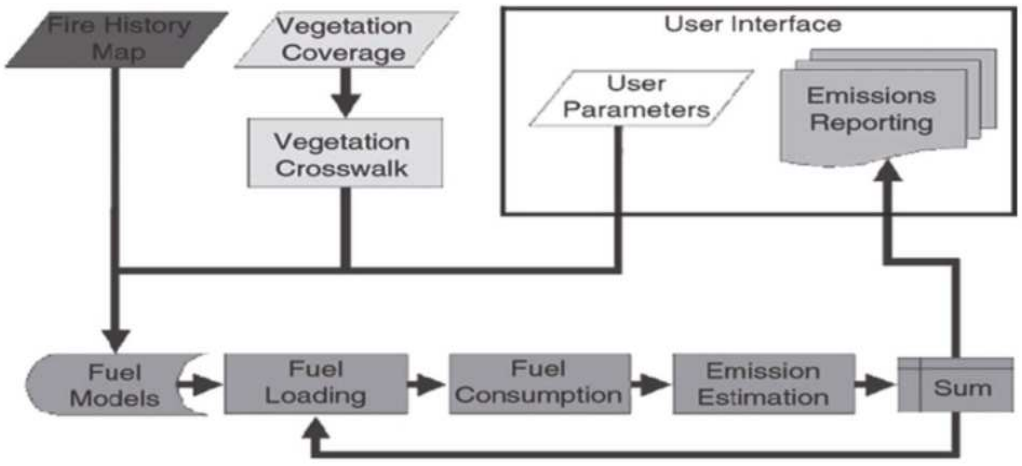


Fig: Emission estimation system (EES) parameters, many of which can be estimated from remote sensing data

Another study of wildland fire was conducted by Hernandez-Leal et al. (2006), in which they used NDVI derived from the Advanced Very-High Resolution Radiometer (AVHRR-NOAA) sensor data over the Tenerife Island in Canary Islands, Spain to define a new wildland fire risk index. The new wildland fire risk index, which incorporated the NDVI values, is known as the Fire Risk Dynamic Index (FRDI. It is an extension of the Fire Risk Static Index (FRSI). The FRSI model is generated from land cover and environmental variables, which includes altitude and slope, solar insolation, proximity to main roads, and type of vegetation cover. The FRSI model output produces a static map of the probability model of fire occurrence by means of the included land cover and environmental variables within a logistic multivariate regression that incorporates past fire ignition events that took place between 1992 and 1995. The FRDI goes a step beyond FRSI in that it is a dynamic index that takes into account areas' gradual increasing in water stress (i.e., decrease in NDVI values), thus dynamically illustrating the changing probability of ignition across the landscape. The FRDI model, which integrates the multiple fire risk variables of FRSI, and further incorporates the NDVI variables derived from the AVHRR satellite sensor as an indirect indicator of vegetation water stress, improved the identification of the fire risk level on Tenerife Island, Spain.

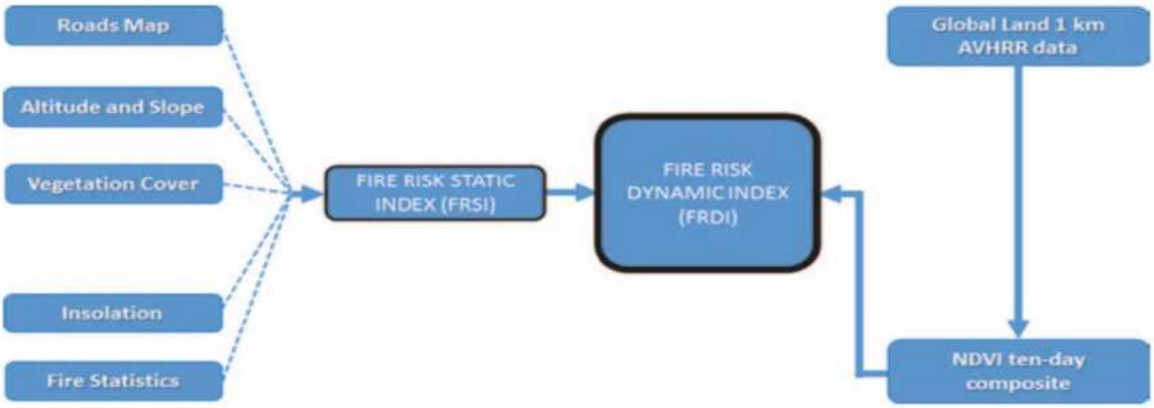


Fig: Diagram of data used to develop the Fire Risk Static Index (FRSI) and Fire Risk Dynamic Index (FRDI) from land cover and environmental variables and Normalized Difference Vegetation Index (NDVI) estimates derived from Advanced Very-High-Resolution Radiometer (AVHRR-NOAA) sensor data.

An FRDI probability map is produced by utilizing NDVI values along with the FRSI model outputs. For the NDVI data, seven NDVI multitemporal composite images were analyzed, covering a period from June 20–30 to August 21–30, 1995. These 10-day composite images were used in order to obtain cloud-free scenes. The AVHRR-NOAA data were acquired from the Global Land 1 km AVHRR Project dataset. The AVHRR-NOAA dataset is composed of five channel, 10-bit, raw AVHRR data, at 1.1-km resolution (at nadir) for every daily afternoon pass over all land and coastal zones using data from NOAA's polar-orbiting TIROS. The data were initially to be collected continuously for 18 consecutive months, from April 1, 1992 through September 30, 1993.

However, the acquisition period was extended to September 30, 1996 and is currently available through the USGS AVHRR Global Land 1 km internet portal. Advantages of using data from AVHRR-NOAA in fire risk modeling include the satellite's global coverage, and high temporal resolution. In addition there are two overpasses per day.

By incorporating the NDVI values into the FRSI model, areas of vegetation water stress may be accounted for in that decreases in the NDVI values across adjacent time periods may be used as a surrogate for water stress in areas of previous fire events.

Other studies have also used optical remote sensing for fire risk mapping. Remote sensing data can play a vital role in identifying wildland fires, delineating burn area, deriving indices of burned and non-burned vegetation, and recording the frequency at which different vegetation types are affected. Hernandez-Leal et al. (2006) demonstrated that FRDI could have a vital role in the prevention of fires, supporting existing fire propagation models, or developing effective strategies for extinguishing an ongoing fire event through the identification of the dryer, water-stressed areas.

Remotely sensed data can collect timely measurements over larger fire-prone areas. Optical remotely sensed data have been used to provide estimates of fire characteristics that are relevant for ecosystem and fire fuel load parameters; such as species composition, biomass estimates, landscape structure, fire history, fuel moisture content, and fuel availability. With the evolution of newer and higher resolution sensors, improved estimates of vegetation species and cover class may serve to further enhance model performance, as well as wildland fire carbon contributions to global greenhouse gas emissions.

Optimizing Sustainable Food and Fiber Production through Remote Sensing:

Precision agriculture—information-based management of agricultural production systems—combines satellite remote sensing and GIS to be able to increase food and fiber production to a growing population. The goals of precision agriculture are to (1) optimize the use of resources to reduce farmer costs and increase sustainability of the farm operation, (2) reduce harmful environmental impacts, and (3) improve the quality of the work environment and the social aspects of farming and ranching.

Remote sensing has been used in a variety of agricultural applications for well over 20 years. Some applications are fairly simple while others are complex and innovative. Due to the lack of cartographic data, many Argentinean farm managers and agronomists use satellite images, in combination with soil maps, to determine the productive aptitude of soils before buying or renting land. Remotely sensed images offer high-quality data, frequent recurrence cycles, and cost effectiveness.

Entire fields are easily captured in one image, allowing farmers to detect bio- physical variability in crops such as water stress, lack of nutrients, diseases, weeds and insect damage. Much of the remotely sensed data used in precision agriculture to detect variability in crop conditions rely on spectral characteristics, predominantly using the red (RED, chlorophyll a and b absorption) and near-infrared (NIR, internal leaf scattering)

wavelength bands. Various combinations of the two bands—spectral vegetation indices—are highly sensitive to vegetation cover and density. Successful mapping of LAI—the area of leaves per unit area of ground (m2/m2)—using IKONOS imagery was shown by Johnson et al. (2003) to be a useful indicator of plant growth and health, as an equilibrium generally exists between climate−soil conditions and LAI. Lack of foliage—either fewer or smaller leaves—usually means that plants are stressed by insects or disease and are dying; more vigorous plants will have more foliage and different spectral reflectance.

Spatial data have been used extensively to increase productivity and yield in croplands—enabling farmers to apply the right treatment in the right place at the right time by adapting fertilizer distribution to varying soil conditions. More recently, additional practices have evolved to improve the sustainability of the food supply. Adapting production in- puts site-specifically within a field and individually for each animal allows for better use of resources to maintain the quality of the environment while reducing costs.

Innovative approaches in applied remote sensing have been successfully implemented to enable product traceability and advance the management of a wide range of agricultural products including viticulture, orchards, livestock and animal fiber production, and turf management.

Improving Wine Harvest and Quality:

Aerial views of vineyards provide a better perspective of canopy conditions than relying on ground observations. This, in turn, allows for better management prescriptions.

A number of studies using radiometric, high-resolution spectral analysis have demonstrated that grape varieties have detectable systematic differences in reflectance intensity and in the spectral form that matches up with vineyard inventory data.

More recently, Cemin and Ducati (2011) conducted a study to see whether the NDVI could distinguish not just the unique spectral qualities of particular grape varieties, but whether their terroir could also be detected. Terroir—the relationship between the attributes of a grape and the particular location it is grown—is a determinant of wine quality, identity, and organoleptic descriptors. The ability to distinguish a terroir's imprint on the spectra of the same grape cultivar is a powerful tool for certifying the geographic origin and authenticity of the product. The researchers examined plots in Bordeaux and Champagne (France), the Aconcagua and Colchagua valleys in Chile, and the Encruizilhada do Sul (Rio Grande do Sul State, Brazil) using all nine spectral bands from ASTER images to investigate whether there were detectable differences in cabernet sauvignon, pinot noir, merlot, and chardonnay grapes at each location. Cemin and Ducati (2011) con- firmed that the four grape varieties did in fact have characteristic spectra that could be distinguished through the NDVI. Additionally, they found that region grouping indicated some spatial influences on spectral behavior reminiscent of terroir effects; however, they were using known field data. Remote sensing techniques are sensitive to changes in reflectance; therefore, further investigation would be worthwhile.

Oenoview®, a joint commercial venture between *Institut Coopératif du Vin* (Groupe ICV) and Infoterra, a subsidiary of EADS Astrium has benefited French viticulturalists. Using aerial and multispectral images (covering nearly 3000 km2) taken at the rate of 1000 plots every 8 s, Oenoview has a precision range of approximately 3 km^2. The images are used to map the surface area and variation of leaf canopy across vineyards—a vital statistic to identify subtle nuances in vineyard vigor, soil moisture levels, bunch and grape weight, and the presence of minerals. Wine growers provide information on their fields, vines, and grape varieties. SPOT-5 and Formosat-2 images are taken in July and August during the period of véraison (when grapes begin to ripen, about 3–4 weeks before grape harvest).

Wine grapes require a moderate amount of water stress to produce top quality wine, although at the expense of reduced grape yield. Berry quality largely depends on achieving an optimum balance between sugars and titratable acidity at harvest. Spectrally, green areas of dense foliage reveals excess soil moisture, while red to purplish areas indicate less moisture, thus pointing to a good vintage. Spatial data are then supplied in a GIS-ready format to be used by the growers to determine when grapes are mature for harvesting and assess variations in grape quality within plots. Rather than acquire plot information empirically over several decades, the data allow growers to separate out lower-grade bunches for vin de table and reserve the superior grapes for higher end grands crus. Vats containing as little as 20% immature grapes lessen the quality of wine at the end of the process, resulting in lower economic returns. The data also allow growers to optimize pruning, fertilizer inputs, and irrigation needs for each vineyard.

Using Remote Sensing to Optimize Grazing and Improve Wool Quality

Australia's vast expanse of crop and pasture land has fostered innovative uses of remote sensing techniques. The Commonwealth Scientific and Industrial Research Organization's (CSIRO) Pastures from SpaceTM program uses spatial informatics and remote sensing to provide farmers with a suite of tools to accurately estimate the amount of feed in their pastures and how quickly their pastures are growing in order to make efficient use of feed resources. This enables farmers to increase the profitability and sustainability of their lands, which has seen extreme drought conditions. Satellite data are used to estimate pasture biomass or "feed on offer" (FOOTM). Pasture biomass data have been combined with climate and soil information to produce "pasture growth rate" (PGRTM) estimates at the national, regional, farm, and paddock scale. This information is updated weekly on the Internet, broad- cast on Australian radio, and signposted in regional areas. Farmers can obtain weekly subscriptions for paddock-level information to assist them with grazing rotations, feed budgeting, and fertilizer applications. Longitudinal data indicate variations in vegetation due to climatic changes and human interventions.

Whelan et al. (2007) have been developing a simulation model to provide an improved and more precise forecast of wool production across the Australian continent. The goal is to predict wool fiber diameter of the wool clip before it is shorn directly from remotely sensed data by using monthly NDVI values and fiber diameter profiles of sheep at the

paddock level. Researchers also hope to predict the effects of modeled future climate change on future wool supplies.

Exploring and Monitoring Oil, Gas, and Mineral Resources:

Ortho-rectified high-resolution satellite images are indispensable in the search for and the development of new oil and gas fields and mineral deposits. Using airborne magnetic or ground gravity surveys to facilitate interpreting sub- surface features, geologists and engineers are able to narrow down the search area for performing more detailed 2-D or 3-D seismic surveys for exploratory drilling.

Satellite imagery is also used to develop digital elevation models (DEMs) to plan the least environmentally damaging route for pipelines, access roads, and facilities by creating a computer visualization of the site area. The use of satellite remote sensing has greatly reduced the time and cost involved in reconnaissance and the placement of oil wells. Remotely sensed spatial data also allow managers and government officials the ability to monitor wellfields and obtain information on the extent of oil spills and how best to mitigate and remediate these areas.

High-resolution providers, such as GeoEye-1, WorldView-2, Worldview-1, QuickBird, IKONOS, SPOT-5, LANDSAT 7 +ETM, and ASTER, have been extensively employed in the quest for surface indicators of subsurface oil and gas along with risk assessment and well field monitoring (to identify security and environ- mental problems).

Using Remote Sensing for Humanitarian and Peace-Keeping Operations:

Tracking the movements of refugees and internally displaced people (IDP), verifying burned and razed villages, documenting the existence of mass graves, and other humanitarian work would be utterly impossible without very-high-resolution satellite imagery. Very high spatial resolution (VHSR) imagery is particularly crucial in assessing the extent of violent conflict, environmental or social justice cases, forced displacement, or other human rights atrocities where field-based assessments are all but impossible in remote, prohibited, dangerous, and/or inaccessible locations. The United Nations High Commissioner for Refugees (UNHCR) and the Internal Displacement Monitoring Center (IDMC) methodology for characterizing and monitoring the nearly 34 million forcibly displaced people worldwide uses GIS, aerial, and satellite imagery.

Refugees and IDPs are a very mobile and fluid type of human settlement, living in small makeshift shelters comprised of thatched huts, clay constructions with flat roofs, and tent-like structures covered with bright materials (e.g., UN tent fabrics or plastic sheets). Estimating the total number of dwellings is extremely complex because of the spectral variability and reflectance of the building material. Bright soil backgrounds and scattered scrub vegetation can make overestimation of rooftops a common classification error in arid regions (false alarms) in the automatic recognition of built-up areas. Rooftops can be under- or overestimated in arid regions as they are misclassified as scattered scrub vegetation. As well, the spatial distribution of scattered vegetation and their contrast with the background is very similar to the spatial distribution of the built-up structures in some

part of the human settlement, including scattered buildings and refugee camps. In particular, the size of tree canopies and their average distance in some cases are similar to the size of built-up structures and their average distance, and then producing overestimation of built-up areas. However, the ability to determine how many IDPs there are is critical to planning and managing effective humanitarian responses. Remotely sensed data allow for continuous monitoring and corroboration of on-the-ground reports with the aim of decreasing or preventing humanitarian disaster and human rights crimes in politically unstable and chronic conflict areas.

Satellite images have effectively been used in legal proceedings and diplomatic negotiations to provide compelling, visual proof and resolve current and future conflicts over highly contested territories. SPOT images were used to achieve the 1995 Dayton Peace Accord. Imagery from India's IRS-1C and US IKO- NOS satellites was used to monitor human activity and mitigate potential conflicts in Spratly Islands in the South China Sea. International humanitarian relief efforts in Thailand, Mexico, Africa, and Europe—particularly Kosovo, Macedonia, and Albania—were made possible by imagery provided by India's IRS-1C, Russia's KVR-1000, and France's SPOT satellites to monitor and mitigate the plight of refugees.

The well-known Eyes on Darfur project, a collaborative initiative between Amnesty International and the American Association for the Advancement of Science (AAAS), is one case study of an active monitoring project. Images allow the ability to track vulnerable villages and monitor changes that may have occurred.

The potential of geospatial visualization for the international human rights community was highlighted by the September 2004 use of QuickBird satellite imagery by the US Agency for International Development (USAID) and the US Department of State in confirming the extent of ethnic cleansing in Darfur. These agencies were able to view and interpret conditions on the ground in Darfur when eyewitness reporting was difficult to verify. Used in conjunction with classified sources, analyses of the imagery led to confirmation of reports of widespread destruction of villages, livestock, and crops as part of an ethnic cleansing campaign. The remotely sensed imagery also proved effective in diplomatic campaigns and alerting the global public.

Archaeology and Cultural Heritage:

The evolution of satellite image analysis has vastly transformed the field of archaeology, allowing researchers to exploit more fully an enormous wealth of data of the earth's surface and subsurface contained in various types of satellite images along with aerial photography. Archaeologists can examine a broad spectrum of reflectivity signatures and bands within the remotely sensed data to focus on perspective archaeological sites to determine if there are subsurface structures.

The South Sinai Survey and Excavation Project in Egypt (SS-SEPE) led by Drs. Gregory Mumford and Susan Parcak of University of Alabama, Birmingham (US), used supervised and unsupervised land use/land cover applications of Landsat TM images as

well as QuickBird imagery to detect vegetation signatures throughout Egypt. This allowed the researchers to isolate water sources in an arid environment and thus identify existing and potential archaeological sites. Infrared images can differentiate between various subsurface materials. Since ancient Egyptians used mud bricks in building construction, which are substantially denser than the surrounding soils, the shapes of houses, temples, and tombs can be detected most easily using winter images. Sites meeting the classification parameters are then "ground-truthed" to verify already identified archaeological sites (i.e., assess the accuracy of the classification) and conduct initial excavations on potential (but unknown) sites. As a consequence of creating this specialized classification, the enormous amount of time and high costs associated with surface detection of vegetation and water signatures in a vast geographical area can be significantly reduced, and the possibility for new discoveries greatly increased.

This innovative technique rewarded the SS-SEPE team with one of the most significant discoveries in Egypt—in May 2011, 17 previously unknown pyramids along with more than 1000 tombs and 3000 settlements were revealed.

The vastness and remoteness of Mongolia, along with the lack of surface remains, has meant that it has been largely unexplored by archaeologists. Starting in 2008, a German research team led by Dr. Jan Bemman of the University of Bonn, used a combination of aerial photographs, satellite images, and surveys. Digital surface models were converted into interactive 3-D models of the area, and superconducting quantum interference devices (SQUIDS) on the ground were used to obtain rapid, high-resolution images of the magnetic field. The combination of advanced techniques allowed for detection of compacted construction materials underneath the soil. In 2011, the team detected a massive settlement in the Orkhon Valley of central Mongolia dating from the eighth and ninth centuries C.E. at the time of the Uighur (Uyghur) Empire.

Safeguarding archaeological sites and antiquities has been aided by remotely sensed images. Authorities can monitor images to detect if a site has been looted and contact Interpol to watch out for antiquities that may be sold illegally.

Summary:

This part provides just a few of the many terrestrial applications of remote sensing. While not exhaustive, presented here are examples of case studies found in the literature that use data directly acquired from satellite and airborne remote sensing, or data derived from remotely sensed data. It is notable to consider that as remote sensing technologies evolve, resolutions increase, and access improves, the attractiveness of a synoptic tool like remote sensing will also increase. The next chapter will provide examples of how remote sensing is used to better understand atmospheric phenomena.

MODULE-III

GIS TECHNOLOGIES AND ITS APPLICATION

GEOSPATIAL TECHNOLOGIES

Geospatial technologies is a term used to describe the range of modern tools contributing to the geographic mapping and analysis of the Earth and human societies. These technologies have been evolving in some form since the first maps were drawn in prehistoric times. In the 19th century, the long important schools of cartography and mapmaking were joined by aerial photography as early cameras were sent aloft on balloons and pigeons, and then on airplanes during the 20th century. The science and art of photographic interpretation and map making was accelerated during the Second World War and during the Cold War it took on new dimensions with the advent of satellites and computers. Satellites allowed images of the Earth's surface and human activities therein with certain limitations. Computers allowed storage and transfer of imagery together with the development of associated digital software, maps, and data sets on socioeconomic and environmental phenomena, collectively called geographic information systems (GIS). An important aspect of a GIS is its ability to assemble the range of geospatial data into a layered set of maps which allow complex themes to be analyzed and then communicated to wider audiences. This 'layering 'is enabled by the fact that all such data includes information on its precise location on the surface of the Earth, hence the term 'geospatial'.

Especially in the last decade, these technologies have evolved into a network of national security, scientific, and commercially operated satellites complemented by powerful desktop GIS. In addition, aerial remote sensing platforms, including unmanned aerial vehicles (e.g. the GlobalHawk reconnaissance drone), are seeing increased non-military use as well. High quality hardware and data is now available to new audiences such as universities, corporations, and non-governmental organizations. The fields and sectors deploying these technologies are currently growing at a rapid pace, informing decision makers on topics such as industrial engineering, biodiversity conservation, forest fire suppression, agricultural monitoring, humanitarian relief, and much more.

There are now a variety of types of geospatial technologies including the following:

Remote Sensing: Imagery and data collected from space- or airborne camera and sensor platforms. Some commercial satellite image providers now offer images showing details of one-meter or smaller, making these images appropriate for monitoring humanitarian needs and human rights abuses.

Geographic Information Systems (GIS): a suite of software tools for mapping and analyzing data which is georeferenced (assigned a specific location on the surface of the Earth, otherwise known as geospatial data). GIS can be used to detect geographic patterns in other data, such as disease clusters resulting from toxins, sub-optimal water access, etc.

Global Positioning System (GPS): a network of U.S. Department of Defense satellites which can give precise coordinate locations to civilian and military users with proper

receiving equipment (note: a similar European system called Galileo will be operational within the next several years while a Russian system is functioning but restricted).

Internet Mapping Technologies: software programs like Google Earth and web features like Microsoft Virtual Earth are changing the way geospatial data is viewed and shared. The developments in user interface are also making such technologies available to a wider audience whereas traditional GIS has been reserved for specialists and those who invest time in learning complex software programs.

Remote Sensing:

For more detailed study on remote sensing, Refer earlier part of this paper

Global Positioning System (GPS)

GPS is a system of twenty-four satellites that allows the coordinates of any point on or near Earth's surface to be measured with extremely high precision. The satellites of the GPS are arranged evenly around the Earth so that at least four are visible at all times from any point on Earth's surface. As one satellite sets below the horizon, another always rises somewhere else.

A special GPS receiver unit, usually handheld, is used to receive signals broadcast by the GPS satellites and to compute its own location from those signals. The GPS is a high-tech shortcut to the goal that surveyors and navigators have long sought by slower, less accurate means: namely, precise knowledge of one's own location. The GPS has only been in widespread use since more affordable GPS receivers first became available in the early 1990s.

The coordinates supplied by a GPS receiver must be matched to other data to be meaningful. A GPS receiver relays where something is located, but a human operator must specify what that something is: a rainfall measurement, well, or some other datum or object. The GPS is not a remote-sensing system because it does not collect data about the Earth. Rather, it facilitates the collection of data at specific points on Earth's surface.

For example, after Hurricane Dennis eroded beaches along the North Carolina shore in 1999, crews from the U.S. Geological Survey drove trucks along 80 kilometers (50 miles) of beach, mapping the new shoreline with GPS receivers. Aerial photography and airborne scanning lasers also were deployed to examine the altered coastline. These remote-sensing missions imaged more coastline than GPS, but with lower precision. Additionally, in 1998, researchers used GPS to accurately locate wells near the South Platte River in Colorado. This dataset was combined with satellite images of crop patterns and surface-water resources to determine how much water could be drawn from the wells and from the surface resources without depleting either.

Geographic Information Systems (GIS)

GIS is a computer system that can be used for scientific research and for water planning and management. This technology integrates powerful computer capabilities with the unique visual perspective of a good old-fashioned map.

It allows users to assemble, store, manipulate, and display geographically referenced information—data that can be identified according to its locations.

GIS requires the use of computer hardware, software, data, and specialists to study data related to Earth and the interconnections between its various features. GIS links information about where things are with information about what things are like. It is much more sophisticated than a paper map, as it can combine many layers of information about a particular spatial area to help yield a better understanding of that place. The layers of information to be studied depend on the researcher's purposes.

The information organized in a GIS comes from many sources, including remote sensing, the GPS, censuses, rock and soil samples, stream gage systems, weather stations, and wildlife sightings. GIS stores information about a geographic area as a collection of themed layers or maps. An individual layer can be anything that contains similar features (e.g., lakes, streets, postal codes, agricultural lands). Reliable and accurate data are necessary for creating high-quality GIS maps.

GIS is utilized in many industries, including business, transportation, communications, and defense; similarly, GIS is an important tool for analyzing water policy and science issues. Because all the layered maps in a given GIS cover the same geographic area, it is possible to link and compare different kinds of data. For example, information about a river network or watershed can be compiled using GIS. A watershed represents the landscape view of water resources, and the effects of spatial patterns of soils, land use, land cover, and urban development can be studied.

Combining topography with vegetation and soil type, for example, may help hydrologists understand how water drains from a given landscape, and thus enable them to predict flooding or pollution transport. GIS makes it possible for earth scientists, city planners, farmers, the military, water resource managers, and many other users to handle the vast quantity of information available from remote sensing, GPS, geology, biology, and other sources.

GIS and other geospatial technologies provide significant input for the management and analysis of large volumes of data, allowing for better understanding of environmental processes and for better management of human activities to ensure environmental quality and economic vitality.

Technology used in GIS

Data creation

Modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is transferred into a digital medium through the use of a computer-aided design program with geo-referencing capabilities. With the wide availability of rectified imagery (both from satellite and aerial sources), heads-up digitizing is becoming the main avenue through which geographic data is extracted.

Heads-up digitizing involves the tracing of geographic data directly on top of the aerial imagery instead of through the traditional method of tracing the geographic form on a separate digitizing tablet.

Relating information from different sources

If you could relate information about the rainfall of a state to aerial photographs of county, you might be able to tell which wetlands dry up at certain times of the year. A GIS, which can use information from many different sources in many different forms, can help with such analyses. The primary requirement for the source data consists of knowing the locations for the variables. Location may be annotated by x, y, and z coordinates of longitude, latitude, and elevation, or by other geocode systems like postal codes. Any variable that can be located spatially can be fed into a GIS. Different kinds of data in map form can be entered into a GIS.

A GIS can also convert existing digital information, which may not yet be in map form, into forms it can recognize and use. For example, digital satellite images generated through remote sensing can be analyzed to produce a map-like layer of digital information about vegetative covers. Likewise, census or hydrologic tabular data can be converted to map-like form, serving as layers of thematic information in a GIS.

Data representation

GIS data represents real world objects such as roads, land use, elevation with digital data. Real world objects can be divided into two abstractions: discrete objects (a house) and continuous fields (rain fall amount or elevation). There are two broad methods used to store data in a GIS for both abstractions: Raster and Vector.

Raster

A raster data type is, in essence, any type of digital image. Anyone who is familiar with digital photography will recognize the pixel as the smallest individual unit of an image. A combination of these pixels will create an image, distinct from the commonly used scalable vector graphics, which are the basis of the vector model. While a digital image is concerned with the output as representation of reality, in a photograph or art transferred to computer, the raster data type will reflect an abstraction of reality. Aerial photos are one commonly used form of raster data, with only one purpose, to display a detailed image on a map or for the purposes of digitization. Other raster data sets will contain information regarding elevation, a DEM (digital Elevation Model), or reflectance of a particular wavelength of light.

Digital elevation model, map, and vector data, Raster data type consists of rows and columns of cells each storing a single value. Raster data can be images (raster images) with each pixel containing a color value. Additional values recorded for each cell may be a discrete value, such as land use, a continuous value, such as temperature, or a null value if no data is available. While a raster cell stores a single value, it can be extended by using raster bands to represent RGB (red, green, blue) colors, colormaps (a mapping between a

thematic code and RGB value), or an extended attribute table with one row for each unique cell value. The resolution of the raster data set is its cell width in ground units.

Raster data is stored in various formats; from a standard file-based structure of TIF, JPEG formats to binary large object (BLOB) data stored directly in a relational database management system (RDBMS) similar to other vector-based feature classes. Database storage, when properly indexed, typically allows for quicker retrieval of the raster data but can require storage of millions of significantly sized records.

Vector

A simple vector map, using each of the vector elements: points for wells, lines for rivers, and a polygon for the lake. In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes. In the popular ESRI Arc series of programs, these are explicitly called shape files. Different geographical features are best expressed by different types of geometry:

Points

Zero-dimensional points are used for geographical features that can best be expressed by a single grid reference; in other words, simple location. For example, the locations of wells, peak elevations, features of interest or trailheads. Points convey the least amount of information of these file types.

Lines or polylines

One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines.

Polygons

Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include lakes, park boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information of the file types.

Each of these geometries are linked to a row in a database that describes their attributes. For example, a database that describes lakes may contain a lake's depth, water quality, pollution level. This information can be used to make a map to describe a particular attribute of the dataset. For example, lakes could be coloured depending on level of pollution. Different geometries can also be compared. For example, the GIS could be used to identify all wells (point geometry) that are within 1-mile (1.6 km) of a lake (polygon geometry) that has a high level of pollution.

Vector features can be made to respect spatial integrity through the application of topology rules such as 'polygons must not overlap'. Vector data can also be used to represent continuously varying phenomena. Contour lines and triangulated irregular networks (TIN) are used to represent elevation or other continuously changing values.

TINs record values at point locations, which are connected by lines to form an irregular mesh of triangles. The face of the triangles represent the terrain surface.

Data Sources for Geographic Information Systems:

Data sources for GISs include the following:

- existing maps;
- aerial photographs;
- satellite images

Types of Geographic Information System Platforms

There are several types of GIS platforms available, such as:

- desktop GIS;
- server GIS;
- Web GIS;
- Mobile GIS.

Desktop Geographic Information Systems

Desktop GIS applications are software and technology that run on a single computer(personal), which allows users to input, store, digitize, analyze, and manipulate geospatial data. Basically desktop GIS is meant for a single user, it cannot be connected to other computers. The existing data are always safe and private with desktop GIS as they are completely isolated from other computers. The user always needs his or her GIS-installed computer to work on GIS. Desktop GISs are divided into two groups:

- Licensed desktop GIS;
- Open source desktop GIS.

Licensed desktop GIS is paid software whereby the user is provided with a single computer license and is equipped with predefined tools. ArcGIS is a paid software.

Open source desktop GIS is free software that anyone can install and work on a computer.QGIS is a free software that fulfills all the basic necessities of the end user.

Server Geographic Information System:

This a software system that offers all GIS facilities and functionalities over a number ofconnected systems within an organization or off site in a cloud computing environment.Many single computers are connected to one another and each and every computer is provided with GIS to share all GIS services.

Web Geographic Information System

A Web GIS is a distributed information system consisting at least a server and a client.The server is equipped with the GIS and the client uses a Web browser or any

desktop software that can work online (via the Internet). It is a communication between client and server using Web technology.

The main advantage of Web GIS is the ability of the client and server to work all across the globe. The client can work from anywhere in the world via a Web browser with the assigned log-in credentials and needs to carry a GIS-installed computer. A team can work simultaneously on the same application while staying at different locations. Real-time monitoring is possible with Web GIS. The main application of Web GIS is ambulance services.

Mobile Geographic Information System

Mobile GIS allows users to access mapping services on mobile devices such as mobile phones and tablets. It works on the concept of wireless GIS mapping. The two main applications areas are:

- field-based GIS services;
- location-based services.

The following technologies are assimilated in mobile GIS:

- Mobile devices;
- Global positioning system (GPS);
- Internet-based GIS access to wireless communications.

GIS/Geospatial Data Formats:

Overview

Geospatial data is created, shared, and stored in many different formats. The two primary data types are raster and vector. Vector data is represented as either points, lines, or polygons. Discrete (or thematic) data is best represented as vector. Data that has an exact location, or hard boundaries are typically shown as vector data. Examples are county boundaries, the location of roads and railroads using lines, or point data indicating the location of fire hydrants.

By contrast, raster data is best suited for continuous data, or information that does not have hard boundaries or locations. As rasters, the data are viewed as a series of grid cells where each cell has a value representing the feature being observed. Think of raster data as appropriate for modeling surfaces like elevation, temperature, precipitation, or soil Ph. These phenomena are measured at intervals (think weather stations), and values in between are interpolated to create a continuous surface. Raster data also includes remote sensing imagery, like aerial photography and satellite imagery.

Vector Formats:

SHP: Shapefile

The ESRI Shapefile has become an industry standard geospatial data format, and is compatible to some extent with practically all recently released GIS software. To have a

complete shapefile, you must have at least 3 files with the same prefix name and with the following extensions: .shp = shapefile, .shx = header and .dbf = associated database file. Additionally, you may have a .prj = Projection file, a .lyr = layer file, and other index files. All these files must be saved in the same workspace.

SDC: Smart Data Compression

SDC is ESRI's highly compressed format, which is directly readable by ArcGIS software.

GDB: Geodatabase

The file geodatabase is a collection of geographic datasets of various types, with the most basic types being vector, raster, and tabular data. There are three types of geodatabases: file, personal, and ArcSDE. Geodatabases are the native data format for ESRI's ArcGIS.

ArcInfo Coverage

An ArcInfo coverage has been phased out and is rarely seen/used today. It has largely been replaced by the geodatabase format. Coverages do not have an individual file extension. Instead it is composed of two folders within a "workspace" which each contain multiple files. One of the two folders carries the name of the coverage, and contains a number of various .adf files. The other folder is an "info" folder, which typically contains .dat and .nit files for all the coverages and grids in the workspace.

E00: Arc Export or Interchange Format

.e00 files are also rarely seen/used today, but are essentially ArcInfo Interchange or export files, used to conveniently copy and move ArcInfo GIS coverages (see above) and grids (see below). An .e00 file must be "imported" and converted in order to use the data in ArcGIS or other GIS software.

Raster Formats:

ArcInfo Grid

An ArcInfo Grid does not have an individual file extension. Instead it is composed of two folders within a "workspace" which each contain multiple files. One of the two folders carries the name of the grid, and contains a number of various .adf files. The other folder is an "info" folder, which typically contains .dat and .nit files for all the coverages and grids in the workspace.

Band Interleaved by Line (BIL), Band Interleaved by Pixel (BIP), and Band Sequential (BSQ).

BIL, BIP, and BSQ are formats produced by remote-sensing systems. The primary difference among them is the technique used to store brightness values captured simultaneously in each of several colors or spectral bands.

DEM (Digital Elevation Model)

DEM is a raster format used by the USGS to record elevation information. Unlike other raster file formats, DEM cells do not represent color brightness values, but rather the elevations of points on the earth's surface.

GeoTIFF

As part of the header of the TIFF file, this provides the Lat/Long boundary extent of the data.

LiDAR

Light Detection and Ranging (LiDAR), is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. File formats vary by deliverable - but raw LiDAR point cloud data has a .LAS file extension. A DEM can be one deliverable from LiDAR.

GIS Software

Overview:

Geographic information system (GIS) solutions automatically produce informational maps after they're fed a set of data. It's easier to understand how trends influence different geographical areas when numerical tables get visually transformed in this way. Almost any type of organization can find this kind of application helpful since it provides a new way to visualize otherwise esoteric data.

GIS programs provide an overall framework for gathering, managing, and interpreting information. This gives businesses the ability to develop an actionable plan from raw numbers they've collected. While this kind of software has been around for decades, developers are starting to make mapping apps that can autonomously analyze any input they're given. Some of the best GIS software packages can even identify trends based on prior experience.

History of GIS Software:

While the earliest modern mapping program was developed in the early 1960s, GIS concepts go back to the earliest mechanical computers. Cartographers in the 19th century used programs encoded on punch cards to help them interpret mathematical data they would then share with a conventional drafting technician. Improvements in visual display technology helped to eliminate the need for paper drafting in the early mainframe era.

Computer-aided topography and demographic studies were already commonplace in many governmental and enterprise organizations by the late 1970s. The rise of graphical user interfaces coupled with public domain survey charts soon made it possible for smaller businesses and county agencies to use GIS packages as part of their own studies.

Due to the fact that much of the early research in the field was done by public sector technicians, open-source GIS solutions appeared on the market fairly quickly.

Considering that detailed street-level maps are easily accessible for free on the Internet, open-source development has continued to dominate the field in the modern age as well.

GIS Developments & Trends

Different GIS programs used various file formats to store maps for many years. While users might not be immediately aware of this fact since they seldom have to load their own maps, this did make it so businesses were locked into a certain cartographic library depending on which application they decided to invest in.

In order to share geospatial data across the Internet and especially between mobile devices, almost all apps used today adhere at least in part to a specific format and transfer protocol. This is giving users the freedom to download and use any set of maps they'd like.

Solutions that use predictive reasoning to automatically analyze data are also becoming more common. These programs apply the same kind of artificial intelligence (AI) technology used in video games. AI modules read numerical data and then compare it to other information available about a geographical area. This can help to uncover trends that might otherwise be difficult for a human technician to find.

Problems & Solutions

Information overload can be an issue for even the smallest firms these days. In part, this is due to the large amount of numerical data that companies have to process when it comes to clients. Collecting all of this data can also be expensive, and firms without a clear path to monetization might not feel it's worthwhile to continue maintaining their databases. Moreover, keeping tabs on large databases can become extremely expensive over time.

Using a GIS program can solve all of these problems. Mapping statistics onto a tangible map can help make sense of them by giving technicians an easy way to visualize what's going on. Some firms use this to find out which areas are more readily ordering different products. They can then focus their marketing campaigns on areas they haven't currently attempted. A mapping system can also help them evaluate market access in the future, after they've made changes. Some of the best GIS software currently available can even develop a business plan based on these maps, which helps when it comes time for monetization.

Organizations don't just use GIS software for marketing and topography, however. Healthcare and insurance groups use it to track the spread of certain maladies. Logistics firms now use a similar application to track vehicles and identify problems in a production chain. Some manufacturing firms have started to use their own GIS system to identify and solve supply issues. Real estate firms and land developers were among the earliest adopters of this technology. They've long used it to figure out consumer home buying patterns, the best way to develop land, and the locations of areas with seriously underdeveloped lots. All of these use cases can save quite a bit of money for the operators.

Storage still tends to be a major problem in many firms, but IT departments are now able to deploy their chosen GIS program in a cloud environment. Using a cloud host can eliminate the need for complicated local storage infrastructure, and it might also help firms who have been looking to outsource some technology solutions.

List of GIS software

Commercial or proprietary GIS software

Most widely used notable proprietary software applications and providers:

• ESRI – Products include ArcView 3.x, ArcGIS, ArcSDE, ArcIMS, and ArcWeb services.

• GRAM++ GIS – Low-cost GIS software product developed by CSRE, IIT Bombay.

• Autodesk – Products include MapGuide and other products that interface with its flagship AutoCAD software package.

• Cadcorp – Developers of GIS software and OpenGIS standard

• Intergraph – Products include GeoMedia, GeoMedia Profesional, GeoMedia WebMap

• ERDAS IMAGINE – A proprietary GIS, Remote Sensing, and Photogrammetry software developed by Leica Geosystems Geospatial Imaging.

• SuperGeo – Products include SuperGIS Desktop & extensions, SuperPad Suite, SuperWebGIS & extensions, SuperGIS Engine & extensions, SuperGIS Network Server and GIS services.

• SuperMap GIS – Products include SuperMap iServer .NET/Java, SuperMap Deskpro, SuperMap Objects, SuperMap Express, SuperMap IS .NET, eSuperMap, SuperNavigation Engine, FieldMapper and services.

• IDRISI – Proprietary GIS product developed by Clark Labs.

• MapInfo – Products include MapInfo Professional and MapXtreme. integrates GIS software, data and services.

• MapPoint – Proprietary GIS product developed by Microsoft.

• Caliper – Products include Maptitude, TransCAD and TransModeler. Develops GIS and the only GIS for transportation.

• Pictometry – Proprietary software which allows oblique images to be draped with shapefiles.

• Black Coral Inc — a leading edge product company developing geospatial collaboration capabilities that enable better outcomes for personnel and tactical teams operating in emergency response and military environments.

• STAR-APIC – european GIS developer, offers GIS products (WinSTAR, STAR GIS), spatial data servers (STAR Server, STAR NeXt, GEOSPatial Hub), GIS-based business solutions (AquaSTAR, STAR ELEC, PipeGuardian, etc.).

• CARIS (Computer Aided Resource Information System) – GIS systems for hydrography and cadastral systems.

• GMS – Three-dimensional environment for building geologic and groundwater models

• Manifold System – Low-cost GIS software package.

• Oracle Spatial – Product allows users to perform basic geographic operations and store common spatial data types in a native Oracle environment.

• Orbit GIS Generic and multi-purpose GIS toolkit, written in Java.

• Safe Software – Spatial ETL products including FME, SpatialDirect and the ArcGIS Data Interoperability Extension.

• Smallworld – developed in Cambridge

• TatukGIS – Products include a GIS development toolkit, Internet Map Server, GIS Editor, free GIS Viewer, Aerial Imagery Corrector.

• Axpand – Proprietary GIS cartography product developed by Axes Systems. Modules include data import/export, automatic generalization, visualization and on-screen editing, pre-print configuration.

Open source software

Most widely used open source applications:

• GRASS – Originally developed by the U.S. Army Corps of Engineers, open source: a complete GIS

• MapServer – Web-based mapping server, developed by the University of Minnesota.

• Chameleon – Environments for building applications with MapServer.

• GeoNetwork opensource – A catalog application to manage spatially referenced resources

• GeoTools – Open source GIS toolkit written in Java, using Open Geospatial Consortium specifications.

• gvSIG – Open source GIS written in Java.

• ILWIS – ILWIS (Integrated Land and Water Information System) integrates image, vector and thematic data.

• JUMP GIS – Java Unified Mapping Platform.

• MapWindow GIS – Free, open source GIS desktop application and programming component.

• OpenLayers – open source AJAX library for accessing geographic data layers of all kinds, originally developed and sponsored by MetaCarta

• PostGIS – Spatial extensions for the open source PostgreSQL database, allowing geospatial queries.

• Quantum GIS – QGIS is a user friendly Open Source GIS that runs on Linux, Unix, Mac OSX, and Windows.

• TerraView – GIS desktop that handles vector and raster data stored in a relational or geo-relational database.

Other GIS software

• AccuGlobe – Fully functional GIS and geoanalysis software platform for Windows developed by DDTI (ddti.net) and available free of charge, but not open source.

• CrossView for ArcGIS – created by A-Prime Software, CrossView is a wizard- based ArcGIS plug-in, which enables map cross-sectioning and profile creation.

• GeoBase – Geospatial platform developed by Telogis. A particular focus is placed on real-time processing for reverse-geocoding, geofencing, etc.

• LandSerf – Free GIS written in Java

• My World GIS – Intuitive low-cost GIS platform for Windows and Mac OSX with robust/intuitive geoprocessing tools, developed for educational.

• Panorama – Russian GIS for military uses.

• SPRING – GIS software developed at INPE –

• SavGIS – Free and complete GIS software available in French, English and Spanish

• MapTools – Suite of open-source GIS products and platforms.

• OpenStreetMap – Online map viewer, with map editing capability.

Data creation

GIS processing software is used for the task of preparing data for use within a GIS. This transforms the raw or legacy geographic data into a format usable by GIS products. For example an aerial photograph may need to be stretched using photogrammetry so that its pixels align with longitude and latitude gradations. This can be distinguished from the transformations done within GIS analysis software by the fact that these changes are permanent, more complex and time consuming. Thus, a specialized high-end type of software is generally used by a skilled person in GIS processing aspects of computer science for digitization and analysis. Raw geographic data can be edited in many standard database and spreadsheet applications and in some cases a text editor may be used as long as care is taken to properly format data.

A geo-database is a database with extensions for storing, querying, and manipulating geographic information and spatial data.

Management and analysis

GIS analysis software takes GIS data and overlays or otherwise combines it so that the data can be visually analysed. It can output a detailed map, or image used to communicate an idea or concept with respect to a region of interest. This is usually used by persons who are trained in cartography, geography or a GIS professional as this type of application is complex and takes some time to master. The software performs transformation on raster and vector data sometimes of differing datums, grid system, or reference system, into one coherent image. It can also analyse changes over time within a region. This software is central to the professional analysis and presentation of GIS data. Examples include the ArcGIS family of ESRI GIS applications, Smallworld, Gram++ and GRASS.

Statistical

GIS statistical software uses standard database queries to retrieve data and analyse data for decision making. For example, it can be used to determine how many persons of an income of greater than 60,000 live in a block. The data is sometimes referenced with postal codes and street locations rather than with geodetic data. This is used by computer

scientists and statisticians with computer science skills, with an objective of characterizing an area for marketing or governing decisions. Standard DBMS can be used or specialized GIS statistical software. These are many times setup on servers so that they can be queried with web browsers. Examples are MySQL or ArcSDE.

Readers

GIS readers are computer applications that are designed to allow users to easily view digital maps as well as view and query GIS-managed data. By definition, they usually allow very little if any editing of the map or underlying map data. Readers can be normal standalone applications that need to be installed locally, though they are often designed to connect to data servers over the Internet to access the relevant information. Readers can also be included as an embedded application within a web page, obviating the need for local installation. Readers are designed to be relatively simple and easy to use as well as free.

Web API

This is the evolution of the scripts that were common with most early GIS systems. An Application Programming Interface (API) is a set of subroutines designed to perform a specific task. GIS APIs are designed to manage GIS data for its delivery to a web browser client from a GIS server. They are accessed with commonly used scripting language such as VBA or JavaScript. They are used to build a server system for the delivery of GIS that is to make available over an Intranet.

Distributed GIS

Distributed GIS concerns itself with Geographical Information Systems that do not have all of the system components in the same physical location. This could be the processing, the database, the rendering or the user interface. Examples of distributed systems are web-based GIS, Mobile GIS, Corporate GIS and GRID computing.

Mobile GIS

GIS has seen many implementations on mobile devices. With the widespread adoption of GPS, GIS has been used to capture and integrate data in the field.

Open-source GIS software

Many GIS tasks can be accomplished with open-source GIS software, which are freely available over Internet downloads. With the broad use of non-proprietary and open data formats such as the Shape File format for vector data and the Geotiff format for raster data, as well as the adoption of OGC standards for networked servers, development of open source software continues to evolve, especially for web and web service oriented applications. Well-known open source GIS software includes GRASS GIS, Quantum GIS, MapServer, uDig, OpenJUMP, gvSIG and many others. PostGIS provides an open source alternative to geo-databases such as Oracle Spatial, and ArcSDE.

Maps:

Common problems cannot be solved without intervention and intervention is impossible without visualization offered by 'Maps'. A table of data may present facts & figures, but it doesn't tell a story. A static table of data can help us realize there is a problem, but it cannot tell us accurately 'where'. Only maps can accurately point out which are the most affected areas, enabling us to know why those areas have got most affected, what can be done to reduce the impact etc. GIS-based mapping is the answer to all. Maps define The Power of Where.

As Jim Herries, Product Engineer and Cartographer, Esri conveys, "Digital maps are pushed into our digital lives regularly. Our fundamental desire to know where things are, how to get there, what the weather is like … these are joined today by a desire to understand where problems or needs exist, and compare alternatives to solving them."

Maps are becoming an indispensable part of our lives. They are becoming all pervasive. From better governance to more profitable businesses to enable the communities to live happier lives, maps are enabling people to make more informed decisions and achieve more efficient outcomes.

As Guruprasad S, Director, Market Screening Solutions, Bosch rightly puts it, "Map as a service is of utopian help, to public health and payers to look at population health management, seasonal diseases heat map and strengthens the focus of social determinants of health, for better healthcare delivery planning, focussed campaigns, targeted outreach programmes etc."

The trend is not new

Maps are not new to mankind. Though the concept of 'democratization of maps 'has picked up recently, maps have been an integral part of the human history for thousands of years. From cave paintings to ancient maps of Babylon, Greece, and Asia, through the Age of Exploration, and on into the 21st century, people have created and used maps as essential tools to help them define, explain, and navigate their way through the world.

It is interesting to discover that the earliest maps were actually 'story 'maps. Cartographers acted as artists, as they painted pictures based on knowledge, memories, and fears of travelers. The maps so created, not only described the landscape, but also the events that had taken place within it. These beautiful pieces of work allowed travelers to identify routes while experiencing a story.

As human intelligence evolved, the power of visualizing location became clearer. With advancements in technology, maps took the form of digital roadmaps and permeated every household through smartphones.

Mapping is a central function of Geographic Information Systems (GIS), which provide a visual interpretation of data. GIS analysts and specialists have emerged as the new gurus of cartographic science. Factors such as extensive use of GPS or Remote Sensing, globalization of data, use of internet, web mapping services, new software applications,

have contributed greatly to the use of GIS and cartography for more and more applications every day.

The world is realizing that common problems cannot be solved unless intervention is made and intervention is impossible without visualization, and thus without ‘maps’.

Web Mapping

In recent years there has been an explosion of mapping applications on the web such as Google Maps, and Live Maps. These websites give the public access to huge amounts of geographic data with an emphasis on aerial photography. Some of them, like Google Maps, expose an API that enable users to create custom applications. These vendors' applications offer street maps and aerial/satellite imagery that support such features as geocoding, searches, and routing functionality.

Some GIS applications also exist for publishing geographic information on the web that include MapInfo's MapXtreme, Intergraph's GeoMedia WebMap, ESRI's ArcIMS, ArcGIS Server, AutoDesk's Mapguide and the open source MapServer.

Maps in Governance

GIS-based mapping helps the governments achieve better governance as they are able to solve problems more quickly and efficiently. Governments use GIS and maps to improve their workflows and services to citizens. Visualizations through maps are used to accomplish better land-use planning, road and utility maintenance, emergency management, infrastructure assessment and development and property management. Local, state and federal governments have found maps particularly useful in urban planning, including classification of land uses, zoning and subdivision planning, land acquisition, assessing the urban growth, environmental impact policy, and water quality management. Mapping can be of great help when it comes to managing urban growth and solving housing issues associated with the increasing population.

In the words of Herries, “Maps help governments assess the needs of citizens, look for any spatial components of those needs or issues, and compare different plans of action to address those needs. For instance, consider the “Clean Streets LA” initiative. The city of Los Angeles put maps to use, assessing every single street in the city with regard to how much trash or even dumping was present. The resulting data might have been kept out of the public’s eye, but instead, the city chose to address the issue of trash and illegal dumping in a very public way. Citizens can see maps of the entire city, and of course go look around their neighborhood, to see how clean or dirty their neighborhood is, schedule a pickup, or engage in other ways. The map helps create that engagement with citizens, to improve their lives specifically and the city overall.”

GIS-based mapping helps the governments achieve better governance as they are able to solve problems more quickly and efficiently.

Maps in businesses

Organizations today are collecting data at every level of their business and in volumes that in the past was unimaginable. It is an accepted fact now that about 80% of all data has a spatial component.

According to Guruprasad, Bosh, "It is estimated that roughly 2.5 quintillion bytes of data are generated per day. With this huge volume of data being churned out, business intelligence solutions have become a necessity rather than a luxury. In this highly data-intensive scenario, spatial analysis provides powerful "where" perspectives and contextual insights. Being able to visualize the "where" is invaluable for planning and enhances many business intelligence applications. As better insights deliver a better impetus for decision making, spatial analysis acts as a key differentiator for businesses today, enabling them to grow faster and smarter."

Traditionally, data would get presented to the user in the form of long reports, either with graphs and pie charts or in a spreadsheet format. Now, given the complex interrelationships of multidimensional data, visualization technology has become ineluctable for offering an accurate, high impact insight to business intelligence users.

Humans think visually, therefore spatially. Data gains immediate visual impact with the help of maps. This is more emphatically true for data with a spatial dimension. Maps best represent spatial phenomena or relationships such as flow or proximity, while also

facilitating visualization of statistical measures for an area or region. In addition, maps allow multi-measure displays.

The importance of visualization in business can be better gauged from Peter Hawkins, Regional Director Digital Content, Asia Pacific, HERE, Singapore's words, "Visualisation on maps or any sort of special platform is critical. I think the old adage applies here that one picture can tell a thousand words. It is critical how people visualize and interact with maps. The maps and special data is going to get more complex, fast pace and near real time. And the way people consume and interact with it has to change. We have announced a stringent visualization strategy. It is going to become an important element in resolving a number of interface problems and challenges faced by the industry."

Spatial analysis is helping the industry to gain invaluable insights in stock delivery, store management, inventory management, marketing and sales.

As per Santiago Giraldo, Director, Product Marketing, Carto, "Historically, location data was only available to highly trained specialists and used to produce static GIS maps depicting the past or current status, however, today location data and insights have become more accessible by turning the map into an interactive model, where all types of professionals can do sophisticated analysis on their own."

Today more people are using spatial data presented on maps to make faster, smarter decisions to improve business operations. "While many early adopters have been in the financial sector, verticals like retail, telecommunications and real estate are also experimenting with and receiving benefits from spatial analysis based on maps today," adds Giraldo.

'Customer mapping 'enables organizations to identify the markets where they can find the highest concentration of the best potential customers. GIS allows efficient mapping and color-coded maps lead to easy identification of customer concentrations. These maps help in site-selection, which involves considering factors like income, community growth rate, available workers, the physical features of the area such as roads, water, etc. and by using GIS, each of these factors can be layered on top of each other to identify the best possible location for a business.

For example, while considering relocation, a children's clothing store could map the population of people with children in the targeted age group throughout the area under consideration. The data, once put into a GIS can generate maps wherein the highest concentration families with children are depicted using dark colors and those without using lighter colors. The final map so generated will highlight the ideal areas for the clothing store to be relocated.

Maps for citizens

Community development scales new heights when the power of maps is put to use. Maps are playing an increasingly important role in helping us create a safer, happier world. Be

it leading a healthier life or producing higher quality food for feeding more mouths or having better preparedness for disasters, maps help in identifying threats and taking corrective actions on time.

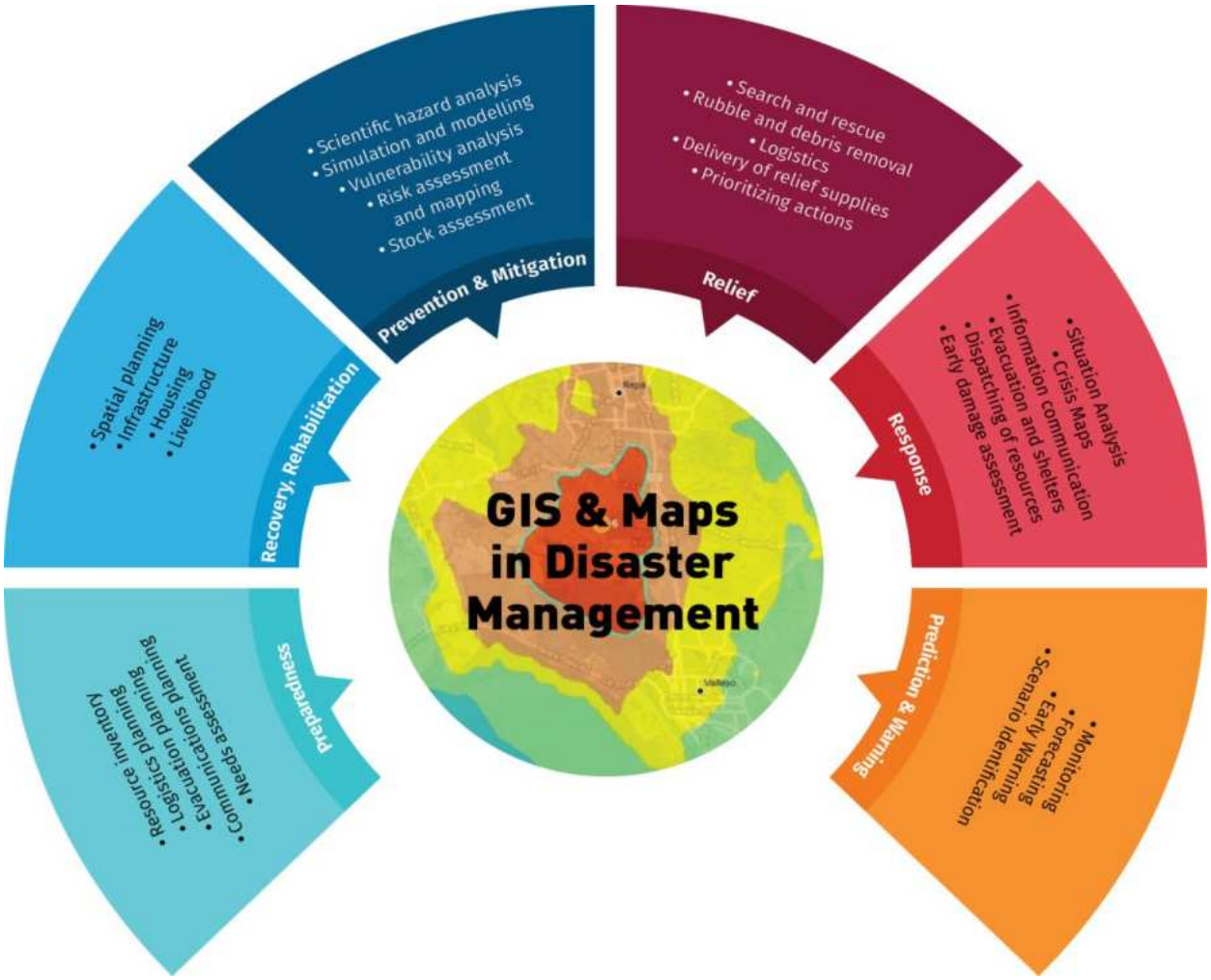
Both public and private sectors are developing innovative ways to harness data integration and spatial visualization power of GIS to provide enhanced healthcare services. Maps play a critical role in determining where and when to intervene, improving the quality of care, increasing accessibility of service and finding more cost-effective delivery modes.

Mapping allows healthcare professionals to identify health-related trends and target healing efforts based on those results more thoroughly. For instance, by integrating visualization in a Cancer Surveillance Program, healthcare professionals can visualize the locations of patients and determine if clusters of specific types of cancer are associated with similar working conditions or residential areas. Such studies often reveal important correlations, such as the association between people residing near heavily sprayed fields and higher incidences of prostate cancer among them. For years, healthcare professionals have relied on hand-drawn maps for identifying affected areas; things have become more systematic and accurate with maps generated by GIS.

With rising incidents of chronic diseases such as cancer, diabetes etc., mapping enables healthcare professionals to identify where certain diseases are more likely to or already have become prevalent and proactively begin implementing preventative strategies.

Using geography and other inputs, GIS can also help in identifying where the diseases are most likely to spread next. This kind of information can help in saving lives as it enables healthcare professionals to prepare in advance for the disease. Maps such as these play a significant role in the management of disease outbreaks as they help visualize where infected people live and the potential spread of the disease. Mapping can also be used to gain a better understanding of vaccination rates in different areas to determine which locations could be hit the hardest in case of a serious outbreak.

Use of maps can enable community leaders and developers to work more closely with hospitals to take larger steps in addressing national healthcare needs. The system can help identify which neighborhoods are in greater need of specific health services such as more rehab centers or senior care facilities. Analysis of patient demographic data can help answer these questions.



Maps for disaster management:

Be it modeling through early warning systems or using decision support systems to understand which disaster is going to affect or is affecting which region the most, visualization achieved through GIS can help in mitigating the risks of a disaster to a great extent. As maps help in identifying disaster-prone areas, preparations can be better, efforts can be more directed and response can be faster.

For instance, landslides are one of the major disasters that occur in the hilly region. The disaster risks can be mitigated using maps. A "Landslide Hazard Map" includes "zonation showing the annual probability of landslide occurring throughout an area" (USGS). A landslide susceptibility map is a basic concept of landslide susceptibility and it includes the spatial distribution of factors related to the instability processes in order to determine zones of landslide-prone areas without any temporal implication.

This approach is useful for areas where it is difficult to secure enough information concerning the historical record of landslide events ranks the slope stability of an area in categories that range from stable to unstable. Susceptibility maps show where landslides

may occur. This identification leads to better preparedness and thus lesser or no loss of lives.

Maps can be used to indicate vulnerability to different extents under different conditions. Areas likely to remain unaffected or remain comparatively safe could be identified and even alternate routes to shelters, camps, and important locations could be worked out.

Identification of vulnerable areas leads to smooth rescue and evacuation operations. Mapping of affected areas lead to better organization of rehabilitation and post-disaster reconstruction works could be properly organized.

More food to eat with maps

Use of GIS-based visualization to achieve higher quality food production is not a new phenomenon anymore.

Agricultural mapping is day by day becoming crucial for monitoring and management of soil and irrigation of farmlands. It is facilitating agricultural development and rural development. Accurate mapping of geographic and geologic features of farmlands is enabling scientists and farmers to create more effective and efficient farming techniques. As farmers are able to take more corrective actions in the form of better utilization of fertilizers, treating pest and weed infestations, protecting the natural resources etc., we are bestowed with more and higher quality food production.

While natural inputs in farming cannot be controlled, they can be better understood and managed with GIS applications. GIS can substantially help in effective crop yield estimates, soil amendment analyses and erosion identification and remediation. More accurate and reliable crop estimates help reduce uncertainty.

Mapping in agriculture helps farmers to achieve increased production and reduced costs by enabling better management of land resources. The risk of marginalization and vulnerability of small and marginal farmers, who constitute about 85% of farmers globally, also gets reduced.

Undoubtedly, the insight gleaned from the dimension of ‘place ’opens doors to new learnings and potential patterns that enable the decision-makers to take better decisions and achieve more productive outcomes.

Exploring Global Change with GIS

Maps have traditionally been used to explore the Earth and to exploit its resources. GIS technology, as an expansion of cartographic science, has enhanced the efficiency and analytic power of traditional mapping. Now, as the scientific community recognizes the environmental consequences of human activity, GIS technology is becoming an essential tool in the effort to understand the process of global change. Various map and satellite information sources can combine in modes that simulate the interactions of complex natural systems.

Through a function known as visualization, a GIS can be used to produce images - not just maps, but drawings, animations, and other cartographic products. These images allow researchers to view their subjects in ways that literally never have been seen before. The images often are equally helpful in conveying the technical concepts of GIS study-subjects to non-scientists.

Adding the dimension of time

The condition of the Earth's surface, atmosphere, and subsurface can be examined by feeding satellite data into a GIS. GIS technology gives researchers the ability to examine the variations in Earth processes over days, months, and years.

As an example, the changes in vegetation through a growing season can be animated to determine when drought was most extensive in a particular region. The resulting graphic, known as a normalized vegetation index, represents a rough measure of plant health. Working with two variables over time would then allow researchers to detect regional differences in the lag between a decline in rainfall and its effect on vegetation. GIS technology and the availability of digital data on regional and global scales enable such analyses. The satellite sensor output used to generate a vegetation graphic is produced by the Advanced Very High Resolution Radiometer (AVHRR). This sensor system detects the amounts of energy reflected from the Earth's surface across various bands of the spectrum for surface areas of about 1 square kilometer. The satellite sensor produces images of a particular location on the Earth twice a day. AVHRR is only one of many sensor systems used for Earth surface analysis

GIS and related technology will help greatly in the management and analysis of these large volumes of data, allowing for better understanding of terrestrial processes and better management of human activities to maintain world economic vitality and environmental quality.

Semantics and GIS

Tools and technologies emerging from the W3C's Semantic Web Activity are proving useful for data integration problems in information systems. Correspondingly, such technologies have been proposed as a means to facilitate interoperability and data reuse among GIS applications and also to enable new mechanisms for analysis.

Ontologies are a key component of this semantic approach as they allow a formal, machine-readable specification of the concepts and relationships in a given domain. This in turn allows a GIS to focus on the meaning of data rather than its syntax or structure. For example, reasoning that a land cover type classified as Deciduous Needle leaf Trees in one dataset is a specialization of land cover type Forest in another more roughly-classified dataset can help a GIS automatically merge the two datasets under the more general land cover classification. Very deep and comprehensive ontologies have been developed in areas related to GIS applications, for example the Hydrology Ontology developed by the Ordnance Survey in the United Kingdom. Also, simpler ontologies and

semantic metadata standards are being proposed by the W3C Geo Incubator Group to represent geospatial data on the web.

Recent research results in this area can be seen in the International Conference on Geospatial Semantics and the Terra Cognita -- Directions to the Geospatial Semantic Web workshop at the International Semantic Web Conference.

GIS and Society

With the popularization of GIS in decision making, scholars have began to scrutinize the social implications of GIS. It has been argued that the production, distribution, utilization, and representation of geographic information are largely related with the social context. For example, some scholars are concerned that GIS may not be misused to harm the society. Other related topics include discussion on copyright, privacy, and censorship. A more optimistic social approach to GIS adoption is to use it as a tool for public participation.

Open Geospatial Consortium (OGC) standards

The Open Geospatial Consortium (OGC) is an international industry consortium of 334 companies, government agencies and universities participating in a consensus process to develop publicly available geo-processing specifications. Open interfaces and protocols defined by OpenGIS Specifications support interoperable solutions that "geo- enable" the Web, wireless and location-based services, and mainstream IT, and empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications. Open Geospatial Consortium (OGC) protocols include Web Map Service (WMS) and Web Feature Service (WFS).

GIS products are broken down by the OGC into two categories, based on how completely and accurately the software follows the OGC specifications. Compliant Products are software products that comply with OGC's OpenGIS Specifications. When a product has been tested and certified as compliant through the OGC Testing Program, the product is automatically registered as "compliant" on this site.

Implementing Products are software products that implement OpenGIS Specifications but have not yet passed a compliance test? Compliance tests are not available for all specifications. Developers can register their products as implementing draft or approved specifications, though OGC reserves the right to review and verify each entry.

CHARACTERISTICS OF THE GEOGRAPHIC INFORMATION SYSTEMS APPLICATION:

As mentioned earlier, GIS allows to combine data from various sources and various types (vector, raster, descriptive data). They also allow to conduct complex spatial analyses, data visualization and simulations of processes and phenomena occurring in our environment. Thanks to such wide possibilities, these systems have been used in many fields, including in forestry and agriculture, in ad- ministration, in environmental protection, in crisis management and rescue, supporting the work of many services such

as: police, fire brigade, ambulance, transport, bank- ing, pharmacy, insurance, spatial planning and many others.

According to GŁOWACKI [2005], there is currently no field of knowledge related in any way to geography or Earth sciences, which are not related directly or indirectly to GIS.

Geographical Information Systems have found the greatest use in public administration offices. Their main task is to support the decision making of local or state authorities, allowing visualization of various processes. Thanks to them, it is possible to plan certain investments taking into account various parameters, including whether there are utility networks in a given place, whether a given plot has access to a public road, etc..

Performing all kinds of urban works, requires gather- ing and analysing a huge amount of data, including concerning terrain, its slope, use, insolation, land ownership, threats (erosive or flood), demography, accessibility of public facilities and many others. The Geographic Information Systems help to investigate the relations between these phenomena and to make the right decisions.

As another industry using geographic data systems, network management companies should be mentioned. Thanks to a coherent database, broad analyses supporting network management are possible, including: statistics on the use of individual network elements, estimation of business benefits, failure location, network performance test- ing, marketing research, network availability determination, process optimization.

These systems are also used with great success in agri- culture, taking into account the micro and macro economic approach. GIS software provides unlimited analytical possibilities in this area, aimed at optimizing the production cycle, the registration of agricultural plots, efficient and effective farm management, assessment of conditions for cultivation, yield forecasting or assessment of the correct- ness of the area's eligibility for subsidies as part of agricultural activities.

Geographic Information Systems help to optimize forest management activities in connection with the society needs and the economic pressure of the market. This system allows to analyse and visualize complex problems, which helps to make all decisions. It allows, among others, to designate areas for afforestation, create thematic maps, visualize areas at risk on the maps, track and analyse changes in land use (tree felling, changing trees, etc.).

GIS class tools are also useful during spatial planning, including in the preparation of urban management plans, preparation of development plans, monitoring of changes in the development of space or modelling of change scenarios, eg. modelling of water reservoirs.

GIS software is a good tool supporting activities related to environmental management and its protection. As part of the management activities in the Silesian Voivodeship, a generally available database of bio- and geo-diversity was developed: BIOGEO-SILESIA, which allows locating objects of interest to the given person and environmental

management, and GIS systems together with properly adapted methods allow to create a functional and efficient system for environmental protection activities.

The use of GIS has also proved to be very important in crisis management and rescue. The topographic database (TBD) is used for this purpose. Data contained in this database can be used to indicate the location of dangerous objects, planning the distribution of population centers, planning escape routes or commuting to places of disaster. The GIS class tools also enable conducting detailed analyses in the areas of potential threats. The use of interactive maps in institutions dealing with crisis management allows to improve work efficiency, ex. the police, fire brigade and ambulance services. For example, for the needs of the police, the National Police Information System was created, containing data on persons suspected of committing a crime or wanted people. Also in the State Fire Service, a geographical visualization system was implemented to improve decision-making processes and more effective rescue operations.

The Geographic Information System also allows performing various analyses to check the functioning of pub- lic transport. It allows, for example, to determine the frequency of buses and trains, which makes it easier for passengers to manage their time.

In tourism, these systems allow you to plan a route and assess the condition of tourist routes. An example of the GIS application in this industry is the geoportal of the Małopolska tourist routes.

The GIS class tools are also used for monitoring the state of cultural heritage, or in the study of historical greenery assumptions. This facilitates the using and management of archival information constituting the source material. Geographic Information Systems in this area are aimed at obtaining from various sources of spatial data about monuments, their conversion and integration, data visualization, their sharing and con- ducting possible analyses, and then monitoring of endangered objects and updating information about them.

GIS is also widely used in archeology. His main task is to manage newly discovered positions and artefacts. It allows to compile data related to the development of settlement, regarding terrain, altitude, soils, communication routes, hydrological networks, vegetation.

GIS Applications and Uses:

GIS in Mapping:

Mapping is a central function of Geographic Information System, which provides a visual interpretation of data. GIS store data in database and then represent it visually in a mapped format. People from different professions use map to communicate. It is not necessary to be a skilled cartographer to create maps. Google map, Bing map, Yahoo map are the best example for web based GIS mapping solution.

Telecom and Network services:

GIS can be a great planning and decision making tool for telecom industries. GDi GISDATA enables wireless telecommunication organizations to incorporate geographic data in to the complex network design, planning, optimization, maintenance and activities. This technology allows telecom to enhance a variety of application like engineering application, customer relationship management and location based services.

Accident Analysis and Hot Spot Analysis:

GIS can be used as a key tool to minimize accident hazard on roads, the existing road network has to be optimized and also the road safety measures have to be improved. This can be achieved by proper traffic management. By identifying the accident locations, remedial measures can be planned by the district administrations to minimize the accidents in different parts of the world. Rerouting design is also very convenient using GIS.

Urban Planning:

GIS technology is used to analyze the urban growth and its direction of expansion, and to find suitable sites for further urban development. In order to identify the sites suitable for the urban growth, certain factors have to consider which is: land should have proper accessibility, land should be more or less flat, land should be vacant or having low usage value presently and it should have good supply of water.

Transportation Planning:

GIS can be used in managing transportation and logistical problems. If transport department is planning for a new railway or a road route then this can be performed by adding environmental and topographical data into the GIS platform. This will easily output the best route for the transportation based on the criteria like flattest route, least damage to habitats and least disturbance from local people. GIS can also help in monitoring rail systems and road conditions.

Environmental Impact Analysis:

EIA is an important policy initiative to conserve natural resources and environment. Many human activities produce potential adverse environmental effects which include the construction and operation of highways, rail roads, pipelines, airports, radioactive waste disposal and more. Environmental impact statements are usually required to contain specific information on the magnitude and characteristics of environmental impact. The EIA can be carried out efficiently by the help of GIS, by integrating various GIS layers, assessment of natural features can be performed.

Agricultural Applications:

GIS can be used to create more effective and efficient farming techniques. It can also analyze soil data and to determine: what are the best crop to plant?, where they should

go? how to maintain nutrition levels to best benefit crop to plant?. It is fully integrated and widely accepted for helping government agencies to manage programs that support farmers and protect the environment. This could increase food production in different parts of the world so the world food crisis could be avoided.

Disaster Management and Mitigation:

Today a well-developed GIS systems are used to protect the environment. It has become an integrated, well developed and successful tool in disaster management and mitigation. GIS can help with risk management and analysis by displaying which areas are likely to be prone to natural or man-made disasters. When such disasters are identified, preventive measures can be developed.

Landslide Hazard Zonation using GIS:

Landslide hazard zonation is the process of ranking different parts of an area according to the degrees of actual or potential hazard from landslides. The evaluation of landslide hazard is a complex task. It has become possible to efficiently collect, manipulate and integrate a variety of spatial data such as geological, structural, surface cover and slope characteristics of an area, which can be used for hazard zonation. The entire above said layer can well integrate using GIS and weighted analysis is also helpful to find Landslide prone area. By the help of GIS we can do risk assessment and can reduce the losses of life and property.

Determine land use/land cover changes:

Land cover means the feature that is covering the barren surface .Land use means the area in the surface utilized for particular use. The role of GIS technology in land use and land cover applications is that we can determine land use/land cover changes in the different areas. Also it can detect and estimate the changes in the land use/ land cover pattern within time. It enables to find out sudden changes in land use and land cover either by natural forces or by other activities like deforestation.

Navigation (routing and scheduling):

Web-based navigation maps encourage safe navigation in waterway. Ferry paths and shipping routes are identified for the better routing. ArcGIS supports safe navigation system and provides accurate topographic and hydrographic data. Recently DNR, s Coastal Resources Division began the task of locating, documenting, and cataloging these no historic wrecks with GIS. This division is providing public information that make citizens awareness of these vessel locations through web map. The web map will be regularly updated to keep the boating public informed of these coastal hazards to minimize risk of collision and injury.

Flood damage estimation:

GIS helps to document the need for federal disaster relief funds, when appropriate and can be utilized by insurance agencies to assist in assessing monetary value of property loss. A local government need to map flooding risk areas for evaluate the flood potential

level in the surrounding area. The damage can be well estimate and can be shown using digital maps .

Natural Resources Management:

By the help of GIS technology the agricultural, water and forest resources can be well maintain and manage. Foresters can easily monitor forest condition. Agricultural land includes managing crop yield, monitoring crop rotation, and more. Water is one of the most essential constituents of the environment. GIS is used to analyze geographic distribution of water resources. They are interrelated, i.e. forest cover reduces the storm water runoff and tree canopy stores approximately 215,000 tons carbon. GIS is also used in afforestation.

GIS Solutions in Banking Sector:

Today rapid development occurs in the banking sector. So it has become more market driven and market responsive. The success of this sector largely depends on the ability of a bank to provide customer and market driven services. GIS plays an important role providing planning, organizing and decision making.

Soil Mapping:

Soil mapping provides resource information about an area. It helps in understanding soil suitability for various land use activities. It is essential for preventing environmental deterioration associated with misuse of land. GIS Helps to identify soil types in an area and to delineate soil boundaries. It is used for the identification and classification of soil. Soil map is widely used by the farmers in developed countries to retain soil nutrients and earn maximum yield.

GIS based Digital Taxation:

In Local Governments, GIS is used to solve taxation problems. It is used to maximize the government income. For example, for engineering, building permits, city development and other municipal needs, GIS is used. Often the data collected and used by one agency or department can be used by another. Example Orhitec ltd can supply you with a system to manage property tax on a geographic basis that can work interactively with the municipal tax collection department. Using GIS we can develop a digital taxation system.

Land Information System:

GIS based land acquisition management system will provide complete information about the land. Land acquisition managements is being used for the past 3 or 4 years only. It would help in assessment, payments for private land with owner details, tracking of land allotments and possessions identification and timely resolution of land acquisition related issues.

Surveying:

Surveying is the measurement of location of objects on the earth's surfaces. Land survey is measuring the distance and angles between different points on the earth surface. An

increasing number of national and governments and regional organizations are using GNSS measurements. GNSS is used for topographic surveys where a centimeter level accuracy is provided. These data can be incorporated in the GIS system. GIS tools can be used to estimate area and also, digital maps can prepared.

Wetland Mapping:

Wetlands contribute to a healthy environment and retain water during dry periods, thus keeping the water table high and relatively stable. During the flooding they act to reduce flood levels and to trap suspended solids and attached nutrients. GIS provide options for wetland mapping and design projects for wetland conservation quickly with the help of GIS. Integration with Remote Sensing data helps to complete wetland mapping on various scale. We can create a wetland digital data bank with spices information using GIS.

GIS Applications in Geology:

Geologists use GIS in a various applications. The GIS is used to study geologic features, analyze soils and strata, assess seismic information, and or create three dimensional (3D) displays of geographic features. GIS can be also used to analyze rock information characteristics and identifying the best dam site location.

Detection of Coal Mine Fires:

GIS technology is applied in the area of safe production of coal mine. Coal mine have developed an information management system, the administrators can monitor the safe production of coal mine and at the same time improve the abilities to make decisions. Fire happens frequently in coal mines. So it can assessed spontaneous combustion risk using GIS tools.(Kun Fang, GIS Network Analysis in Rescue of Coal Mine)

Assets Management and Maintenance:

GIS helps organizations to gain efficiency even in the face of finite resources and the need to hold down the cost. Knowing the population at risk enables planners to determine where to allocate and locate resources more effectively. Operations and maintenance staff can deploy enterprise and mobile workforce. GIS build mobile applications that provide timely information in the field faster and more accurate work order processing.

GIS for Planning and Community Development:

GIS helps us to better understand our world so we can meet global challenges. Today GIS technology is advancing rapidly, providing many new capabilities and innovations in planning. By applying known part of science and GIS to solve unknown part, that helps to enhance the quality of life and achieve a better future. Creating and applying GIS tools and knowledge allow us integrating geographic intelligence into how we think and behave.

GIS in Dairy Industry:

Geographic Information System is used in a various application in the dairy industry, such as distribution of products, production rate, location of shops and their selling rate. These can be monitored by using GIS system. It can be also possible to understand the demand of milk and milk products in different region. GIS can prove to be effective tool for planning and decision making for any dairy industry. These advantages has added new vistas in the field of dairy farm and management.

Tourism Information System:

GIS provides a valuable toolbox of techniques and technologies of wide applicability to the achievement of sustainable tourism development. This provide an ideal platform tools required to generate a better understanding, and can serve the needs of tourists. They will get all the information on click, measure distance, find hotels, restaurant and even navigate to their respective links. Information plays a vital role to tourists in planning their travel from one place to another, and success of tourism industry. This can bring many advantages for both tourist and tourism department.

Irrigation water management:

Water availability for irrigation purposes for any area is vital for crop production in that region. It needs to be properly and efficiently managed for the proper utilization of water. To evaluate the irrigation performance, integrated use of satellite remote sensing and GIS assisted by ground information has been found to be efficient technique in spatial and time domain for identification of major crops and their conditions, and determination of their areal extent and yield. Irrigation requirements of crop were determined by considering the factors such as evapotranspiration, Net Irrigation Requirement, Field irrigation Requirement, Gross Irrigation Requirement, and month total volume of water required, by organizing them in GIS environment. (A. M. Chandra, S. K. Ghosh, Remote Sensing and Geographical Information System)

Fire equipment response distance analysis:

GIS can be used to evaluate how far (as measured as via the street network) each portion of the street network is from a firehouse. This can be useful in evaluating the best location for a new firehouse or in determining how well the fire services cover particular areas for insurance ratings.(Himachal Pradesh, Development Report)

Worldwide Earthquake Information System:

One of the most frightening and destructive phenomena of nature is the occurrence of an earthquake. There is a need to have knowledge regarding the trends in earthquake occurrence worldwide. A GIS based user interface system for querying on earthquake catalogue will be of great help to the earthquake engineers and seismologists in understanding the behavior pattern of earthquake in spatial and temporal domain. (A. M. Chandra, S. K. Ghosh Remote Sensing and Geographical Information System)

Volcanic Hazard Identification:

Volcanic hazard to human life and environment include hot avalanches, hot particles gas clouds, lava flows and flooding. Potential volcanic hazard zone can be recognized by the characteristic historical records of volcanic activities, it can incorporate with GIS. Thus an impact assessment study on volcanic hazards deals with economic loss and loss of lives and property in densely populated areas. The GIS based platforms enables us to find out the damage and rapid response against volcanic activities may helps to reduce the effect in terms of wealth and health of people.

Energy Use Tracking and Planning:

GIS is a valuable tool that helps in the planning organizing and subsequent growth in the energy and utilities industries. The effective management of energy systems is a complex challenge. GIS has enormous potential for planning, design and maintenance of facility. Also it provide improved services and that too cost effectively.

GIS for Fisheries and Ocean Industries:

GIS tools add value and the capability to ocean data. ArcGis is used to determine the spatial data for a fisheries assessment and management system. It is extensively used in the ocean industry area and we get accurate information regarding various commercial activities. To enhance minimizing cost for the fishing industry. Also it can determine the location of illegal fishing operations.

Monitor Rangeland Resources:

GIS is a valuable tool used to monitor the changes of rangeland resource and for evaluating its impact on environment, livestock and wild life. Accurate observation and measurements are to be made to find out the changes in the rangeland conditions. GIS is also used to monitoring ecological and seasonal rangeland conditions .

Reservoir Site Selection:

GIS is used to find a suitable site for the dam. GIS tries to find best location that respect to natural hazards like earthquake and volcanic eruption. For the finding of dam site selection the factors include economic factors, social considerations, engineering factors and environmental problems. This all information are layered in the GIS.

Forest Fire Hazard Zone Mapping:

Forest is one of the important element of the nature. It plays an important role in the local climate. Forest fires caused extensive damage to our communities and environmental resource base. GIS can effectively use for the forest fire hazard zone mapping and also for the loss estimation. GIS also help to capture real time monitoring of fire prone areas. This is achieved by the help of GNSS and satellite Remote Sensing.

Pest Control and Management:

Pest control helps in the agricultural production. Increasing in the rate of pest and weeds can lead to decrease in the crop production. Therefore GIS plays an important role to map out infested areas. This leads in the development of weed and pest management plan.

Traffic Density Studies:

GIS can effectively use for the management of traffic problems. Today's population along with the road traffic is increasing exponentially. The advantage of GIS make it an attractive option to be used to face the emerging traffic problems. By creating an extensive database that has all the traffic information such as speed data, road geometry, traffic flow and other spatial data and processing this information will provide us the graphical bigger picture for the traffic management.

Deforestation:

Nowadays forest area is decreasing every year, due to different activities. GIS is used to indicate the degree of deforestation and vital causes for the deforestation process. GIS is used to monitor deforestation.

Space Utilization:

GIS helps managers to organize and spatially visualize space and how it can best be used. Operational costs can be decreased by more efficiently using space including managing the moves of personal and assets as well as the storage materials. The 3D visualization in GIS platforms helps planers to create a feeling of experience like virtual walk inside the building and rooms before construction.

Desertification:

Desertification is the land degradation due to climatic variations or human activities. GIS can provide the information of degraded land which can be managed by governmental agencies or by the communities themselves. GIS plays a vital role to reduce the desertification, the local governments are now widely depends on GIS for reducing desertification. With location based GIS analysis we can find where or which area is suitable for planting new vegetation and which area for the pipeline construction.

Disaster and Business Continuity Planning:

Viewing building and locations assets along with emergency information such as weather patterns, and disaster zones, can provide organizations the required information to make better decision. GIS provide holistic understanding of facility status and performance, and brings together department, business systems, and data source for a comprehensive view into and throughout the organization. (Faisal I. Al-Shukri, GIS Utilization in Facility Management)

GIS for Business:

GIS is also used for managing business information based on its location. GIS can keep a track of where the customers are located, site business, target marketing campaigns, and

optimize sales territories and model retail spending patterns. Such an added advantage is provided by the GIS to enhance in making companies more competitive and successful. (Sita Mishra, GIS in Indian Retail Industry-A Strategic Tool)

Utilities:

The GIS is used for different type of utilities like electricity, telecom and cooking gas on a daily basis and utilities to help them in mapping, in inventory systems, track maintenance, monitor regulatory compliance or model distribution analysis, transformer analysis and load analysis.(Gulzara Mamazhakypova)

Lease Property and Management:

Revenue can be increased, operations and maintenance cost can be reduced when GIS is used to help manage space. Real estate and property managers can see and make queries about space including its availability, size and special constraints for the most cost effective use.

Development of Public Infrastructure Facilities:

GIS has many uses and advantages in the field of facility management. GIS can be used by facility managers for space management, visualization and planning, emergency and disaster planning and response. It can be used throughout the life cycle of a facility from deciding where to build to space planning. Also it provides facilitate better planning and analysis.(Gulzara Mamazhakypova)

GIS for Drainage Problems in Tea Plantation Areas:

Drainage problem in tea plantation differ widely because of its varied nature of physical conditions. Tea crop requires moisture at adequate levels all times of its growth. Any variation either excess or lack has a direct impact on the tea yield. This become greatly influenced the productivity of tea. Required some hydraulic design to solve this problem such as design of drains, checking the adequacy of the river and classification of water logged areas etc. GIS helps to reduce the water logging by establishing well developed plans.

Collection of Information about Geographic Features:

GIS is not simply a computer system used for making maps. A map is simply the most common way of reporting information from a GIS database. So these systems are not only for creating maps but also most importantly the collection of information about the geographic features such as building, roads, pipes, streams, ponds and many more that are located in your community.

GIS for Public Health:

GIS provides the cost effective tool for evaluating interventions and policies potentially affecting health outcomes. GIS analysis, environmental health data is also helpful in explaining disease patterns of relationships with social, institutional, technological and

natural environment. It can be understand the complex spatial temporal relationship between environmental pollution and disease, and identifying exposures to environmental hazards. GIS can significantly add value to environmental and public health data.(The application of GIS in environmental health sciences: opportunities and limitations.)

Location Identification:

This technique is used to find a location for a new retail outlet. It helps to find out what exists at a particular location. A location can be described in many ways, using, for instance, name of place, post code, or geographic reference such as longitude or latitude or X/Y.

Knowledge Based System for Defense Purpose:

Regular analysis of terrain is essential for today's fast paced battlefield. Conventional method of studying paper topographical maps is being replaced by use of maps in digital form to get terrain information. It is increasingly being used to derive terrain information from digital images. Which help to the selection of suitable sites for various military uses more accurate and faster. The uses of GIS provide information regarding the terrain features which can be useful for planning today's war strategies.

Pipeline Route Selection:

Pipeline route planning and selection is usually a complex task. GIS technology is faster, better and more efficient in this complex task. Accurate pipeline route selection brings about risk and cost reduction as well as better decision making process. GIS least cost path analysis have been effectively used to determine suitable oil and gas pipeline routes. An optimal route will minimize reduce economic loss and negative socio-environmental impacts.

Producing Mailing Labels for abutter Notification:

Zoning board of appeals hearings or proposed action by a town or city require notifying abutting property owners. A GIS application for producing abutter mailing labels enables you to identify abutting property owners are in different ways. Once the properties are identified this kind of GIS applications can produce mailing labels and be integrated with a word processing "mail merge "capabilities.(http://www.mass.gov/)

Site Suitability for Waste Treatment Plant:

There is an increasing amount of waste due to the over population growth. This has negative impact on the environment. With the help of GIS we can integrate various aspect layers in GIS and can identify which place is suitable for waste treatment plant. This process will reduce the time and it is cost effective. Also it enhances the accuracy. It provides a GIS analyst to identify a list of suitable dumping sites for further investigations. It also provides a digital bank for future monitoring program of the site.

Geologic Mapping:

GIS is an effective tool in geological mapping. It becomes easy for surveyors to create 3D maps of any area with precise and desired scaling. The results provide accurate measurements, which helps in several field where geological map is required. This is cost effective and offers more accurate data, there by easing the scaling process when studying geologic mapping.

Environment:

The GIS is used every day to help protect the environment. The environmental professional uses GIS to produce maps, inventory species, measure environmental impact, or trace pollutants. The environmental applications for GIS are almost endless. It can be used to monitor the environment and analyze changes.(by S Farog Mostafa)

Infrastructure Development:

Advancement and availability of technology has set a new mark for professionals in the infrastructure development area. Now more and more professionals are seeking help of these technologically smart and improved information systems like GIS for infrastructure development. Each and every phase of infrastructure life cycle is greatly affected and enhanced by the enrollment of GIS.

Coastal Development and Management:

The coastal zone represents varied and highly productive ecosystem such as mangrove, coral reefs, see grasses and sand dunes. GIS could be generating data required for macro and micro level planning of coastal zone management. GIS could be used in creating baseline inventory of mapping and monitoring coastal resources, selecting sites for brackish water aquaculture, studying coastal land forms.

Crime Analysis:

GIS is a necessary tool for crime mapping in law enforcement agencies worldwide. Crime mapping is a key component of crime analysis. Satellite images can display important information about criminal activities. The efficiency and the speed of the GIS analysis will increase the capabilities of crime fighting.

River Crossing Site Selection for Bridges:

The important geotechnical consideration is the stability of slope leading down to and up from the water crossing. It is advisable to collect historical data on erosion and sedimentation. On the basis of these information asses the amount of river channel contraction, degree of curvature of river bend, nature of bed and bank materials including the flood flow and the flow depth, all these can be done in GIS within estimated time and accurately. This information has been often used for river crossing site selection for bridges.

Land Use Changes Associated with Open Cast Strip Mining:

Mining is the back bone of the developing economy of any country. Mapping, monitoring and controlling the impact caused by the mining activities is necessary so as to understand the character and magnitude of these hazardous events in an area. The data required to understand the impact of mining from the environment is coming from different discipline, which need integration in order to arrive hazard map zonation.

Economic Development:

GIS technology is a valuable tool used for the economic development. It helps in site selection, suitability analysis, and for finding the right sites to locate new business and grow existing ones. Within economic development, GIS is used to support the emerging trend of economic gardening, a new way to foster local and regional economic growth by existing small business in the community.(By Ahmed Abukhater,GIS for Planning and Community Development: Solving Global Challenges)

Locating Underground Pipes and Cables:

Pipe line and cable location is essential for leak detection. It can be used to understand your water network, conducting repairs and adjustments, locating leaks known distance for correlating etc. Pipelines are continually monitored, check for leak detection and avoid the problem of geo hazards.

Coastal Vegetation Mapping and Conservation:

Coastal vegetation like Mangroves are the protectors of coast from natural hazards like tsunami , so that the conservation of these vegetation are highly important. GIS enable us to map which are having higher density of vegetation and which area need more vegetated? Integration of these details to coastal zone mapping helps to identify the area prone to coastal erosion and we can plant more vegetation to reduce coastal erosion.

Regional Planning:

Every day, planners use Geographic Information System (GIS) technology to research, develop, implement, and monitor the progress of their plans. GIS provides planners, surveyors, and engineers with the tools they need to design and map their neighborhoods and cities. Planners have the technical expertise, political savvy, and fiscal understanding to transform a vision of tomorrow into a strategic action plan for today, and they use GIS to facilitate the decision-making process. (ESRI, GIS Solutions for Urban and Regional Planning)

GIS for Land Administration:

In a number of countries, the separate functions of land administration are being drawn together through the creation of digital cadastral databases, with these database they can reuse land for suitable needs ,digital taxation and even utilities are also easily handle using these database.

Snow Cover Mapping and Runoff Prediction:

Systematic, periodical and precise snow cover mapping supported by GIS technology, and the organization of the results in a snow cover information system forms the basis for a wide range of applications. On the practical side, these applications are related to the monitoring of seasonal and yearly alterations of the snow cover under the presently existing climatic conditions, to simulate and forecast runoff, to map the regional distribution of the water equivalent, and to document the recession process of the snow cover during the melting period in its relation to geological features.

GIS for Wildlife Management:

Man made destruction such as habitat loss, pollution, invasive species introduction, and climate change, are all threats to wildlife health and biodiversity. GIS technology is an effective tool for managing, analyzing, and visualizing wildlife data to target areas where international management practices are needed and to monitor their effectiveness. GIS helps wildlife management professionals examine and envision.

MODULE-IV

LAWS RELATING TO REMOTE SENSING

LAWS RELATING TO REMOTE SENSING

INTRODUCTION:

Space law is a newly developed field of law with a relatively short history. The discussion of space law began in the 1950s following related technological developments achieved by the end of World War II. Space development originated with the invention of a long-range liquid fuel rocket by the German army. The German V-2 rocket, completed in 1942, was able to fly outside the Earth's atmosphere and became the foundation for the first artificial satellite. The incentive for space technology was then driven forward by the subsequent Cold War, in the form of an arms race between the Soviet Union and the United States.

On October 4, 1957, the Soviet Union took the lead in the race – first by placing Sputnik-I, the first man-made satellite, successfully into orbit in outer space. Following the launch of Sputnik, the need for a legal regime governing outer space became apparent and the legal status of outer space suddenly became an urgent and real question to resolve – rather than merely a theoretical and speculative matter.

The fundamental question was the legal status of outer space in terms of sovereignty: specifically, whether or not sovereignty recognized in airspace extended to outer space. US air law expert J.C. Cooper contended that sovereignty did not extend to outer space; this view prevailed, and the legal status of outer space based on that view continued to be recognized in the context of reconnaissance satellites.

The permissibility of observing foreign territories from space was first proposed by the United States. The official step toward legitimizing remote sensing for reconnaissance purposes was the proposal for an Open Skies Policy by President Eisenhower to allow the United States and the Soviet Union to monitor each other's territory to avoid a surprise attack. Although rejected by Moscow at the time, afterwards the policy was accepted by the two superpowers on a de facto basis as they started to monitor each other's territories with reconnaissance satellites in the 1960s.

The next question concerned where the boundary between airspace and outer space lay. There was no clear answer, since air law had never established a definition of airspace with a precise boundary. After Sputnik, numerous theories were proposed in attempts to determine the demarcation of outer space. Cooper and common law experts believed that outer space simply stopped at the point below which an orbit could not be sustained. The higher boundary of airspace meant more protection against unfriendly overflights, as sovereignty was extended in airspace. In the UN COPUOS, the Soviet Union proposed to fix the boundary line at an altitude of 100–120km above sea level, and most delegates were in agreement. At present, there is still no agreement as to the From this history, one can clearly see that space law boundary of outer space. From this history, one can clearly see that space law developed in a political context, as the major space powers attempted to codify their particular interests.

Today there are two primary sources of space law under which satellite remote sensing activities are addressed: space law derived from international legal rules, and space law derived from national laws developed in several countries. This Module provides an overview of the legal regime of outer space from the standpoint of satellite remote sensing by examining international multilateral trea- ties, national laws, and national policies.

Specific Law for Remote Sensing

As introduced briefly, the body of law specifically dealing with remote sensing was adopted by consensus in the form of the UN General Assembly Resolution in 1986. Christol contends that the UN Remote Sensing Principles gave formal approval for states to engage in information gathering activities from space as international customary law, that is, practices and beliefs that are so vital and intrinsic a part of a social and economic system that they are treated as if they were laws. Indeed, the UN Remote Sensing Principles are a re-establishment of legitimacy for data collection from space, which was already an accepted practice inferred under the Outer Space Treaty and, for the first time, establishing concrete rules with regard to data access and availability at an international level.

Drafting History of the UN Remote Sensing Principles

Following the initial considerations to codify principles at the United Nations in the late 1960s, it took more than fifteen years for states to come to a consensus in 1986 on the general principles regarding remote sensing. The lengthy drafting history is attributed to difficulties in achieving a consensus amongst various nations with different positions and conflicting interests. The stances adopted by states were fundamentally split between those COPUOS members representing developed nations with sensing capabilities on the one hand and the developing nations that lacked such technology on the other. The former position was taken by the United States and many Western states, who insisted upon the freedom of acquiring and imparting information as a human right; the latter position was held by those states amongst the develop- ing and Soviet-led socialist countries, who insisted upon the principle of state sovereignty over natural resources as well as the information concerning such resources."

The disparate positions stemmed from the interpretation of the term sovereignty, and location where the sovereignty in question was stressed. The first question was whether freedom of sensing was permissible. The location of a target for sensing, in which the sovereign right of states was exercised, was stressed by developing nations;146 the developed nations stressed the location from which sensing takes place, where sovereignty does not extend. The second question was whether sovereignty extends to acquired information. Whilst developing nations claimed their sovereign right over acquired information relating to natural resources in their territory, developed nations argued other- wise. The conflicting positions seemed to be impossible to reconcile at first. Indeed, the drafting history of the UN Remote Sensing Principles had been a difficult

process of compromise between the dissenting views, which progressed gradually over a period of time.

The initial examination of the subject by the UN COPUOS started in 1968 in Vienna. Until the text of what is now the UN Remote Sensing Principles was adopted, a series of proposals by different nations were presented. The major proposals to be examined in this Chapter are as follows:

- 1970 Proposal by Argentina[1]
- 1973 Proposal by the Soviet Union co-sponsored by France[2]
- 1974 Joint draft by the Soviet Union and France[3]
- 1974 Joint Draft by Argentina and Brazil[4]
- 1975 Proposal by the United States[5]
- 1981 Proposal by Mexico[6]
- 1982 Proposal by Brazil[7]
- 1984 Proposal by Chile[8]

The content of the proposals, which were subject to negotiation, can be categorized into three critical elements: conditions for sensing, conditions for access and distribution of data, and international responsibility regarding conducting remote sensing activities.

The negotiation was put forward mainly in two stages: first, debates on conditions for sensing – such as prior consent, limit on location, and veto right; and second, debates on rules concerning the resulting information – such as priority access and control on dissemination of data. The detailed examination of drafting history can be roughly divided into three periods: 1) the era prior to the 1978 Moscow Convention on the Transfer and Use of Data of Remote Sensing of the earth from Space;[9] 2) the Moscow Convention and International Satellite Monitoring Agency; and 3) post Moscow Convention towards the 1986 UN Remote Sensing Principles. The debate regarding the freedom of sensing took place primarily during period 1 and the debate regarding access and dissemination characterising priority access and control on the dissemination of data took place in periods 2 and 3. It is important to look at how divergent were the views and positions presented, how they met opposition from the other side, and how gradual convergence to agreement resulted in each period.

The initial formulation phase of the UN Remote Sensing Principles began with a 1970 proposal by Argentina, which claimed that prior consent was required from the sensed

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1 UN Doc. A/AC.105/C.2/L.73, 26 (1970)
2 UN Doc. A/AC/105/111 (1973).
3 UN Doc. A/AC.105/C.2/L.99 (1974).
4 UN Doc. A/AC/1/1047, Oct 15, 1974.
5 UN Doc. A/AC.105/C.2/L.103 (1975).
6 UN Doc. A/AC.105/288 (1981).
7 WG/RS (1982)/WP.11 (1982).
8 WG/RS (1984)/WP.12 (1984).
9 UN Doc. A/33/162, 29 June, 1978. [Hereafter: Moscow Convention]

state before another state conducted remote sensing. This position was based on the contention that, since certain UN General Assembly Resolutions provide that states have permanent sovereignty over their own natural resources, information on the these assets was also included in the concept of sovereignty.

The 1974 Brazil and Argentina draft proposal again insisted on prior consent for sensing any foreign territory and rigid control over sensing natural resources – a proposal so extreme that it would have denied the remote sensing practice that had been conducted by space powers at that time, and would have made remote sensing activities practically impossible to conduct. That proposal was not acceptable to space-faring nations. The United States strongly opposed this position for legal, technical, and practical reasons, contending that it was legally inconsistent with the provisions of the Outer Space Treaty and that the legality of sensing should depend upon the site of the sensing device rather than the location of the sensed object. Furthermore, the United States argued, from a technological standpoint it is not possible for remote sensing equipment to distinguish international borders; and besides, it would be financial impracticable to develop such capability.

The United States maintained its stance for freedom of sensing, adhering to the Open Skies Policy and recognizing the commercial potential of remote sensing data. The United States did not mention the sovereignty issues in its proposal, a working paper entitled *Legal Implications of the Earth from Space*. The United States contended that the disclosure of useful information derived from sensing would contribute to the "(...) preservation of environment and effective management and control by states of their natural resources." Freedom of sensing was proposed by only a few states then.

The Soviet Union and France made a joint proposal in 1974. This proposal also required prior consent and the legality of sensing was limited in its location, suggesting that freedom of sensing be permitted only in the areas outside the national jurisdiction of any state. The proposal also introduced the notion of control over the dissemination of data and suggested a requirement of prior consent from sensed states.

Under the French-Soviet proposal, data was divided into two types. Data acquired with a spatial resolution greater than 50m would be classified as 'global 'and would not be subjected to restrictions imposed for sensing and dissemination; data of higher than 50m resolution would be classified as 'local 'and would be subject to control. This proposal was based on the view that sovereignty of sensed states extended to acquired information by sensing states, rather than any grant of superior rights to sensing states to have access to critical information on natural resources in the territory of sensed states.

The only exception to the application of prior consent and the right of veto in the French–Soviet proposal was distribution for the purpose of disaster management and environmental protection. The draft stipulated that no veto rights would be exercised in the event of a natural disaster or phenomena detrimental to the environment; and the sensing state could distribute data without the knowledge or approval of the sensed

state(s). Because it called for 1) classification of data by ground resolution with consequential dissemination policies, and 2) giving preferential treatment for data availability for public benefit, the proposal can be regarded as an attempt to establish concrete data policies hitherto not adopted for inclusion in the final document.

The 1974 Soviet-French proposal led to the 1978 Moscow Convention on the Transfer and Use of Data of Remote Sensing of the Earth from Space. This convention set forth the detailed rules with respect to the dissemination of data, which can be seen as a data policy. The convention was signed in Moscow by Cuba, Czechoslovakia, the German Democratic Republic, Hungary, Mongolia, Poland, Romania, and the Soviet Union. At the time of this convention, the argument was shifting from the freedom of sensing from space to the control of resulting information and attempts to regulate the access and dissemination of data. The control over dissemination specifically imposed in Article IV of the Moscow Convention stipulates that "A Contracting Party in possession of initial data of the remote sensing of the Earth from outer space, with a better than 50 metres ground resolution on the terrain, relating to the territory of another Contracting Party, shall not disclose or make them available to anyone except with an explicit consent thereto of the Contracting Party."

Article IV of the Moscow Convention therefore required prior consent from sensed states for dissemination of initial data and derived information concerning natural resources of the sensed states, and also established international responsibility for use of remote sensing data. The intention was clear: Article IV attempted to protect the sovereign rights and interests of sensed states through control of dissemination of the information. Prior consent for the dissemination of data infers veto rights by sensed states, and it can be construed that if a party considers the dissemination of the data as detrimental to them, they can hamper the dissemination by exercising their right of veto.

The Soviet Union was specifically opposed to the free dissemination of data and rejected the idea that remote sensing data should be freely purchased, as that would constitute a free market in remote sensing data. At the time of the convention, the Soviet Union also proposed that the sensing state should have international responsibility for any serious damage caused by the dissemination of the data; however, such proposal was not taken into account.

The Moscow Convention was not ratified by any further states apart from the first signatories of the socialist nations and failed to become a globally accepted legislation on remote sensing. Over time, it was clear that the convention had been discarded. This was a natural outcome, as communism came to an end in the 1990s; the former Eastern-bloc nations – which comprised the majority of the parties to the convention – have joined the western systems since then. Today, an increasing number of states that were strictly the subjects of sensing activities back in 1986 now have their own space capabilities.

It should be noted that in 1978 – during the first special session of the UN General Assembly devoted to disarmament, France proposed establishment of the International

Satellite Monitoring Agency (ISMA), a specialized agency of the UN, responsible for collecting, processing, and disseminating data and information gathered by satellites. The proven capability of satellite remote sensing to verify the bilateral agreements such as the SALT and ABM treaties led to this proposal, which would also apply such capability to multilateral agreements. The main functions for ISMA were to be the monitoring of the implementation of multilateral arms control and disarmament agreements and the investigation of crisis situations. The ISMA was to be established in three phases: 1) it would operate an international data processing and interpretation facility and disseminate resulting information to member states where data would be acquired from states that operate surveillance satellites; 2) it would establish ground receiving stations, possibly working with national satellites; and 3) it would establish its own space segment as a supplement to national systems.

In response to the submission for a vote on the ISMA to the United Nations, the United States and the Soviet Union abstained and the General Assembly created a committee of experts to conduct a feasibility study. The feasibility study concluded that establishing the ISMA was technically feasible and not in conflict with international law. The ISMA did not come into existence, however, because both superpowers were against its establishment. The Soviet Union argued that allowing an international agency to gain control of military or strategic information would have violated the principle of national sovereignty, whilst the United States contended that such an agency would have permitted states to engage in espionage or activities that were inconsistent with national security or national policies. The failure to establish the ISMA indicates that, even amongst the developed nations with remote sensing capabilities, their interests were not uniform.

The Moscow Convention did not resolve the fundamental problem associated with achieving consensus for a set of principles governing remote sensing; thus, during the period from 1976 to 1981 no progress was made toward an agreement on the principles of state sovereignty and prior consent.

With the 1981 Mexico proposal, meaningful debate toward agreement resumed. Mexico proposed priority access as well as prior notification. The phrase ‘prior notification ’ instead of ‘prior consent ’was a reflection of some attitudes of compromise shown by developing states, as ‘prior notification– ’in contrast to ‘prior consent – ’does not imply veto rights. The proposal also required that sensing states provide preliminary information and final results, whilst prohibiting dissemination of information without the prior consent of sensed states. The debate was shifting more towards the conditions necessary for access and dissemination, together with the responsibility of states to carry out remote sensing activities.

The 1982 Brazilian working paper provided a compromise solution by way of a restriction of state responsibility as well as data availability. It advocated for priority access and international responsibility on dissemination, and it pro- posed priority access by sensed states as: a “Sensed State shall have timely and non-discriminatory access to primary data obtained by remote sensing of the Earth from outer space concerning

territory under its jurisdiction before access is granted to any third party." The Brazilian proposal suggested that sensing states should be held internationally responsible for dissemination of data that adversely affect the interests of sensed states.

Both socialist nations and developing countries were ready to agree to this proposal; however, it proved unacceptable to sensing states as it would have meant that state responsibility extended to monitoring data dissemination by private entities conducting remote sensing.

Specific responsibility for the use of remote sensing data was also proposed in a working paper by Chile in 1984. Principle XI states that "States shall bear international responsibility for improper or discriminatory use of analysed information resulting from remote sensing." This language can be construed to mean that the misuse of data that could be detrimental to the interests of sensed states is prohibited.

The emergence of civilian-operated remote sensing satellites made the developed states adhere even more to their position for freedom of sensing with unregulated dissemination of data. The United States began operating Landsat in 1972, and its position on remote sensing reflected a clear intention to vitalise the Landsat system and its data dissemination. The United States intended to commercialize the remote sensing system through the 1984 US Land Remote Sensing Commercialization Act. France initially supported the Soviet view for requiring prior consent, but shifted to follow the US position in anticipation of the development of the French SPOT – the first non-US civilian satellite – in 1986.

The final UN Remote Sensing Principles mainly reflect the US view and are clearly the product of a high degree of compromise by the developing states. None of the proposals from developing nations with regard to the rights of sensed states and obligations of sensing states were incorporated in the way that these sensed states originally wished. The major contention of developing nations – including, but not limited to, prior consent for sensing and dissemination of data, privileges in accessing data by sensed states, concrete data policies, and responsibility for dissemination of data – were discarded; only ambiguous phrases on international responsibility and the respect of the interests of sensed states remained, and these were incorporated into the final UN Remote Sensing Principles. It was a victory for the proponents of sensing, represented by the United States, which managed to codify most of its contention that the freedom of sensing and the unregulated dissemination of data were consistent with the Open Skies Policy. The only matter that was not incorporated into the Remote Sensing Principles was the US view regarding intellectual property rights. The United States has claimed that once collected data is transformed into product though processing and analysis, it becomes the intellectual property of its owner and thus subject to copyright law. This view is now incorporated in data policies of individual entities and widely practiced, but this practice invokes questions as to the applicability of such data policies to different types of products.

The UN Remote Sensing Principles were adopted after a long period of difficult negotiations. In the end, the Principles adopted turn out to be ambiguous; they do not impose specific obligations, and they contain significant loopholes. The resulting Principles reiterate general concepts of international law or formalize existing customary practice. Even after the formulation of the Remote Sensing Principles, dissatisfaction – particularly amongst the developing countries – remained undiminished. For example, the Latin American nations 'claim for more regulated legislation came to a concrete proposal in 2003. Argentina, Brazil, and Mexico submitted a working paper to the UN COPUOS on a new agenda item calling for an international convention for remote sensing.

The Legal Value of the UN Remote Sensing Principles:

The legal value of the UN Remote Sensing Principles is often debated. In examining their legal value, it is necessary to approach the issue from two stand- points: the analysis of UN General Assembly Resolutions amongst international law instruments, and the actual practice associated with remote sensing.

The UN Remote Sensing Principles are in the form of a UN General Assembly Resolution. It is generally perceived that a UN General Assembly Resolution is not binding as a document in itself, as it is clearly distinguished from a binding instrument such as a treaty or a convention. A binding instrument is a law made, executed, and ratified by governments. In fact, the Assembly is considered to be an advisory body with binding decisions only on issues of threats to international peace and security as adopted by its Security Council. Hence, it is understood that the UN General Assembly Resolution itself is recommendatory in nature – as a recommendation made to the member states of the United Nations in accordance with the UN Charter.

Although commonly perceived as recommendatory, different types of UN General Assembly Resolutions have varying degrees of value. Particularly, a distinction should be made between a declaration and mere principles. Kopal compares the 1963 Declaration of Legal Principles to the UN Remote Sensing Principles; he contends that only the former is called a 'declaration 'and declared principles qualify as legal. In addition, the 1963 Declaration opened a treaty-making process that lead to the conclusion of legally binding instruments such as the Outer Space Treaty. In that respect, the UN Remote Sensing Principles were not designated as a declaration, nor did they open a treaty-making process; therefore, they do not go beyond the status of a recommendation.

Even non-declaration types of General Assembly Resolutions (such as the UN Remote Sensing Principles) address the general code of conduct for all UN member states, or even for all states around the globe; hence, they possess not only political meaning but moral weight. A certain view exists that the significance and weight is increased for a General Assembly Resolution that is unanimously adopted; this means that no states found shortcomings in the resolution and did not vote against it to block its adoption. Indeed, delegates of states such as the United Kingdom and India distinguish between ordinary General Assembly Resolutions and those that are unanimously accepted, and

India even contends that unanimously accepted resolutions are accepted as part of international law. Since the UN Remote Sensing Principles document is accepted unanimously, it is considered authoritative – if not universally recognized as a binding document.

Even if the UN Remote Sensing Principles document does not gain sufficient support for it to be binding in nature, its content can be considered to reflect an element of international customary law. Article 38 of the International Court of Justice (ICJ) Statute recognizes international custom as evidence of general practice accepted as law. The element of international custom requires *opinio juris* and state practice, and the UN Remote Sensing Principles satisfy both. First of all, as previously discussed, large numbers of proposals from states including Argentina, the Soviet Union, Brazil, France, Chile, Mexico, Venezuela, and Austria were taken into account in the drafting process prior to the adoption of the Resolution. It can be considered, therefore, that the Resolution is a final synthesis of different countries 'views on remote sensing from space.

The UN Remote Sensing Principles have been serving as general guidelines for activities in the field of remote sensing from outer space and no disputes have arisen thus far with regard to their application. As far as freedom of sensing is concerned, the Open Skies Policy is a clear indication of *opinio juris* between the United States and Russia since 1960, and have been accepted later by many other states.

The UN Remote Sensing Principles are incorporated into continuing state practice. Over two decades, the UN Remote Sensing Principles have been widely followed by various states and entities. With regard to the most fundamental of these Principles, namely, the principle of sensing from space without prior consent, states have sought no permission and such practice has not encountered protests from the states whose interests were affected. Non-discriminatory access to data is also realized worldwide through an extensive availability of satellite data and derived products via the Internet. These Principles are viewed as a codification of customary legal principles that are binding on nations, pursuant to years of practical implementation, as nations continue specifically to refer to the Principles in domestic, bilateral, and multilateral legal documents. The Principles are actually the only source of legislation devoted to satellite remote sensing at an international level, and other relevant legislation or principles tend also to follow them. For instance, the phrase 'non-discriminatory basis 'is used in international data exchange instruments such as the WMO Resolution, as well as in data policies of space agencies such as NASA and ESA. However, in the absence of confirmation given by the ICJ on its customary value, the binding value of UN General Assembly Resolutions has to be treated with caution.

The Scope of the UN Remote Sensing Principles

To understand the scope of the UN Remote Sensing Principles, it is necessary to look at the precise applications, activities, and types of data to which they apply. Principle I provides the various definitions and scope of the Principles, as discussed in detail below.

Unlike the Outer Space Treaty, which allows for certain military uses of outer space and is open to commercial activities, the scope of the UN Remote Sensing Principles pertains to civil remote sensing for limited applications – specifically natural resource management, land use, and protection of the environment. From this provision, it can be interpreted that military applications fall outside the scope of the Principles, thus excluding satellites used for reconnaissance or intelligence purposes. A question remains as to whether or not dual use remote sensing satellites, which serve for both civil and military purposes such as Global Monitoring for Environment and Security (GMES), are covered under these Principles. Indeed, GMES is intended to monitor the Earth's environment as well as to serve for security purposes; thus, the programme is partially covered under the Principles. Furthermore, it is difficult to construe that commercial applications other than the three purposes stated above are covered under the UN Remote Sensing Principles. A particular issue may be raised with respect to applying the Remote Sensing Principles to high resolution satellites, which are nowadays a critical source of information in various decision-making activities. These satellites have the capability to reveal very sensitive information and the application of the UN Remote Sensing Principles to remote sensing activities of such a nature would affect the concerned parties extensively.

Today there are many other applications apart from natural resource management, land use, and protection of environment in civil and commercial remote sensing – regardless of their humanitarian, commercial, or military nature – to name but a few: disaster management, registry of land, archaeology, urban planning, map making, agriculture, and the variety of verification purposes already mentioned in the Introduction. The use of data for these applications may not fall within the scope of the UN Remote Sensing Principles and issues associated with these applications are not addressed under the present regime, which needs improvement with regard to this point.

The UN Remote Sensing Principles give clear definitions with regard to the extent of remote sensing activities: 1) the operation of remote sensing space systems; 2) the operation of primary data collection and storage stations; 3) the activities in processing; 4) interpreting; and 5) disseminating the processed data. Although data handling activities and data distribution are covered under the scope of the Principles, the use, as well as the application of remote sensing information is not covered.

It is significant to point out that data handling activities and dissemination, which take place on the Earth, are within the scope of remote sensing activities defined under the UN Remote Sensing Principles. Indeed, only the first and second activities listed above take place in space; the rest are conducted on the Earth. Long before the formulation of the Remote Sensing Principles, W.P. Heere stated that Earth resources are a terrestrial matter, and thus should fall under terrestrial law and not space law; likewise, Franco Fiorio suggested that a distinction should be made between remote sensing activity itself and the use made of the resulting picture. Contrary to such opinions, the Principles do not distinguish between data collection taking place in outer space and data handling

operations taking place on the Earth. The Principles apply even if states are involved in only terrestrial operations such as data processing, interpretation, value-adding activities, or just information extraction, as long as satellites are the original source. Although remote sensing takes place in outer space where there is no sovereignty, the data are collected for potential use on Earth, where state sovereignty prevails over territory and airspace. The international community needs to recognize that the situs of remote sensing activities lie on the Earth, where the information acquired is transformed into useful media. The transformation to useful knowledge, as well as use of such knowledge, is the part that should be regulated and the current legal framework needs improvement in this regard.

It is also important to examine the coverage of the UN Remote Sensing Principles with regard to activities conducted by private entities. The UN Remote Sensing Principles provide nothing more than is provided by the Outer Space Treaty. They are silent as to private entities except for Principle XIV, which makes a link between state activities and those of private entities, recalling Article VI of the Outer Space Treaty. This means that private entities are bound by the regulations imposed by the states whose jurisdiction covers such entities but neither Article VI of the Outer Space Treaty nor Principle XIV of the UN Remote Sensing Principles give details as to how non-governmental entities should be authorized and supervised. Either the particular national jurisdiction exercises control through a licensing regime, or such activities are left unregulated.

As mentioned in the Introduction, remote sensing data are classified in three types: primary data, processed data, and analysed information. In reality, there are many other terms apart from the three definitions used, such as: raw data, unenhanced data, derived product, and value-added product. The elaboration of what constitutes analyzed information is of particular importance from the standpoint of intellectual property rights, as it addresses the critical question of whether or not the information includes content that has been modified to the extent that it does not retain the original pattern and, as such, may not then be subject to protection under intellectual property laws. The coordination of these definitions with actual practice, as well as elaboration, may be necessary.

Contents of the UN Remote Sensing Principles:

As has been discussed, the UN Remote Sensing Principles were the codification of the interests of the spacefaring nations in safeguarding their right to gather information from space. A number of propositions on the rights of sensed states and their obligations associated with sensing arose during the formulation process, but were not incorporated. The Remote Sensing Principles proposed a general framework with respect to data collection, data availability, and a state's responsibility for conducting remote sensing activities, all of which allowed for flexible interpretation. The resulting Principles have established new rules whilst repeating the provisions that were already in place. This section analyzes the content through key elements newly established in the UN Remote Sensing Principles, and reiteration of principles established by the Outer Space Treaty.

The newly established Principles clearly set forth the fundamental norms and rules regarding data collection but are limited to the issues of access, distribution, and use of data. The key elements the UN Remote Sensing Principles can be divided into three categories: freedom of remote sensing, respect of rights and interests of sensed states, and data rules.

Principle IV is a core provision and one of the two most critical Principles of all fifteen. Principle IV stipulates that "Remote sensing activities shall be conducted in accordance with Article I of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space" which establishes the free use of outer space. Although not explicitly stated, Principle IV establishes the right of states in sensing the entire globe from outer space using satellites. Accordingly, this provision established the data collection rule as: 1) there is no restriction on areas for observation based on geography or objects for observation including natural resources or sensing sea surface beyond national jurisdiction; 2) no prior consent, consultation, or notification is required before sensing and, therefore, no veto right is granted to sensed states for their territories being sensed; and, 3) no conditions are imposed for sensing capabilities in terms of spatial and temporal resolution, or type of sensors such as radar or optical.

All states are given the right of data collection from outer space. Later in Principle IV, the sovereign rights of sensed states are respected, in that: "These activities shall be conducted on the basis of respect for the principle of sovereignty of all States, and peoples over their own wealth and natural resources (...). Such activities shall not be conducted in a manner detrimental to the legitimate rights and interests of the sensed State." As seen earlier, the sovereignty of sensed states was the major issue of contention during the negotiation process before formulation. Yet both sentences are ambiguous and fail to clarify what the principles of sovereignty and the legitimate rights of sensed states actually entail. The obligation not to conduct remote sensing activities against the legitimate rights and interests of sensed states appears to refer only to the conduct of remote sensing itself and not to what may happen after the dissemination of data. The interest of sensed states is most commonly affected by the use and misuse of the resulting data, but the Principles impose neither specific obligations on sensing states (such as the obligation to be liable for damage suffered by sensed states for misuse of data), nor clarify the specific rights of sensed states (such as control of access and dissemination for data concerning natural resources). Those who are concerned that data gathered from outer space might be used or misused to their detriment by others – either by the sensing state or by third parties – cannot confidently rely on the provision of the UN Remote Sensing Principles.

Principle XII addresses data rules, establishing the rule regarding data access and dissemination, and thus determining the general availability of remote sensing data. Principle XII stipulates that: "As soon as the primary data and the processed data concerning the territory under its jurisdiction are produced, the sensed state shall have access to them on a *non-discriminatory basis* and on *reasonable cost terms"*. There are

several important implications of this provision. It can easily be inferred from the provision that prior consent before dissemination is not required. Neither veto rights nor control on information for dissemination are granted to sensed states; hence, theoretically, sensed states can neither choose the states to which their territorial information is disclosed nor determine the type of data to disseminate, such as data of high ground resolution.

Principle XII means that sensing states have an obligation to provide the data to sensed states under the same conditions as they provide the data to other interested states. Indeed, sensed states do not have an exclusive, free, or preferential right of access to the data. No privilege is given to sensed states in terms of timing or cost to access to the data. Sensed states are not granted the right of access to the data prior to the sensing states – or any other state – which may affect their interests extensively. Likewise, no financial privilege is given to sensed states, such as data provision either free of charge or at a lower cost than for other states. The provision 'reasonable cost terms 'is ambiguous and open to different interpretations, as it is not defined under the UN Remote Sensing principles. It could mean marginal cost (which is more specifically phrased on a domestic level as the data policy set by different data generators), or it could mean commercial market price if it is considered to be 'reasonable 'for a particular image.

Non-discriminatory access within Principle XII generates an obligation to make imagery available to the sensed states; however, whether sensing states actually make the data available hinges on their good faith. There are no means to force sensing states to release data to sensed states in case the sensing state does not follow this rule. It is practically impossible for sensed states to keep track of the precise time and location of observation of their territories by all the satellites. Whether data is actually accessed by the sensed state is entirely at the discretion of the data generators and the interested state's ability to pay for the data. Therefore, this Principle can be construed as a 'passive 'obligation to disseminate data to any other states if requested.

Principle XII is based upon the presumption that a distinction is made only on the basis of sensing states and other states, and not on consideration of other factors such as the purpose for which the data is used. Principles X and XI oblige the disclosure of information for environmental protection and disaster management, but they do not stipulate the conditions for such disclosure. In reality, certain data use – such as for disaster relief – and certain types of users under governmental space programmes receive preferential treatment, including a price waiver. The practical questions of under what conditions free provision of data is allowed, and the subsequent implications arising are not addressed anywhere.

Another issue to be addressed is the availability of analysed information derived from remotely sensed data. There is a loophole in Principle XII, and the provision becomes even more complicated regarding this analysed information, specifically, "The Sensed States shall also have access to the available analysed information concerning the territory under its jurisdiction in the possession of any state participating in the remote sensing

activities on the same basis and terms." Strictly speaking, this may exclude cases where the analysed information is not in possession of any state. The obligation to provide analysed information may not extend to individuals or juridical persons engaged in analysing information, such as a processing wholesaler and/or information extractor. This is again a loophole and results in a gap between the implied position and the reality of current practice. The mechanisms surrounding data availability should be phrased differently in the context of data policy.

The other principles endorsed by the UN Remote Sensing Principles fundamentally repeat the provisions established under the Outer Space Treaty. Yet, some reiterated principles are tailored to situations specifically associated with remote sensing from space and worthy of attention. This section reviews the issues of application of international law, international cooperation, and responsibility and liability.

Principles II and III fundamentally reiterate the provisions of the Outer Space Treaty, stipulating that remote sensing activities are to be conducted for the benefit and interests of all countries and in accordance with international law. Application of general international law means that remote sensing activities are carried out under the rubric of the UN Charter and the Outer Space Treaty.

Several principles refer to the issue of strengthening international cooperation, which basically repeat the norm established by the Outer Space Treaty, but adapted to remote sensing activities. Principle V and Principle XIII share the common objective to promote international cooperation through remote sensing activities. Principle V states that "States carrying out remote sensing activities shall promote international cooperation in these activities. To this end, they shall make available to other States opportunities for participation therein." This principle is slightly further elaborated in Principle XIII, which states that "To promote and intensify international cooperation, especially with regard to the needs of developing countries, a State carrying out remote sensing of the Earth from space shall, upon request, enter into consultations with a State whose territory is sensed in order to make available opportunities for participation and enhance the mutual benefits to derived therefrom." These Principles, however, do not impose any obligation for price waivers or mutual exchange of data.

Principles VI, VII, and VIII provide concrete guidance on how to promote international cooperation. Principle VI encourages states to conclude agreements for the establishment and operation of data collecting and storage stations and processing and interpretation facilities, and likewise, Principle VII encourages remote sensing operating states to give technical assistance to other interested states. Principle VIII invokes the role of UN agencies and the relevant agencies in promoting cooperation and technical assistance. Principle IX calls for the transparency of remote sensing activities, requiring the sensing states to report their activities to the UN Secretary General, and encourages the dissemination of information to those states affected by the activity; however, nothing substantial is added to the rights of sensed communities.

Principles X and XI affirm that states must warn of danger in cases of harm to the environment or impending disasters by rapidly and freely disclosing the relevant information. These two concepts had been supported from the initial phase of negotiation on the formulations of the UN Remote Sensing Principles; indeed, remote sensing has been used extensively for assessing damage resulting from natural disasters. For example, when flooding occurred around the city of Saint Louis, Missouri, in the United States, the ERS-1 satellite assessed the extent of the flooded area and its effect on cultivation. The Disaster Charter, originally started as an agreement between CNES and ESA, is a now viable example of extensive international cooperation making satellite data and derived information available for any state affected by disaster.

Finally, Principle XIV of the UN Remote Sensing Principles that deals with international responsibility also needs to be examined. Principle XIV makes reference to Article VI of the Outer Space Treaty and stipulates that: "States operating remote sensing bear international responsibility for their activities." It is possible to argue that the state is internationally responsible for remote sensing activities, including the dissemination of data, but not for what happens afterwards as a result of any activity by the state or a third party. Furthermore, a loophole exists in Principle XIV where it states that: "*States operating remote sensing satellites* (emphasis added) bear international responsibility for their activities (...) whether such activities are carried out by governmental or non-governmental entities. Although government entities are not the only entities carrying out remote sensing activities, the language in Principle XIV raises questions as to its coverage for all potential parties who may be held responsible. Therefore, the provision may be construed literally – that responsibility is imposed only on states operating remote sensing satellites.

Strictly speaking, the UN Remote Sensing Principles do not impose responsibilities on either those states or entities that are not operating satellites but who are actually receiving images and/or engaged in data handling activities as well as distribution, or on the third parties who use the data. In fact, there are many states and entities that do not operate satellites, but rather house value-added resellers where the users should also be held responsible for the misuse of data. This can be seen as a significant loophole and the gap needs to be filled.

Overall, the UN Remote Sensing Principles succeed in codifying basic norms to govern sensing from space and derived operations. They clarify the conditions for sensing as well as data dissemination, and establish the general responsibilities expected of sensing states. The rights and obligations provided by the Remote Sensing Principles are: 1) the right of any state to sense anywhere on the earth from space without prior consent; 2) the obligation of sensing states to provide data to sensed states on a non-discriminatory basis; 3) the right of sensed states to access data on a non-discriminatory basis; 4) the obligation not to infringe the right of sensed states in sensing; and 5) the obligation to bear international responsibility in conducting remote sensing.

On the other hand, the UN Remote Sensing Principles are ambiguous and inadequate because they do not address some critical issues. There are gaps, shortcomings, and loopholes, which result in the Principles not being entirely effective.

There are major shortcomings in that the rights and obligation of concerned parties in remote sensing are not properly addressed in the UN Remote Sensing Principles. They are ambiguous with regard to responsibility and the liability associated with remote sensing data and its use in terms of consequential dam- age. Another shortcoming is that issues with respect to data availability and accessibility are not sufficiently addressed. Principle XII is the only provision related to the practical issues of data availability and pricing policy, but it does not serve as a concrete guideline for the variety of policies on satellite remote sensing data that exist today. With regard to data accuracy and data validation, the Principles are completely silent. The present legal framework is inadequate in terms of data policy, criteria for data accuracy, and guidelines for data authentication – all of which affect widespread use of data for applications such as disaster management and protection of the environment.

It should be reemphasized that the content of the UN Remote Sensing Principles centres on the rights and obligation of sensing states and the interests of sensed states, which highlight a gap and discrepancy with reality. The Principles reflect the politics and technologies of the 1980s, rather than the present day; they were sensible back then, since the most important issue at that time was to reconcile the interests of sensed states and sensing states. Only a few sensing states existed, and the rest of the world was composed of sensed states. Over the two decades since the Principles were adopted, increasing numbers of nations that were once standing on the ‘sensed ’side, now possess their own remote sensing capabilities in orbit. Consequently, the debate has shifted more to considering the rights and obligations of data providers, data recipients, and third parties. The debate that is now of importance focuses on issues related to data policy, data accuracy, and authentication as well as the responsibility associated with the provision and use of data. The question is whether these issues that are not sufficiently regulated internationally are covered in the national context. In order to make the analysis complete, it is necessary to look at the national measures related to space activities and remote sensing.

Revisit of Legal Principles Surrounding Satellite Remote Sensing in Disaster Management:

The use of remote sensing for mitigating the impact from disasters is supported by the UN Remote Sensing Principles. A review of the provisions of the UN Remote Sensing Principles is necessary for further examination of the rights and obligations associated with disaster management. There is only one principle addressing natural disasters. Principle XI encourages the supply of disaster related information to affected or potentially afflicted states: “Remote sensing shall promote the protection of mankind from natural disasters. To this end, States participating in remote sensing activities that have identified processed data and analysed information in their possession that may be

useful to States affected by natural disasters, or likely to be affected by impending natural disasters, shall transmit such data and information to States concerned as promptly as possible." This provision stands on the presumption that imaging of states takes place without prior consent.

The major reason remote sensing can contribute to disaster management is that it enables disaster response unaffected by political impediment, at least in terms of information gathering. Since remote sensing permits data collection of afflicted states without their consent, case-by-case response from outside is improved. Foreign states and external entities that wish to render assistance do not have to wait for the approval of the afflicted state to sense and, even in case of refusal of such offer, the stricken country can still be sensed from space without intrusion. On the other hand, even in case of a deadly disaster, sovereignty concerns by affected countries are still of great importance. Following the 2004 Indian Ocean Tsunami, India was sensed only by its own satellite IRS series.

Critical information can be obtained externally about the extent of disasters as well as identification of priorities of affected areas, regardless of the capacity of the afflicted state. On the basis of such information, useful knowledge can be provided, and international bodies and NGOs can send in relief teams more effectively and efficiently. Constant updates of data collection covering all of the damaged areas through effective coordination minimizes the overlapping services and reduces the level of disparities in served areas.

Legal Analysis of a Successful Model Based on the Disaster Charter

As discussed in earlier chapter, the Disaster Charter is a successful model for the effective coordination of disaster relief based on supply of satellite images. At this point, the stance of operations will be analyzed from the legal standpoint including the legal nature, and the implications for the responsibility and liability associated with the provision of aid.

The Disaster Charter is a non-binding legal instrument based on goodwill and best endeavours; the cooperation is voluntary. Throughout the provisions of the text, the voluntary nature is confirmed by the language: "shall use best endeavours." For instance, Article 4.5 states: "The parties shall use their best endeavours, in accordance with the identified crisis scenarios, to supply associated bodies and, where appropriate, beneficiary bodies with data, and if necessary associated information and services, gathered by the space facilities." No liability is involved in its whole course of operations; indeed, any liability is clearly waived under the Charter. Article 5.4 of the Disaster Charter clearly states that: "The parties shall ensure that associated bodies which, at the request of the country or countries affected by disaster, call on assistance of parties undertakes to confirm that no legal action will be taken against the parties in the event of bodily injury, damage or financial loss arising from the execution or non-execution of activities, services, or supplies arising out of the Charter." In short, the services are not guaranteed: members will not be held liable either in the case in which the Charter was not activated for a particular disaster, nor where actual provisions of images did not lead to successful

rescue operations. The intention of those who drafted the Disaster Charter was clearly that they do not wish to be held responsible for their favours; however, it is questionable whether the free provision of service is sufficient to waive any potential liability. The waiver of liability is not agreed upon by all potential afflicted states or concerned parties, such as families of aid workers. It is uncertain whether a unilateral waiver of liability is enforceable, and this situation emphasizes the need for clarification of liability.

The Need for an Improved Regime

There is an urgent need for a clear legal regime governing disaster relief to enhance effectiveness, as well as an unambiguous liability regime associated with the supply of satellite data. A better coordination with the division of responsibility will improve effectiveness. Furthermore, the liability associated with disasters (such as liability of volunteers) needs clarification.

How a Better Coordination with Division of Responsibilities will Enhance Effectiveness

The earlier section demonstrated that, in most disasters, the competence to provide assistance to the victims is shared amongst a number of actors; however, such operations are often uncoordinated. For instance, following the flash floods and landslide that hit Venezuela in December 1999, the issue of division of responsibilities and decision-making between central and decentralized powers became a source of conflict. The coordination and division of responsibilities is also a key issue in provision of disaster relief using satellite remote sensing as various actors are involved before the delivery of final products. A better coordination is critical to minimize possible conflicts that may arise amongst diverse actors and enhance the effectiveness of operations.

Disaster response in the past has occasionally involved inappropriate assistance and/or unwanted side effects. For instance, following the Indian Ocean Tsunami, an unknown NGO had vaccinated some of the children without leaving any vaccination records, thus generating confusion as to who had and had not been served. Obviously, there is the need for establishing clear mandates and responsibilities for each organization and/or specific tasks to enhance effectiveness and avoid serious mistakes.

The Disaster Charter demonstrates a well-coordinated disaster response that includes a predictable mechanism with the division of responsibility and effective direction of aid based on the provision of disaster information. Since a project manager appointed for each case is responsible for directing specific satellite operators to provide data to the appropriate Charter partner for imaging a particular location, data collection is effectively arranged, overlaps are minimized, and response time is improved.

Minimizing errors is crucial to achieve effective operations. A clear mandate and division of responsibilities of the authorized users and Charter partners would contribute to error reduction; however, minimizing errors involves cost. Providing assistance is already costly and covering the cost of accidents can place a severe burden on donors, who already bear the costs for liability risks. The aid provided is often not sufficient both in

terms of quantity and quality, particularly following deadly large scale and prolonged disasters, where the need usually exceeds the offers of assistance.

The provision of aid should be something appreciated and praised; however, it is also true that the victims sometimes do not look at the efforts made or the surrounding circumstances; rather they can only see the loss they or their family have actually incurred.

Issues of Clarification of Liability: Analysis of Lawsuits following Disasters against Volunteers

Lawsuits have been brought on unreasonable grounds following disasters. Volunteers who have rendered assistance in good faith are not exceptions, and they, too, have become the target of lawsuits. For instance, Mark Morice, a local New Orleans lawyer who used boats to rescue reportedly more than 200 Hurricane Katrina victims, was sued by the boat owner although the lawsuit was not pursued.

A large scale lawsuit that arose in relation to the Indian Ocean Tsunami is striking and worth examining in detail. A group of Austrian and German victims have since brought action against the NOAA Pacific Early Warning Centre, together with the Thai government and the French hotel chain Accor for not responding properly to the disaster. The case is notable, as this type of lawsuit is the first of its kind. The NOAA Pacific Center is accused of having registered the earthquake but failing to alert Indian Ocean countries of the impending tsunami. NOAA is a member of the Disaster Charter. Although the lawsuit is irrelevant to the operations of the Disaster Charter, it raises an important question as to risks of exposure to liability and the uncertain outcome of claims. Another question is whether the Good Samaritan doctrine applies in this case.

The Pacific Tsunami Warning Center of NOAA had no obligations to warn, since it was covering only the Pacific Region, but it attempted to contact the affected countries in vain, so it can be considered that the Center was a 'Good Samaritan'. In contrast, the Charter partners may *not* be considered as Good Samaritans, particularly taking into account the fact that the relationship of dependence does not necessarily require the existence of a contract or a personal relationship between the rescuer and rescued – insofar as the one aided counts on the aid by the rescuer. The primary reasons for the status of the Charter partners in this scenario are:

- The initiators of the Disaster Charter actually set up the mechanism deliberately in advance to help the potential crisis victims, and followers appreciate this philosophy;
- The Disaster Charter service takes place after the request from the afflicted states;
- Under the Disaster Charter, there is no contract; but the degree of dependency by the crisis victims is high;
- A certain degree of duty of care is assumed; and

- Waiver of liability is unilateral; since there is no agreement between the afflicted states and partners or potential claimant(s), a waiver may not be enforceable.

Compared to NOAA's case in the Indian Ocean Tsunami, the Disaster Charter service appears to have a greater exposure to liability. In fact, as with any operation, assistance cannot be 100% successful. With respect to the Disaster Charter, services provided were not completely successful due to late response, unavailability of data, and the limited usefulness of the products that were supplied. According to the 6th Annual Report of the Disaster Charter, following the Suriname flood of early May 2006, it was found that the delivered products were of limited use because they focused on the initial area of interest and did not cover the main flood areas that were later discovered. The Report shows that end users of the Disaster Charter were by and large appreciative of and benefited from the information provided, even if it was not completely useful. It is not possible to completely eradicate the risk that inaccuracies will lead to inappropriate decisions or actions that may result in unexpected loss. It is less likely that beneficiaries would bring actions against Disaster Charter partners for their aid that turn out to be unsuccessful; however, Disaster Charter partners may be at risk, for example, with regard to claims brought by families of aid workers against Charter partners for providing inaccurate images leading to loss of the aid workers 'lives. In case of deadly disasters, the possibility of aid workers becoming victims is high. Rescue operations can be dangerous and aid workers are vulnerable to numerous risks, including endemic diseases. In fact, infectious diseases accounted for over 75% of the emergency evacuations of humanitarian workers. If the families of victims sue data suppliers for inaccurate data that indirectly led to their deaths, the outcome of possible lawsuits is not easily predicted under the current uncertain legal regime.

In the Indian Ocean Tsunami lawsuit case, since it was brought in the US court, the application of the Good Samaritan doctrine is foreseeable. Since the Good Samaritan Principle is well recognized, the US Congress has considered a Samaritan act specifically addressing natural disasters. A bill entitled "The Good Samaritan Liability Improvement and Volunteer Encouragement Act of 2005" has been introduced to grant certain immunities from liability to both national and international disaster relief volunteers, as well as to governmental and intergovernmental organizations. Many countries lack comprehensive Good Samaritan laws and, consequently, foreign relief personnel and organizations are exposed to liability risks arising as a result of unsuccessful aid. Considering the international nature of disaster management, particularly assistance based on satellite remote sensing, clarification and universal applicability of the Good Samaritan Principle is essential.

States or organizations would become more confident about providing or receiving aid if they know precisely the scope of their responsibility and that they will not be held liable, even if assistance is unsuccessful. Indeed, concern about vicarious liability was one of the factors contributing to the decision by FEMA and other United States agencies to refuse

any international offers of certain types of aid, including blood products, medical kits, and most search and rescue personnel arriving to assist the people affected by Hurricane Katrina. The fear of being sued in association with providing aid has also generated reluctance to accept aid.

Reluctance to accept aid may arise with respect to assistance based on satellite remote sensing as well. The close examination of the Good Samaritan Principle in association with the Indian Ocean Tsunami lawsuit case and the Disaster Charter has reaffirmed the need for establishing a clear liability regime applicable to the operation of systems and data provision. Establishing a more comprehensive legal regime that clarifies responsibility and liability would mitigate unwillingness and hesitation, and facilitate data supply as both donors and beneficiaries would then be able to accept or provide data without concern for the outcome of the assistance.

National Laws and Policies

As noted earlier, the *corpus juris spatialis* provides the general framework for member states to regulate national space activities through more specific rules. National laws are the concrete implementation of Article VI of the Outer Space Treaty, which requires the authorization and continuing supervision by the appropriate state party of the national activities conducted by its non-governmental entities. The provision, in reality, requires national licensing and regulatory legislation; in fact, domestic legislation devoted to space activities has been endorsed in several nations.

National Legislation on Space Activities:

Currently, states that possess national space legislation relating to space activities include: the United States[10], Sweden[11], the United Kingdom[12], Russia[13], South Africa[14], Ukraine[15], Hong Kong[16], Australia[17], Belgium[18], Korea[19], the Netherlands[20], Japan[21], and France[22].

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10 National Aeronautics and Space Act, Public Law 85–568, 85th Congress, H.R. 12575, 29 July 1958, Commercial Space Launch Act, Public Law 98–575, 98th Congress, H.R. 3942, 30 October 1984, Land Remote Sensing Commercialization Act, Public Law 98–365, 98th Congress, H.R. 5155, 17 July 1984, Land Remote Sensing Policy Act 1992, Public Law 102–555, 102nd Congress, H.R. 6133, 28 October 1992.

11 Act on Space Activities 1982: 963, 18 November 1982. [Hereafter: Swedish Space Act].

12 Outer Space Act, July 18, 1986, 1986 Chapter 38. [Hereafter: UK Outer Space Act]

13 Law of Russian Federation on Space Activity, August 20, 1993, Presidential Edict No. 185. [Hereafter: Russian Space Act]

14 Space Affairs Act, September 6, 1993. [Hereafter: South African Space Act]

15 Ordinance of the Supreme Soviet of Ukraine on Space Activity Law of Ukraine, 15 November 1996. [Hereafter: Ukrainian Space Act]

16 Outer Space Ordinance of 1997, 13 June 1997.

17 Space Activities Act, December 21, 1998, No. 123. [Hereafter: Australian Space Act]

18 The Law of 17 September 2005 (Belgian Official Journal of 16 November 2005) on the Activities of Launching, Flight Operation or Guidance of Space Objects.

19 Space Exploration Promotion Act, 1 December, 2005. [Hereafter: Korean Space Exploration Promotion Act]

20 Rules Concerning Space Activities and the Establishment of a Registry of Space Objects, 13 June 2006. [Dutch Space Activities Act]

21 Basic Law for Space Activities adopted 13 May 2008.

The fundamental role of national legislation is to provide a regulatory means for a government to authorize actors under its jurisdiction to engage in space activities and to exercise control over them. By and large, rules established by national legislation comprise the concrete obligations under Articles IV, VII, and VIII of the Outer Space Treaty – namely, measures for authorization, continuing supervision, sanctions, responsibility, and liability, as well as for exercising jurisdiction and control through the registration of space objects. It is common that authorization is given through a permit or license to conduct space activities, particularly regarding launch operations; the government supervises continuously to ensure that licensed entities are in compliance with the requirements established under such licenses. This section examines the scope of government authorization for, and continuing supervision of, space activities carried out by domestic actors.

Scope

The scope of space activities covered under domestic laws of different countries varies by legislation, but primarily extends to one or a combination of the following: 1) launching of a space object and/or operation of a launch facility; 2) operation of a space object in orbit; and 3) conducting any other activities in outer space. Domestic law is less likely to apply to simply manufacturing a satellite or receiving signal from a satellite at the ground station.

Generally speaking, national space legislation applies to space activities carried out by nationals, and those space activities that take place from its territory – including activities conducted by foreign nationals. A noteworthy example that is distinctive from others is the United States. In contrast to other states, the United States requires licenses from foreign persons even if they conduct space activities from outside US territory or areas outside its jurisdiction if the controlling interest is held by either US nationals or entities incorporated under US law. In addition, foreign nationals need to obtain a license in cases where there is an agreement between the United States and a foreign state stating that the United States exercises its jurisdiction over a specific activity such as launching operation. In this way, the US Commercial Space Launch Act illustrates how the terms ‘national activities ’and ‘appropriate state party ’can be broadly interpreted in the national context.

Authorization:

Authorization is required for entities wishing to carry out space activities if required under domestic law of the state whose jurisdiction covers the activities of the entities in question. Although not always stated explicitly, in accord with the ‘appropriate state party ’language of the Outer Space Treaty, authorization appears to be required from a single jurisdiction even if an activity may fall under multiple jurisdictions. For instance,

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[22] French Law on Space Operations, Act no. 2008–518 du 3 juin 2008 [Hereafter: French Space Operations Act]

the UK Outer Space Act states that a license is not required "for activities in respect of which it is certified by Order in Council that arrangements have been made between the United Kingdom and another country to secure compliance with the international obligations of the United Kingdom."261 In Australia, with regards to overseas launches, space legislation states that overseas launch requires an overseas launch certificate if "a space object is launched from a launch facility located outside Australia and the launch is not authorized by an overseas launch certificate held by any person; and an Australian national is a responsible party for the launch."

Whilst there are several elements required for authorization, this section focuses primarily on the discussion of liability and financial aspects, specifically a regime of reimbursement, a regime surrounding third party loss, and a regime surrounding inter-party liability.

Given the high risk of space activities, financial capability of a licensee – particularly in terms of preparedness for liability – is one of the essential elements needed for government authorization. Since the responsibility for national space activities falls upon states, states seek certain security in the event of accident or negligent failures. Accordingly, a state has an imperative to properly arrange the measures for reimbursement between the state and entities that are subject to its jurisdiction and control. Most of the time, domestic legislation – as endorsed by the United Kingdom, the Netherlands, Sweden, and France– requires indemnification for the loss caused by the licensee to the government when the respective state is held internationally liable under the scope of the Liability Convention. More often than not, failure occurs during a launching phase, so an agreement between a government and a launch operator is not uncommon. For instance, with regard to a launch by an Ariane rocket, it is agreed that Arianespace would be required to reimburse the French government up to a maximum of € 60 million. This was the practice for years in Ariane operations and the approach seen in the agreement was codified into the French Space Operations Act, which states that in case the government paid compensation for damage, it may then present a claim for indemnification against the operator that caused the damage for which France was held internationally liable – to the extent that the government has not already benefited from the insurance or financial guarantees of the operator up to the amount of the compensation. As commercial launch services emerge and grow in an increasing number of states, such an arrangement or domestic law referring to the rule is deemed essential and likely to proliferate in the future.

As a reasonable measure to prepare for risks, some states such as Australia, Russia, Ukraine, Korea, and the Netherlands make a compulsory insurance regime part of their licensing requirements. Most compulsory insurance is coverage for a third party loss; thereby, a state secures de facto a measure of protection in case of failures. The United States has a detailed liability regime applicable to launch operations. The Commercial Space Launch Act requires the licensees either to purchase insurance or demonstrate financial capability so as to cover the potential third party loss. The maximum amount of

obligation a licensee owes for the third party loss is US$ 500 million, and US$ 100 million with respect to the loss of or damage incurred to government property. On the other hand, the government would pay up to US$ 1.5 billion for damages that exceed US$ 500 million insofar as the damage was not due to wilful misconduct of the licensee. The French Space Operations Act takes a similar approach by obliging licensees to obtain insurance or another financial guarantee whilst placing a ceiling on the maximum amount that operators need to pay for third party loss during the launch phase. Claims by the government to operators for indemnification are limited to that amount: operators can benefit from the state guarantee if the amount exceeds € 60 million. This state guarantee - that is, reimbursement of indemnifications by the government if liability exceeds € 60 million – is also available in the cases where operators are sued in any court.

Inter-party liability is less addressed within a legislative context; rather, it is tailored to each contractual agreement. Some legislation, however, does address and refer specifically to this matter, such as the US Commercial Space Launch Act and the French Space Operations Act. The Commercial Space Launch Act contains a reciprocal waiver of liability regime that applies to all the parties involved in a launch, including the government, any of its agencies, licensee, contractors, subcontractor, customers, and their contractors and subcontractors. Likewise, the French regime holds inter-party waiver of liability in case of damage to a person taking part in the space operation or the production of space object(s) except in the case of wilful misconduct.

Even if it is not established in legislation, the stance taken by the parties engaged in launch activities is to waive liability amongst them. For instance, ESA agrees to waive all claims for compensation against France as far as these claims result from launch operations at the Centre Spatial Gyuanais. This minimizes the risk of inter-party claims. The practical tendency in the exercise of inter-party waiver of liability logically follows the rule of the Liability Convention, which does not offer protection for damage incurred to persons participating in the launch.

For the most part, the government's intention is to minimize the potential cost incurred in the instances of its international liability resulting from irresponsible operations of national actors, as well as in the instances of loss incurred amongst the concerned parties. These measures help the concerned parties to quantify properly the involved risk.

Continuing Supervision:

Continuing supervision is more complex and difficult to exercise. The term infers the obligation to 'keep an eye 'on the authorized person after the initial authorization. Continuing supervision can well be associated with the monitor- ing and control of the licensed entity and launched space object that are subject to the jurisdiction of a particular state. This part reviews the measures for monitoring compliance with licensing conditions, sanction, and control of a space object, as related to registration.

Overall, national legislation attempts to control licensees through monitor- ing their compliance for license requirements and, in case of non-compliance, suspend or revoke

the license. In South Africa, the United Kingdom, and Sweden, licenses may be withheld if the licensing requirement is breached. Conditions for suspension differ in each state, but they all perform a function of continuous supervision and regulation of the licensed activity. In the case of South Korea, the license is withheld if the launch does not take place within one year from the scheduled launch date. as launch delays are frequent. This may be a stringent condition, Continuing supervision of national space activities and control of a space object can also be enforced through punitive measures. Some states specifically provide measures for sanctions in case of breach of the provisions of the legislation. The type of sanction imposed is usually fine or imprisonment, or both. For instance, the Swedish Space Act establishes that persons conducting space activities without a license, whether wilfully or through negligence, are fined or sentenced to imprisonment for up to one year. The US Commercial Space Launch Act holds any person convicted of committing a prohibited act liable for civil penalties of not more than US$ 100,000 per day for each violation. A fine imposed in such a manner generates great incentives to offenders to cease the prohibited act immediately. Sanctions serve as a powerful incentive for actors to refrain from engaging in space activities without authorization from the appropriate jurisdiction, as well as for licensees not to breach licensing provisions.

Continuing supervision can be exercised through control over a space object based on the registration of that space object established by Article VIII of the Outer Space Treaty. Several nations including Ukraine, Russia, Australia, the Netherlands, and Korea require the registration of space objects and have established a national registry in accordance with the Registration Convention. Pursuant to the Registration Convention that obliges state parties to register domestically, national space legislation establishes a mechanism of state registry with more specific rules as to how the domestic registration of a space object takes place. There are two major rules with regard to registration established under the Registration Convention: control of a satellite to be exercised effectively by a state of registry – that is, usually the launching state – and prohibition of double registration; both are incorporated into national space legislation.

In reality, with the increasing lifespan of satellites, conceptual separation between the launching and operational phase of a satellite is feasible; the gap is growing between the law and practice. The situation is even more complicated recently with the cases of lease or transfer of ownership in orbit, including sale of a spacecraft after it is placed in orbit. Such complexities could give rise to at least five different possibilities for the status of a satellite in terms of its link with a launching state, state of registry, and controlling state, as shown in the table below:

Table:1: Possible Status of Satellites with Different Types of Configurations

Launching State	State of Registry	Controlling State
A	A	A
A	A	B
A	B	B
A	B	A
A	B	C

*A signifies as state A, B signifies as state B and C signifies as state C.

The first case A-A-A is the orthodox situation that is assumed under the Registration Convention – A single launching state registers and controls the launched space object. The second case, A-A-B, would be best explained by a situation of a lease of a satellite. State A launched, and registered the launched space object, but later leased it to state B; therefore, state B controls the space object, even though state A still owns it. The A-B-B case could be illustrated by the situation that would involve certain transfer of ownership after the launch. The foremost example is the sale/purchase of a satellite in orbit. State A launched the space object and later transferred its ownership to state B, which re-registers and controls the object. For the A-B-A case, one can envisage a scenario as follows: State B, a developing state, bought a satellite in orbit from state A, a developed state. Later, from a technical reason, state B becomes no longer able to control the space object; state A agrees to resume the operation for the benefit of state B. The last A-B-C case could be explained by the combination of a transfer of ownership of a satellite from state A to state B, who then leases it to state C.

The above described situations are not at all hypothetical. In reality, there have been cases where an original state of registry does not exercise jurisdiction and control over a space object later in the operational phase due to its change of ownership. Such examples concern four communication satellites returned from the United Kingdom to China in accordance with the return of Hong Kong. Following the return of Hong Kong on 1 July 1997, the United Kingdom informed the United Nations on 27 March 1998 that it was no longer the state of registry and then requested an amendment to the UN registry as well as removal of those satellites from its national registry. Even though a launching state is no longer linked with a state of registry, this case is relatively simple because jurisdiction and control is transferred along with the change of ownership so that only one state of registry exists for those satellites in orbit. This case illustrates the A-B-B scenario in the table above.

A more complex situation exists when jurisdiction and control may be exercised by more than one state. An example of such a case concerns a broadcasting satellite BSB-1A. BSB-1A was originally registered by the United Kingdom in 1990, but purchased in orbit

by Sweden in 1996. n contrast to the case discussed above, although Sweden registered BSB-1A nationally as Sirius-1 in 1999 and notified the United Nations with specific mention of the United States as the launching State, the United Kingdom did not remove BSB-1A from its registry. Therefore, BSB-1A is 'doubly 'registered, and this creates a situation that is not envisaged by the Registration Convention: the launching state is the United States; the state of registry is both the United Kingdom and Sweden; and the controlling state is Sweden. This situation is a slightly complicated version of the A-B-C case; that is, the state of registry is really two states, B/C rather than just state B. The cases like BSB-1A diminish the effectiveness of the control regime established by the Registration Convention.

Not only was the BSB-1A type of situation not addressed under the Registration Convention, there is no national legislation at present that adequately fills the existing gap – particularly with regard to either leasing or the transfer of ownership of a space object and the subsequent impact on the juris- diction and control over the space object. The ongoing and future practice of lease, sale, and transfer of ownership of a satellite may require adaptation of the rule in accordance with the practice at a domestic level.

Overall, there is no national legislation addressing how the responsibility associated with a space object are divided between the concerned parties when the state of registry and the state that actually controls the space object are different. Such cases may be increasingly common in the future, and there is a need for further clarification.

Finally, national legislation is inadequate to address how control by the state of registry over its space object should take place. The obligation to exercise jurisdiction and control by the state of registry is particularly relevant to remote sensing since information acquired by the satellite affects the interests of both the state and the international community. Increasingly, states with remote sensing capabilities are adopting laws and/or policies to control the data collection and subsequent dissemination. The next section reviews those regulations relevant to remote sensing and analyses the overall tendencies and implications for remote sensing activities.

National Regulations Associated with Remote Sensing:

National regulations addressing space activities in general are written to implement concrete measures for continuous supervision of the actors under a government's jurisdiction. A similar role is performed by national regulations on satellite remote sensing. There are two main purposes for governmental control of remote sensing activities imposed on commercial remote sensing satellite systems: 1) to protect national security by denying or restricting access to information; and 2) to guarantee that the government has priority access to the system's capabilities during times of crisis. The measures taken to achieve these goals can be divided into restrictions on data collection and/or data dissemination. This section first examines those states that have legislation specialising in remote sensing, and then reviews other states that have adopted certain policies with regard to data collection and dissemination.

Although some provisions of national space legislation addressing launching and general space activities have some implications on satellite remote sensing operations, generally speaking, existing domestic legislation on space activities does not address properly the rules applicable to remote sensing. Corresponding to the emergence of private actors and commercial remote sensing satellites, the United States, Canada, Germany, and France have established specific regulations/legislation devoted to remote sensing from space. It is notable that amongst these, the legislation of Canada and Germany addresses solely the matters regarding satellite remote sensing, whilst neither country possesses domestic legislation addressing overall space operations. The existing legislation on remote sensing authorizes and controls the actors.

The United States

As stated earlier, the United States has enacted several pieces of space legislation, one of which is dedicated to remote sensing activities. The legislation on remote sensing has evolved in accordance with the trends surrounding remote sensing from space, particularly reflecting advances in technology and market development as well as changing policies. Compared to legislation from other countries, US legislation addresses practical matters such as data policies as well as measures of protection to maintain the competitiveness of domestic actors.

Looking at the historical evolution of US laws and policies associated with remote sensing, the major rationale for making both law and policy reflects the government's striving to maintain the leadership in this field whilst safeguarding national security and foreign policy interests. Starting its operation in 1972 under the auspices of NASA, by the late 1970s the United States started to consider privatizing the Landsat system. That attempt was codified into the Land Remote Sensing Commercialisation Act of 1984. This Act was adopted to commercialise the Landsat programme by transferring remote sensing operations to the private sector. The Earth Observation Satellite Corporation (EOSAT), a partnership of Hughes Aircraft and Radio Corporation of America (RCA), was selected as the executor of the project to commercialize Landsat under a ten year contract. The original plan was to delegate a private sector operation of the Landsat system that would become commercially viable through data sales and then to develop the successive Landsat series on a private-sector-driven basis. Commercialisation did not progress as planned because of the sharp increase in data price which resulted in a sharp drop in data needs. Coupled with the 1986 emergence of the powerful competitor, SPOT, which benefited from funding by the French government – and the significant market share attained by SPOT soon afterwards – the United States relinquished the attempt at commercialization.

Having experienced the unsuccessful attempt to privatize Landsat, at least in the short term, the US government was compelled to return to the regime to support the Landsat system. The Land Remote Sensing Commercialisation Act of 1984 was then supplanted by the Land Remote Sending Policy Act in 1992. The 1992 Land Remote Sensing Policy Act gave the operation of Landsat back to the public sector under the Department of

Defense (DOD) and NASA, whilst leaving the licensing authority under the Secretary of Commerce through NOAA.

In the longer term, United States had not renounced its plan for commercialization. The strategy was to let the public recognize the value of the Landsat data. In the Land Remote Sensing Policy Act, availability and affordability of Landsat data was set up to diffuse its utility. Cost hurdles based on the market price were lifted and a standard for pricing of unenhanced data was established. The Act states that "to maximize the value of the Landsat program to the American Public, unenhanced Landsat 4 through 6 data should be made available at a minimum to US agencies, to global environmental change researchers, and to other researchers who are financially supported by the US government at cost of fulfilling user requests, and unenhanced Landsat 7 data should be made available to all users at the cost of fulfilling user requests." Furthermore, US government and affiliated users could access the unenhanced data at a reduced rate.

In an attempt to stimulate the development of the commercial market, exclusive rights for Landsat data sale were no longer granted to a single entity. Under the Land Remote Sensing Policy Act, a data policy for Landsat 7 was set to allow competition within the private sector for distribution of unenhanced data and value added services. This provision assumes the possibility of competition amongst different licensed entities that provide unenhanced data and, particularly, value added services at a non-uniform price. The Act emphasizes that the license application should not be rejected on the basis of protection of existing thus permitting data collection and sale of licensees from competition, Landsat data worldwide.

The Land Remote Sensing Policy Act addresses the issue of licensing for the operation of private remote sensing systems. The Act anticipated that commercial players would operate remote sensing systems other than the Landsat and undertake subsequent data dissemination. The Act required persons under US jurisdiction and control to obtain a license to operate private remote sensing systems. Conditions of operation were imposed on licensees carrying out the operation in a manner to preserve US national security, to make unenhanced data available to the government of any country, and to inform the Secretary of Commerce on both the characteristics of the system and any intentions of conclusing agreements with foreign states. The Act contains an enforcement mechanism similar to that in the aforementioned Commercial Space Launch Act, but the penalty is much lower – US$10,000 per day per violation.

The 1992 Land Remote Sensing Policy Act remains as the principal legislation governing US remote sensing activities today and serves as an overall framework, updated, complemented, or implemented concretely by relevant policies and regulations, namely: Presidential Decision Directive 23 (PDD-23); the US Policy on Foreign Access to Remote Sensing Capability;303 the Kyl- Bingaman Amendment to the 1997 National Defense Authorization Act; the 2003 Commercial Remote Sensing Policy; and the 2006 Regulation on Licensing of Private Land Remote Sensing Space Systems. The following

chronological progression of law and policy developments serves to capture the essential transitions in the field of remote sensing in the United States.

In 1994 PDD-23 was announced, recognizing the emergence of non-US remote sensing capability and the need to ensure continued US industrial competitiveness in the global arena. The objective of PDD-23 is roughly three- fold: 1) to relax restrictions placed on data sale; 2) to clarify the operational regime of Landsat; and 3) to specify national security measures as a licensing requirement. As to the first objective, PDD-23 addressed the question of which agency develops and operates the Landsat system and markets the resulting data by establishing an operational regime for Landsat that delegates different operations to three agencies: the operation of satellites is conducted by NOAA; archiving and distribution is conducted by the US Geological Survey under the Department of the Interior; and the development of satellites is conducted by NASA.

As to the second objective, in order to allow the national actors to compete internationally, PDD-23 – for the first time – allowed US entities to sell satellite images up to one metre ground resolution. PDD-23 relaxed the restrictions, encouraged the sale of high resolution data services from US providers, and even permitted the export of turnkey systems and sensitive components on a case-by-case basis, subject to export controls and requirements for government-to-government agreements.

As to the last objective, a concrete measure was taken toward ensuring US national security and foreign policy interests. An explicit provision to justify the interruption of operation, which is known as 'shutter control', was introduced: "[W]hen national security or international obligations and/or foreign policy may be compromised as defined by the Secretary of Defense or the Secretary of State, respectively, the Secretary of Commerce may after consultation with the appropriate agencies, require the licensee to limit data collection and or distribution by the system to the extent necessitated by the given situation." This provision remains today to be invoked and enforced if necessary.

An earlier provision of the Land Remote Sensing Policy Act on a licensee's obligation to preserve US national security and foreign policy interests was implemented concretely with the Kyl-Bingaman Amendment to the 1997 National Defense Authorization Act. The amendment prohibits licensees from disseminating imagery of Israel that is more detailed or precise than what is available from foreign commercial sources. This section on prohibition of collection and release of detailed satellite imagery relating to Israel states that "A department or agency of the United States may issue a license for the collection or dissemination by a non-Federal entity of satellite imagery with respect to Israel only if such imagery is no more detailed or precise than satellite imagery of Israel that is available from commercial sources."

At present, limitation of spatial resolution is implemented through a two-tiered policy. Electro-optical imagery of 0.5 meters can be marketed generally, whereas imagery higher than 0.25 meters can only be disseminated with specific authorization to recipients individually authorized by the US government. For the latter case, before such

authorization is granted to a US firm, the State Department must first obtain assurances from the foreign government that the imagery will not be disseminated further without authorization. It is worth noting the policy for implementation of de facto shutter control. This policy is known as 'buy to deny 'because all the data for specific locations was bought up by the government to hamper the access to data by any other users for a certain period of time. The notable example is the invocation of this policy in 2001 when US Federal agencies essentially restricted access to satellite imagery over Afghanistan by acquiring exclusive rights to all IKONOS satellite imagery.

Realizing that remote sensing was not yet commercially viable, the United States recognized the need to actively support its national remote sensing actors and to foster the industry. In 2003, the US government issued a Commercial Remote Sensing Policy that supersedes the earlier PDD-23. The objective of the 2003 Commercial Remote Sensing Policy was to enhance the competitive- ness of national actors by freeing restrictions as well as supporting the national remote sensing industry.

The 2003 Commercial Remote Sensing Policy further realizes the deregulation of the earlier PDD-23. The policy has taken away the restrictions on spatial, spectral, and radiometric resolution and encourages US companies to build and operate commercial remote sensing systems, inferring the favourable review of license applications.

The key feature of the 2003 Commercial Remote Sensing Policy is the enhancement of governmental reliance on US commercial remote sensing capabilities. The policy states that the US government will "rely to the maximum practical extent on US commercial remote sensing space capabilities for filling imagery and geospatial needs." The policy also states that the US government should fill the gap only "if fulfilling their data needs cannot be effectively, affordably, and reliably satisfied by commercial providers." This confirms the government's intention to become a major customer for data from US private remote sensing systems.

In order to implement the policy concretely, the 2003 Commercial Remote Sensing Policy calls for the establishment of the National Imagery and Mapping Agency (NIMA) that is responsible for acquisition and dissemination of data for national security and foreign policy requirements to enhance the governmental reliance on US commercial remote sensing capabilities. The 2003 Commercial Remote Sensing Policy is clearly aimed at encouraging operations of domestic commercial remote sensing actors through deregulation and the 'data buy 'approach.

To effectively implement the 1992 Land Remote Sensing Policy Act on private actors, the United States adopted the Licensing of Private Land Remote Sensing Space Systems in 2006 (Remote Sensing Licensing Regulations). This latest licensing regulation endorses detailed procedures for licensing terms and conditions, review procedures, and monitoring compliance pursuant to the provisions related to the US Remote Sensing Licensing Regulations under the Land Remote Sensing Policy Act.

In addition to the first time authorization to operate remote sensing systems, any new actions are closely monitored. The regulation requires a license holder to file an application in case of amendment to the license as well as to notify when a license holder intends to enter into an agreement with any foreign nation or foreign entity. Moreover, the regulation requires licensees to undergo an annual audit, as well as to record their data for one year and report on the data acquisition and dissemination related to Israel.

Audits are undertaken annually to review compliance with licensing conditions and changes associated with the licensee. The licensees are obligated to report at different time frames: 12 months before launch; six month prior to launch; when the system is in operation; and every three months afterwards. Specifically, the regulations implement shutter control measures on a regular basis: four times a year, licensees are obliged to report on estimated resolution of all images collected and disseminated on the state of Israel. The Licensing Regulations require licensees to keep all records and data from the previous 12 months, including tasking information and associated metadata. Under the requirement, the government is able to ascertain the time and locations of images collected from private remote sensing systems. This close monitoring mechanism enables the systematic and regulated control on different satellites operated by different entities.

Another notable provision of the Remote Sensing Licensing Regulations establishes data policies that take satellite funding mechanism into account. The Regulations distinguish three different situations: 1) remote sensing systems that are not funded by the US government; 2) systems that are partially funded by the US government; and 3) systems fully or significantly funded by the US government. As to the non-government- funded systems, a licensee is allowed to provide access to its unenhanced data at reasonable commercial terms and conditions, subject to the requirement of providing data to the government of any sensed state. As to the systems that are partially funded by the US government, it will be determined "whether the interest of the United States in promoting widespread availability of remote sensing data on reasonable cost terms and conditions requires that some or all of the unenhanced data from the system be made available on a non-discriminatory basis in accordance with the Act." For fully or significantly funded systems, a licensee is required to make all data available on a non-discriminatory basis.

Canada

Canada, like the United States, has comprehensive domestic law relating to remote sensing – specifically, an Act governing the Operation of Remote Sensing Space Systems (hereafter: the Remote Sensing Space Systems Act) complemented by the Remote Sensing Space Systems Regulations that implemented the detailed rules of the Act. Whilst the law was adopted in 2005, steps to formulate certain rules on satellite remote sensing date back to the late 1990s. The rationale behind the formulation of rules lies in the planned change in the operational regime of a Canadian radar satellite system, RADARSAT, which was first launched in 1995. Following the success of RADARSAT-1 – owned and operated by the Canadian government – Canada decided to increase the private sector involvement in its remote sensing missions starting with RADARSAT-2.

Since RADARSAT-2 was funded by the private sector, the government of Canada was forced to consider the need for legally established controls on the collection and dissemination of data, which were not required in the case of the earlier RADARSAT-1 system. The first legal instrument for establishing rules on satellite remote sensing was the conclusion of a bilateral agreement between Canada and the United Stated, the Agreement between the Government of Canada and the Government of the United States of America Concerning the Operation of Commercial Remote Sensing Satellite Systems, in 2000.

The Remote Sensing Space Systems Act regulates the overall activities of remote sensing actors through licensing and continuous supervision using measures of enforcement of regulations such as inspections by the authorities, and imposition of sanctions.

The scope of the Act is broad: it applies to public, private, and public-private systems; this means that the Act not only applies to commercial satellites, but also covers satellites of the Canadian Space Agency (CSA) as well as other governmental satellites. The coverage for 'public 'systems exists because commercial operations under the framework of CSA and the government remain subject to the data distribution controls set by the Minister of Foreign Affairs. The intended use of a satellite is irrelevant to the application of the Act;332 hence, the Act could apply to dual use satellites. The fact that the law applies to public systems is distinctive, as most domestic legislation is intended to regulate only private and public-private systems.

The wide scope of this Act is evident in other aspects as well. A 'remote sensing satellite ' is defined broadly as "a satellite that is capable of sensing the surface of the Earth through the use of electromagnetic waves," and satellites that are subject to control include satellites with optical, radar, thermal infrared, multi-spectral, and other types of sensors. Application of the Act is not limited to high resolution satellites; furthermore, it applies to operations from inside and outside Canada. As to the operation outside Canada, the law is applicable to certain persons such as 1) Canadian citizens; 2) permanent residents; 3) Canadian corporations; and 4) classes of persons as maybe specified in the Regulations.

Whilst the Act holds virtually every possible Canadian remote sensing system within its scope, the Minister of Foreign Affairs is authorized to exempt any persons, satellite systems, or data, on an individual or class basis from any or all aspects of the licensing regime. This exemption would avoid the situation where the Canadian government unnecessarily exercises jurisdiction over operations that are primarily in the hands of other states. With respect to the operation of remote sensing satellite systems by CSA or the Department of Defense, the Governor in Council may issue an order to adapt the provision of this Act or the regulations. It is anticipated, therefore, that the operation of a purely governmental satellite could be excluded from the application of the Act at any time. In this way, Canada takes the approach to first cover all potential remote sensing activities that may fall under Canadian jurisdiction, and can later make exemptions to the Act on a case specific basis.

The Remote Sensing Space Systems Act establishes a licensing regime to authorize persons under the jurisdiction of Canada to carry out remote sensing activities. Licenses are granted by the Ministry of Foreign Affairs and can be amended, suspended for a period of up to 90 days, or cancelled at the discretion of the government. Conditions include licensee compliance with restrictions that may be placed upon communication of raw data from the licensee to any persons other than the licensee, as well as on the provision of remote sensing products from the licensee to any persons other than the licensee.

A large portion of the Act is devoted to the obligations of the licensee and rights of government in relation to managing the operation of the remote sensing system and control of subsequent data distribution. In fact, the government can issue orders in order to exercise governmental control of operations. One such order concerns the licensed person's obligation to follow measures deemed appropriate by the government upon the cancellation or suspension of a license considering the national security and system disposal plan. Others concern interruption of service and priority access. For the orders described here, opportunity for making representation within a limited period of the receipt of the notice of an order is granted to licensees.

The Act establishes the government's right to interrupt remote sensing services by actors subject to the jurisdiction and control of Canada. Both the Minister of Foreign Affairs (hereafter: the Minister) and Minister of Defence may order a licensee to restrict or interrupt any operation for a specified period if the Minister believes that continuation of that operation would harm the national interest of Canada. The Act is silent as to the specific spatial resolution subject to the interruption of service by the government. As to the concrete measures of restriction, it is understood that a licensee is not required to stop data collection and distribution, but the distribution could be delayed, and the spatial resolution of data may be reduced as well. Since such restrictive measures could affect commercial business operations, interruption of service is only invoked at a ministerial level and only in the rarest of circumstances.

The Canadian government retains the right of priority access to the data. Priority access to services means that the Act permits the Minister, the Minister of Defence, and the Minister of Public Safety and Emergency Preparedness to order a licensee to provide any remote sensing service to the government of Canada for the purpose of international relations and national defence interests of Canada. More specifically, priority access to service is available to her Majesty, the Royal Canadian Mounted Police, and to the Canadian Intelligence Service. The Act guarantees the Canadian government's right to priority access to data in case of emergency. Whilst it is anticipated that priority access will not be invoked regularly, it could be invoked more frequently than shutter control, since priority access can be invoked at the Deputy Minister level.

Whilst the government may cover the cost associated with priority access, no right to compensation is granted to a licensee against the government for any financial losses resulting from actions taken in good faith by the government under this act. Such actions

include: amendment of a system disposal plan; amendment, suspension, or cancellation of a license; ordering licensees to take measures upon cancellation or suspension of a license; interruption of service; and priority access. Hence, the government is not liable for the loss suffered by licensees unless the government intentionally caused such loss.

The Remote Sensing Space Systems Act establishes how continuing supervision by the governmental authority is exercised effectively through operations by inspectors and enforcement officers. The Act authorises inspectors designated by the Minister to enter and inspect, at any reasonable time, any place owned by or under the control of a licensee, a system participant, or any other person who may be carrying on a controlled activity in the operation of a remote sensing space system. An inspector then could serve as an enforcement officer, and may issue a notice of violation in any case in which he believes there are reasonable grounds that a violation has been committed.

The Act has a detailed enforcement mechanism. There are two levels of breach of the provisions of the Act: one is 'violation 'and the other is 'offence'. Violation is not a criminal act and a licensee is entitled to make representation upon a notice of 'violation ' within 30 days, whereas a licensee who commits an offence is liable on summary conviction with no reference to the opportunity to respond. Whilst a violation may concern the breach of any of 43 provisions of the Act and regulations, an offence concerns only four provisions: 1) operation of satellite systems without a license; 2) letting a person outside Canada command the satellite; 3) not complying with the Minister's order to take measures upon suspension or cancellation of a license; and 4) not complying with the Minister's order with regards to interruption of service.

Sanctions for breaches of the Act are set at two tiers. Any individual committing a violation will be fined up to $ 5,000; the fine is $ 25,000 for other cases. It should be noted that the amount is imposed per day and adds up as long as the violation continues. This approach is equivalent to that taken by the US Land Remote Sensing Policy Act. By contrast, a person guilty of an offence can be fined up to $ 50,000, receive 18 month imprisonment, or both. In other cases, most notably, a juridical person committing an offence is fined up to $250,000. Certain illegal acts are regarded as both violations and offences, but a person cannot be charged for the same act first as a violation and again as an offence.

Germany:

Germany, without a launch site in its territory, had no pressing need for developing domestic space legislation. This changed, however, with the development of high resolution remote sensing satellites and private sector involvement. In fact, the drafting for a law specific to remote sensing from space began during the implementation of the first large scale Public-Private Partnership (PPP) in the field of Earth observation, TerraSAR-X. Drafting for the German Act on Satellite Data Security, *Satellitendatensicherheitsgestz*, came into force on December 1, 2007. The law established governmental control over collection and dissemination of data from high

performance remote sensing satellites to minimize any threat to the security of Germany and the security of other nations.

The German Act on Satellite Data Security applies to 1) the operation of high-grade remote sensing systems; and 2) the handling of data generated by a high-grade remote sensing system. A 'high grade remote sensing system 'is defined as "a space-based transport or orbital system, including the ground segment, by means of which data about the Earth are generated, where its sensor is itself/sensors are themselves technically capable either alone or in combination with one or more other sensors of generating data with a particularly high information content within the meaning of Paragraph 2." Information content must be determined according to 1) geometric resolution, 2) spectral coverage, 3) the number of spectral channels and the spectral resolution, 4) the radiometric resolution, and 5) the temporal resolution. In addition, the information content of microwave sensors or radar sensors must also be determined according to the polarization characteristics and phase history. The German Act on Satellite Data Security limits its scope to high grade remote sensing systems and appears to exclude its application to low resolution satellites. The Act applies to both the operation of high-grade earth remote sensing systems and to the handling of data generated from those systems by: a) German nationals – juridical persons or associations under German law; b) foreign juridical persons or associations of foreign nationals having their head office within the territory of Germany; and c) if the command to the system is given from the territory of the Federal Republic of Germany.

It is notable that the German Act on Satellite Data Security distinguishes between remote sensing system operators and data distributors, and imposes different types of authorization, respectively. Whereas the Act requires a remote sensing system operator to obtain 'approval', it requires a data distributor to obtain a 'license. 'Considering that other legal systems tend to have only one type of license – usually, for a system operator – it is unique to hold two distinctive types of authorizations related to remote sensing actors. This corresponds well to the growing tendency of separation between the satellite operation phase and operations related to data exploitation and distribution.

The approved and licensed persons share common obligations such as the duty to notify the responsible authority for any changes after the authorization; the duty to provide information requested by the authority; and the duty to let the responsible authority inspect the operations and undertake examinations. Furthermore, both remote sensing system operators and data providers have a duty to prioritize government requests in terms of generation and distribution of data. These governmental rights will be restricted to rare cases of crisis, and transaction costs can be charged to the government at a market price.

Obligation for documentation is distinct for system operators and data distributors. A system operator is required to record: command sequences to control the sensor, orbital, or transport systems; time and path of the command sequences; and details of encryption processes, and they must maintain the record for at least five years. For data distributors,

obligations with respect to duty of documentation seem much more detailed and burdensome. All data requests need to be recorded, regardless of their sensitivity. The information data distributors need to record are, among others: requesting party (ies) and their usual places of residence; procedure for, and the result of, sensitivity checks; data generation order; reports on the processing sequences of the ground segment; metadata – including the location of observation, time of data generation, sensor operating mode, and data processing parameters; and invoices. In short, a data distributor is obliged to record the precise detail of every transaction. Again, the records must be maintained for at least 5 years and need to be available for inspection.

When a data distributor wishes to comply with the data request, a sensitivity check is required. The sensitivity of the data request is determined by considering the elements of the information content of data, the location observed, who purchases the data, the country of destination, and the time between data acquisition and the processing of the data request. As to the information on the purchaser, the data provider must check the identity of the requesting party, as well as the names of the persons who necessarily come into contact with the data and their places of residence. Some areas are excluded for almost all the customers, for instance, military operation zones. This can be construed as ban on the data collection for customers rather than a ban on data dissemination.

The sensitivity check consists of a twofold process: first, to be performed by, and in the full responsibility of, the data distributor; second, to be conducted on a case-by-case basis by the Federal Office of Economics and Export Control. As to the first stage, evaluation of the sensitivity of a data request is undertaken by the data distributor in accordance with a set procedure and clearly established criteria with no room for discretionary assessment. If the data request is classified ‘not sensitive’, the data distributor is allowed to deliver the requested data without further approval from the government.

In case a data request is found to be sensitive as a result of the evaluation by the distributor, and yet the distributor wishes to proceed with the data request, the data distributor files an application for a permit to the Federal Office. The Federal Office then conducts a case by case review evaluating the risks involved in complying with the data request. A permit is required to comply with sensitive data requests, and cases where data are to be distributed without data request are treated likewise. The Federal Office issues a permit if the data request in question would not endanger the security of Germany. In case compliance with the data request is found to be risky, a permit may be conditionally granted through measures such as reduced spatial resolution of data, time delay, reduced processing quality of the data, or the avoidance of certain target areas. The flow for the evaluation of sensitivity and resulting action taken is depicted in the Figure 1. Although the government reserves its right to prohibit data distribution, approximately 99% of permit applications is usually granted; therefore, the restriction imposed on data distribution is considerable but not at the level to seriously disrupt the commercial operation. In addition, to avoid hampering the commercial transaction unnecessarily, the

fundamental policy is to limit the duration of a case specific review by governmental authority to maximum one month.

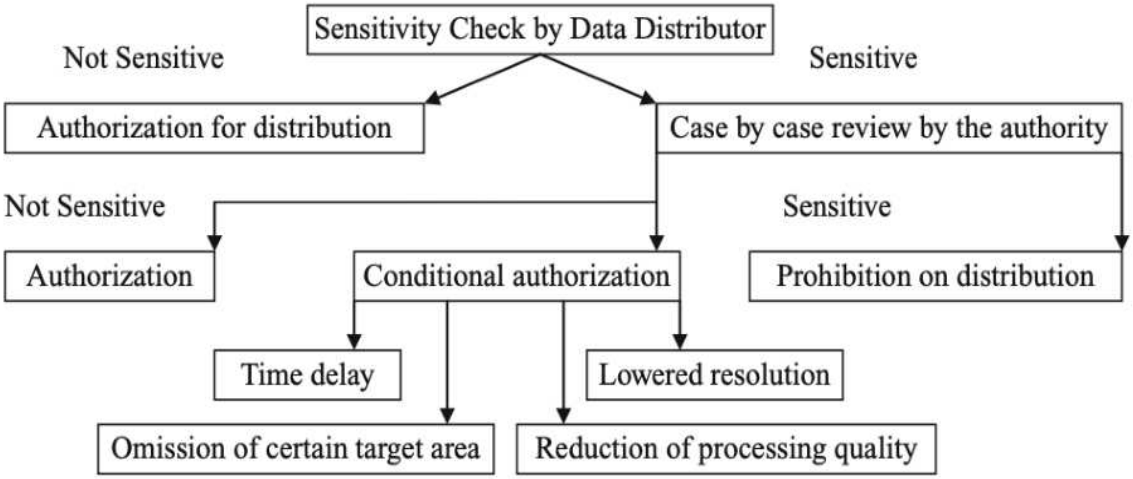


Figure:1 Flow of the Sensitivity Check and Resulting Actions

As is the case in Canada, the German government reserves its right of priority access to data in the event of an emergency. Data providers owe an obligation to prioritize in case of threat to German military and civilian forces in a foreign country or to foreign officers employed at German foreign embassies. These rights will be restricted to rare occasions of crisis.

Rules endorsed in the German Act on Satellite Data Security are enforced through sanctions. As to the form of sanctions, a three-tier penalty scheme is set depending on the type of offence. Offences can be categorized as either serious ones with heavier fines that may be replaced by sentence to imprisonment, or those that are less serious with lower fines. The highest fine of up to € 500,000 is imposed for offences such as: operating remote sensing system without permission; complying with a sensitive data request without permission; and distributing data without a permit. A fine of up to € 50,000 is imposed for offences such as failing to undertake the sensitivity check and conducting the check not using the designated procedure or conducting it incompletely. Any of the offences listed above in the first category may result in imprisonment up to five years instead of a fine. Finally, for those offences categorized as least serious, a fine of up to € 25,000 is imposed. Such offences include failing to provide the information requested by the authority as well as failing to report any changes that occurred after the issuance of license.

France:

Unlike many other states, France does not have a specialized law for remote sensing as such, but the French Space Operations Act addressing general spacecraft control includes Title VII (Title VII : Space-based Data) devoted to the issues of remote sensing operations and data dissemination control. Remote sensing activities are addressed only by three articles – Articles 23 to 25 in Title VII of this law – and provisions are fairly general. The

domestic French space law serves as an overall framework and is complemented by more detailed regulations in the form of decrees. The decree of 6 June 2009 supporting the applications of measures provided by Title VII of the French Space Operations Act389 effectuates the regulations of Title VII of French Space Operations Act, and articulates how rules are applied.

It is noteworthy that the part of French legislation addressing data control was developed separately by the Ministry of Defence, whilst the rest of the law was prepared by the Council of State, signifying the critical impact data collection and dissemination may have on national security. The scope of the legislation is limited to the natural or juridical person responsible for the programming of a remote sensing satellite or responsible for the collection of space-based remote sensing data. Therefore, mere data resellers and value added service providers that are not involved in the operation of the satellite or data collection are not covered under the legislation. Data from military spacecraft or data collected on behalf of the Ministry of Defence is excluded from the scope: it neither applies to activities of CNES nor to military applications. Title VII applies to data from panchromatic optical sensors, multi-spectral optical sensors, stereoscopic sensors, infrared, and radar sensors. A separate decree is to be adopted for further defining the data resolution, and the characteristics of precision.

Remote sensing data exploitation is subject to prior declaration to the Administrative Authority. It is clarified in the French Remote Sensing Decree, which states that the decree of 6 June 2009, which supports the applications of measures provided by Title VII of the French Space Operations Act, provides that the Administrative Authority is Secretary General for National Defence (SDGN). A declaration needs to be made at least two months prior to the starting of operations. In case the declaration is not in conformity with the regulations, or is incomplete, the authority asks the candidate to declare in a designated or complete manner.

Governmental control is exercised by declaration instead of through a license. Particular attention should be paid to French law adopting a system of a declaration. A declaration, which is a weaker form of a license, is closer to a notification than to an authorization. A declaration is a one-sided operation and implies that such a declaration will not be rejected – unlike the case of a license, which normally requires an application that is then granted or rejected upon review by the authority. No conditions to declare are articulated under the French Space Operations Act.

Title VII of the French Space Operations Act refers to possible restrictions on remote sensing actors to safeguard the national interest. Article 25 makes it clear that the Administrative Authority shall ensure that the primary operator of space-based remote sensing data does not interfere with the fundamental interests of the nation. Concrete measures of restriction are not specified, but there are historic incidents of suspension of data for a certain period, such as when France exercised the control of data dissemination by suspending Spot Image's data dissemination to Iraq during the Gulf War. In fact, a mechanism of control by the French government on commercial distribution has been

operational via GIRSPOT, an inter-ministerial working group that reports on the specific cases that trigger the restrictive measures. GIRSPOT is composed of representatives of SDGN: the Ministry of Foreign Affairs, Ministry of Defence, Ministry of Space, and CNES. Upon the recommendation made by GIRSPOT, the Prime Minister has the responsibility to impose limitation on Spot Image. Since operations of GIRSPOT remain confidential and the legality of data control implemented in its framework was questioned, the need arose for a law to formally address the issue. Incorporating rules associated with satellite remote sensing into French law on space operation will codify and implement the operational regime already in place and, at the same time, will address the issue of shutter control in a more official and transparent manner.

Types of restrictions considered to be implemented include: the immediate suspension on data distribution for a limited period of time; the obligation to delay the data distribution, and the permanent prohibition of data dissemination for certain locations. It is envisaged that locations such as nuclear plants in France, the location of French troops abroad (e.g., the Ivory Coast), or the location of allied troops abroad (e.g., US Army troops in Iraq) are most likely to be the targets for restrictions.

Finally, the French Space Operations Act has a concrete enforcement mechanism imposing a € 200,000 fine against a person that distributes data without a declaration, as well as those who do not comply with data restriction regulations. This is a civil penalty with no distinction between an individual, and other person (e.g., juridical person). One can conclude at this point that the French Space Operations Act is intended primarily to ensure governmental control of remote sensing activities and subsequent data distribution, and has little provision for fostering the industry.

Overall, the remote sensing laws that exist at the domestic level serve as a regulatory regime for non-governmental as well as public-private remote sensing operations. With the exception of Canada, the respective laws are not applicable to national and military operations. One can conclude that the existing national laws addressing remote sensing perform primarily two functions:

1. to provide a regulatory regime to authorize and supervise remote sensing operations, and enforce associated regulations through a licensing frame- work; and
2. to codify and ensure enforcement of the government's right to interrupt services, and to have priority access to data.

The laws reflect the government's intention to regulate remote sensing activities, and to exercise control to ensure that a licensed operation does not harm the government's interests. The laws, however, are not intended to safeguard the right of the potential users or that of other parties affected.

Generally speaking, national remote sensing laws are not intended to serve the purpose of promoting remote sensing activities. Only the United States takes an active approach to realize that goal. The United States has kept pace with changing policies and regulations in line with the market evolution in the field of EO, and has attempted to maintain the

competitiveness of national actors by adopting measures to foster the industry. Such a tendency is found to a minimal extent in other states. Certain elements of consideration for not hampering commercial business can be seen, however, to the extent of limiting restrictive measures by the governmental authority to the benefit of licensees. Examples include limiting the exercise of shutter control to only rare occasions; adopting a review process that is not overly lengthy; and government's willing- ness to pay for the transaction costs associated with priority access. The next section reviews the policies associated with remote sensing and analyses the general tendencies found in the existing remote sensing laws that also apply to such policies.

Whilst not established as a law, an increasing number of states adopt certain policies with respect to data dissemination. Driven by the needs that have emerged with the launch or planned launch of high performance remote sensing satellites and consequent data dissemination, states have moved to adopt, or consider framing, policies that endorse data- specific rules worldwide.

It is of particular importance to gain an understanding of the existing remote sensing policies of various states and to analyze their feature and impact on the data access environment. In theory, certain data policies exist for all satellites of different states currently in operation. The following part will look only at the policies implemented and exercised by state governments that significantly affect the actors; the discussion will focus on a state-by-state review of the policies and practices of China, India, and Russia.

China

The milestone from the standpoint of China's Earth Observation policy was the launch of Beijing-1, a high resolution satellite of 4 m in 2005. Beijing-1 forms a part of the Disaster Monitoring Constellation (Hereafter: DMC) that consists of satellites from several states/entities, whereby 32m data can be exchanged amongst the DMC partners. It is the policy of China not to provide its 4m resolution data of Chinese territory from the Beijing-1 satellite to users outside China. This practice is, in a way, de facto shutter control. Furthermore, the National Mapping Service has up-to-date maps available, but users who are not authorized by the Chinese government are only allowed to access up to 1: 1 million scale maps. Restrictions placed on a map scale for dissemination is relevant to remote sensing, as maps are often based upon or derived from satellite remote sensing data. This may serve as an impediment to open access to the satellite-derived maps and serves as a restriction on data availability on a global basis.

India

India has a comprehensive EO data policy. The Remote Sensing Data Policy established in 2001, fulfils a twofold purpose: 1) to establish a licensing mechanism; and 2) to establish guidelines to control the dissemination of remote sensing data.

With regard to licensing, India's policy requires a license and /or permission from the ministry in charge – the Department of Space – to operate remote sensing systems as well as to acquire /distribute remote sensing data within the country. The Department of Space

assigns licensing operations to two entities: the National Remote Sensing Centre, and Antrix Corporation Limited, known as a commercial arm of the Department of Space. The National Remote Sensing Centre takes charge of the acquisition/distribution of remote sensing data within India whilst Antrix Corporation handles granting license for acquisition/distribution of IRS data outside of India.

With regard to guidelines for data dissemination, the policy is three-tier, depending on the resolution of data: 1) data lower than 5.8 m; 2) data between 5.8 m and 1 m; and 3) data higher than 1 m. The Remote Sensing Data Policy makes data lower than 5.8 m ground resolution available on a non-discriminatory basis and on an "as requested basis". Data between 5.8 m and 1 m resolution "can be distributed to users after screening and ensuring that the sensitive areas are excluded." Distribution of higher than 1 m differs by type of users. Whilst government users do not require further clearance, other users are subject to case-by -case review by an inter-agency High Resolution Image Clearance Committee (HRC), which makes decisions as to whether or not to grant such requests. The distribution of 1m resolution commercial imagery is kept under check through specific sales agreements containing non-disclosure clauses.

The Remote Sensing Data Policy does not provide a definition of sensitive areas; however, the examples of certain sensitive areas can be illustrated using an agreement concluded by the Indian government with a foreign operator in the past. Under a July 2000 agreement between the government of India and Space Imaging – a foreign private entity – sensitive Indian installations such as military bases and airfield will be blotted out of IKONOS images before their distribution in India. The conclusion of this agreement in 2000 signifies that a case-specific legal instrument was already adopted before the establishment of the Remote Sensing Data Policy that addresses guidelines for data dissemination in a general context. Furthermore, the National Remote Sensing Centre prohibits the dissemination of data concerning India's borders up to eighty kilometres inside the territory, including the states of Jammu and Kashmir. Whilst the Remote Sensing Data Policy does not provide for sanction measures such as fines, it is clearly characterised by rigid governmental control, and is closer to a law than a policy.

Russia:

Russia went through phases of relaxing the restrictions on the resolution of available data whilst retaining the right of data refusal in the interests of national security. It was not until 1987 that the commercial images of 5 m high resolution were authorised for dissemination, and it was 1992 when Russia authorized the dissemination of 2m images. Russia started to distribute high resolution images acquired by its KVR-1000 panchromatic camera, which was initially designed for intelligence applications. Whilst restrictions may be imposed on data from specific locations of military sensitivity, in response to the evolution in marketing of commercial images Russia lowered the restriction on resolution to 1 m in 2000419 when the Russian Space Agency announced the commercial distribution of 1m spatial resolution space images taken by its KOMETA satellite system. Russia currently operates Resurs DK1, and imagery from Resurs DK1

and other remote sensing satellites is marketed on a commercial basis by SOVZOND JSC, a private firm established in 1992 to exploit the data.

Russia has placed restrictions on the map scale, just like China. The maps of a scale better than 1:200,000 are regarded by the state as confidential, and a combination of the Federal Security Service and Roskartografia, the National Mapping Agency of Russia, reviews and controls all cartography at map scales better than 1:200,000. The KOMETA images are used to produce 1: 50,000 scale topographic maps that are currently prohibited for civil commercial use. Again, this can serve as an impediment to access to data for public benefit purposes.

From the foregoing discussion, one can argue that 'control of the space object 'if applied to remote sensing satellites (i.e., data collection and dissemination), is much more specifically defined and implemented in the national framework addressing satellite remote sensing. As far as the remote sensing policies discussed in this Chapter are concerned, the tendency found in the analysis of law is only applicable to the first component; that is, to perform the function of a regulatory framework to authorize and supervise the domestic actors, as well as to ensure the rights of the government to interrupt the remote sensing operations. With regard to the remote sensing policies exercised at a national level, their aim is primarily to safeguard the national interests and they reflect little to no element of fostering the domestic industry.

Remote sensing actors are, to a greater or lesser extent, subject to restrictions imposed by governments in the national context. As conditions are mandatory on the licensed remote sensing operators, actors are forced to adhere to the provisions under the domestic regime, despite their possible inconsistency with the international regime. Indeed, if a government decides to exercise interruption of service, limitation on access to the data from any entity that is under the jurisdiction of that government is inevitable.

National legislation and policies relevant to remote sensing that exist today in different countries largely serve as restrictions, rather than to encourage a global data use or to bridge gaps that exist in the present international regime. They only clarify what can and cannot be done by national actors within the particular jurisdictions, and do not adequately complement the international regime by covering the issues not addressed therein.

Conclusion:

The current legal framework surrounding remote sensing neither promotes nor regulates remote sensing activities sufficiently. International rules do not adequately address the critical issues associated with supply and use of data, whilst national legislation largely serves as a means for a government to exercise control on the activities of actors under its jurisdiction.

The inadequacy of the current international legal regime closely reflects the highly political background for, and drafting histories of, the existing international laws governing outer space. The Outer Space Treaty was a compromise of views of the early

space powers, largely motivated by the justification of their interests, such as the non-appropriation of outer space and the protection of 'spy 'satellites; but the Treaty was not intended to generate practical rulemaking to realize the stimulation and regulation of space activities. The UN Remote Sensing Principles codified the views of states with sensing capabilities, mainly reflecting the viewpoint of the United States, which won the negotiation with a high degree of compromise by the developing nations. It was not that concrete rules – such as stating the liabilities arising from the dissemination of data – were never considered. Quite the contrary: various proposals to formulate concrete rules were not incorporated because the states failed to reach consensus. In certain respects, the ambiguities in the current regime were inevitable or, to some extent, even generated deliberately.

With respect to existing national laws and policies, these were primarily motivated by interests of respective states, and are characterized as regulating national actors through governmental control largely with regard to national security and foreign policy interests. Whilst certain rules are intended to minimise the negative impact of restrictive governmental measures on commercial operations, they would only benefit domestic actors, and not the global communities affected by remote sensing activities at large.

The present international law regime on satellite remote sensing supports data applications for environmental protection and disaster management; however, the provisions dealing with data availability and pricing policy do not particularly promote the use of data for these applications. Furthermore, the current international legal regime fails to address important commercial and operational issues regarding use and application of data, such as data policy issues including intellectual property rights, guidelines for accuracy validation and data authentication, and liability issues. The uncertain legal environment currently pertaining to remote sensing from space restricts the widespread use and realization of the full benefits of this powerful tool.

The international legal regime is now at a turning point, as the environment surrounding remote sensing has changed since the formulation of the UN Remote Sensing Principles; this change has been particularly dramatically in the last few years. Today remote sensing has a more global presence, is used for a wide range of applications, and has further potential as a critical information tool. It is now time to regulate and promote remote sensing activities through an unambiguous legal framework. There is an urgent need for clarification of ambiguities and for studies of current practice, as well as a more comprehensive regime.

MODULE-V

LEGAL ISSUES OF GIS TECHNOLOGIES

LEGAL AND ETHICAL ISSUES OF USING GEOSPATIAL TECHNOLOGIES IN SOCIETY

INTRODUCTION

Geospatial technology, along with bio- and nano-technologies, has been recognized by the scientific community as one of the three leading technologies that will shape the development of science, technology, and society in the years to come. Generally speaking, geospatial technology is an amalgamation of several technologies, including (but not limited to) remote sensing (RS), geographic information systems (GIS), global positioning systems (GPS), location-based services (LBS), and related fields such as computer mapping, spatial modeling, and data visualization. Not very long ago, an editorial in the Wall Street Journal alerted its readers that "... tools of geographers are changing society today as much as the tools of physicists did at the time of the atomic bomb". Indeed, the atomic bomb could serve as an illuminating metaphor for the mixed, far-reaching, broad social impacts we are just beginning to appreciate for geospatial technologies. On the one hand, it has been demonstrated that geospatial technologies can be used to document cases of gross human rights abuses, find land mines, and identify concentrations of the poor and the hungry in dire need. On the other hand, recent years have witnessed a growing outcry by the general public on the increasing use of geospatial technologies for tracking people.

Indeed, the growing applications of geospatial technologies have contributed to a new geography of hope and fear, which concomitantly raised a series of legal and ethical issues. During the past five years, we have witnessed an increasing coverage by both popular media and scholarly articles on the issues brought by the breathtaking development of geospatial technologies and their expanding capabilities for surveillance purposes. Since its very early days, geospatial technology has been characterized as a major tool for surveillance, and today it has become an integral component of the surveillance infrastructure. Not surprisingly, concerns about unintended consequences have also grown with the increasing sophistication of these surveillance capabilities. The social implications of GIS have always been one of the major research areas in geographic information science. Scholars in many fields have contributed to our understanding of GIS from legal and ethical perspectives, but the scholarly work on this topic has been scattered throughout a large interdisciplinary literature. The primary goal of this chapter is to present a synthesis of the literature on the legal and ethical issues of using geospatial technologies in society. In doing so, I aim to bring the legal and ethical dimensions of geospatial technologies to a broader audience and help open more dialogues and discussions among the stakeholders in this area. To achieve this goal, we shall first review the key elements of the new geospatial technologies that have enhanced our surveillance capabilities, followed by a synopsis of the legal and ethical problems these technologies have brought to society in the third section. The fourth section discusses some possible remedies for these problems, and the last section contains a summary and conclusions.

The Changing Technological Landscape for Positioning, Tracking, and Mapping: From Surveillance to Sousveillance:

Although concerns over legal and ethical issues of geospatial technologies were voiced throughout the 1990s, these discussions were confined to the scholarly community and did not gain much public attention. This was primarily due to two reasons. First, earlier applications of geospatial technologies focused disproportionately on environment and resource applications at a crude spatial resolution (10 m by 10 m or coarser). Those dealing with socioeconomic applications were conducted mostly at the aggregate level, not focusing on individuals explicitly. Second, high-resolution satellite remote sensing or aerial imageries (sub-meter resolution) were tightly controlled by government (mostly classified), and GPS, although in use from 1972, was not declassified for civilian applications or commercialization until 1983.

The developments of geospatial technologies during the past 15 years have dramatically changed the technological landscape. Recent advances in surveillance capabilities of geospatial technologies have rendered science fiction movies, such as Enemy of the State (produced in 1998), more like a documentary in the early days of the twenty-first century. The new technological breakthroughs have not only equipped Big Brother with the ability to conduct extensive surveillance on citizens, but have also empowered individual citizens to conduct surveillance among themselves or inverse surveillance on the watcher. Furthermore, under the new paradigm of citizens as sensors, individuals, and informal groups of individuals popularly known as smart mobs, can record, describe, and disseminate information on activities at either the individual or collective level from the perspective of the participants – a new form surveillance called sousveillance. Several key components of the geospatial technologies have contributed to the transition from surveillance to sousveillance.

Throughout human history, a variety of different location technologies, ranging from mechanical, acoustic, optical, radio, and electromagnetic, have been developed. Generally speaking, geotracking – obtaining the locational coordinates of the target being tracked – has mostly relied on three primary techniques for determining location: (1) triangulation, which can be done via either lateration (using multiple distance measurements between known points) or angulation (using measured angles or bearings relative to points with known separation); (2) proximity, which measures nearness to a known set of points; and (3) scene analysis, which examines a view from a particular vantage point. Different geotracking technologies use different combinations of these three techniques. These different technologies have different coverage, spatial-temporal resolution, and accuracy, and have increasingly been embedded into a variety of consumer products such as car navigation systems, smart cellular phones, printers, underwear cosmetics, and so on (Table. 1). Custom-designed tracking devices have also been available in the market, such as Digital Angel, Wherify child locator and various other types of WhereWare (Pfeiffer, 2003). Among the many technological breakthroughs during the past 15 years, the

following are particularly relevant when we discuss the legal and ethical implications of geospatial technologies:

Global Navigation Satellite Systems and High-resolution Remote Sensing

Among these different positioning technologies, perhaps the most significant one is the global navigation satellite system (GNSS), which was instrumental in promoting the development of location-based industry. As of 2009, the US NAVSTAR GPS is the only fully operational GNSS. However, the global dominance of positioning systems by the USA is eroding with rapid development of GNSS by the EU, Russia, China, Japan, France, and India. The European Union's Galileo positioning system is a GNSS in the initial deployment phase, scheduled to be operational in 2013. The Russian GLONASS is a GNSS in the process of being restored to full operation. China has indicated it may expand its regional Beidou navigation system into a global system. The current Beidou-1 system (made up of four satellites) is experimental and has limited coverage and application. However, China has planned to develop a truly global satellite navigation system consisting of 35 satellites (known as Compass or Beidou-2). The Quasi-Zenith Satellite System (QZSS) is a proposed three-satellite regional time transfer system and enhancement for GPS covering Japan. The first satellite is scheduled to be launched in 2010. Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) is a French precision navigation system. Indian Regional Navigational Satellite System (IRNSS) is intended to be completed and operational by 2012. Obviously, more and more countries have recognized the growing importance of GNSS to their military operations as well as various civilian applications, which explains their growing investment in the global navigation infrastructure to develop their own independent systems.

Table-1: Location/Positioning Technologies

Technology	Coverage	Accuracy	Updates	Location Data
GPS	Earth	0.01m-100m	<1s	x, y, and z coordinates
Mobile phone (tower triangulation)	Populated areas	120m-30km	4.6ms-2hrs	x, y coordinates
CCTV	City centers	1m	1/30s	Camera location
RFID	Near readers	1m	Sporadic	Distance to reader
Credit card	Payment Kiosk	1m	Sporadic	Kiosk location

Advances in remote-sensing technologies have made high resolution (sub-meter) commercially available satellite from GeoEye and DigitalGlobe (see http://www.vterrain.org/Imagery/commercial.html for a more complete list of vendors). The corporate sector is increasingly interested in collecting information at the local and individual level. GoogleTM and Microsoft® are investing in Street View

(http://www.everyscape.com/). Satellite navigation systems and high-resolution remote sensing are instrumental in contributing to what Regan (2004) called the creeping legibility of both people and places.

Radio-frequency Identification and Biometric Systems

Radio-frequency identification (RFID) technology relies on storing and remotely retrieving data using radio waves. An RFID tag can be attached to or embedded in a product, animal, or person for identification or tracking. An RFID chip typically is composed of a tiny antenna attached to a tiny ID chip, and it can be passive (without an internal power source) or active (with a built-in power source). As GPS signals are usually too weak to be used for tracking purposes inside a building, the development of RFID technology, especially once it is fully integrated with GIS, may potentially track and map everything on surface of the earth. EPCglobal, a system of tags to create globally unique serial numbers for all products using RFID technology, may be a concrete step forward toward stitching together a new electronic skin for the Earth.

Since each individual is identifiable spatially and temporally via GPS and RFID, we are subject to the linkage of our positioning information to other types of biometrics such as finger prints, iris/retina scans, face recognition scans, or thermal maps of the body, as well as to detailed genetic information at the individual level (http://www.23andme.com). GPS and RFID especially in the form of sub-dermal implantation, along with biometric and genetic information, have brought surveillance to a new level of unprecedented detail ranging from genetic all the way to global levels. One particular interesting recent trend is the integration of GPS with RFID. The two complementary systems could potentially close the location positioning gaps for the entities we aim to track and map.

People-based GIS, Participatory Sensing, and the Development of Sensor Webs

One of the most significant advances is the development of people-based GIS. Until the mid 1990s the development of GIS had been driven by a place-based paradigm, in which environmental and socioeconomic data are aggregated to spatial units of various sizes (e.g., census tracts, traffic analysis zones, or grids of varying sizes). We often rely on place-based, aggregated information to infer information about individuals. Advances in information and telecommunication technologies and related changes in peoples' activity patterns have increasingly made such inferences problematic. Inspired by Hägerstrand's time geography and activity theories, Miller (2007) proposed the concept of people-based GIS, which is capable of monitoring, tracking, analyzing, and visualizing people's activities in space and time. Many real-world applications such as transportation planning, emergency evacuation, and disease surveillance all demand people-based, rather than place-based GIS. The development of people-based GIS represents a major conceptual departure from place-based GIS. The increasing applications of people-based GIS are made possible because of a growing array of location-aware technologies.

People-based GIS is made possible partially by the location-aware technologies such as the smart cellular phones people carry with them. Detailed spatial and temporal

information is recorded, thus making the spatial and temporal analysis of trajectories possible. Humans are becoming sensors for collecting data about other people and the environment. The so-called participatory sensing – individuals using cellular phones to collect data – has emerged in recent years with growing areas of applications (Burke et al., 2006). Participatory sensing is an integral part of the emerging sousveillance.

Ubiquitous Computing, Web 2.0, and Volunteered Geographic Information

The explosive growth of Web 2.0 technologies and the concomitant growth of user-generated content marked a new era for the development of geospatial technologies and their surveillance applications. Perhaps the most significant development for this new era is the dazzling growth of volunteered geographic information contributed by citizens using Web 2.0 technologies through the new paradigm of cloud computing. In addition to its contributions to a bottom-up process for the growth of spatial data infrastructure, VGI is also contributing rather significantly to the social transition from surveillance to sousveillance, as a large amount of VGI reflects extreme details about personal experiences voluntarily provided. Besides the explicitly geocoded data that citizens contributed to VGI sites such as openstreetmap.com or wikimapia.com, the past five years have also witnessed the rapid growth of geotagged, user-generated content on the web, ranging from twits, blogs, and photos, to YouTube™ videos and online social networking activities on Facebook™ or MySpace™ . Nowadays even Twitting is increasing geotagged and readers can tell where you are twitting from. The emerging new infrastructure for ubiquitous computing (ubicomp) has increasingly become context- or location-aware, which contributes to both surveillance and sousveillance capabilities unprecedented in human history.

Indisputably, ubicomp will embed more conventional GIS functions into various kinds of enhanced LBS. Location-aware computing, or more broadly “context-aware” computing, will equip information infrastructure of all kinds with special capabilities to recognize and react to real-world contexts in which it operates. “Context” encompasses a plethora of factors, including user identity, time, physical location, and environmental conditions (such as local weather, and so on). The two most critical aspects of context are location and identity. Context-aware computing systems respond to a user's location, either spontaneously (e.g., a friendly reminder of approaching a favorite restaurant, or warning of a nearby hazard) or when activated by the user's request (e.g., is this area prone to traffic jam or accidents?). With the continual growth of a variety of LBS, many GIS functions that were previously confined to desktop PCs may become embedded as part of ubicomp or ambient intelligence.

The development of ubicomp will also entail another round of explosive growth of data of many kinds with greater spatial and temporal resolution. Real-time data acquisition (RTDA) will become a reality in the age of ubicomp, which will make just-in-time mapping (JITM) a routine operation in the near future. For example, the development of smart “dust sensors” – devices that combine microelectromechanical sensors with wireless communication, processing, and batteries into a package about 1 mm3 in size –

could potentially revolutionize RTDA and JITM. Although currently still in their infancy, prototype smart sensors have demonstrated their capabilities to monitor environmental conditions that are hazardous to humans, determine the velocity and direction of passing vehicles in remote areas, or to be attached to humans, animals, or even insects to record where they travel. The data transmitted wirelessly in real time from these sensors increases not only the volume but also the complexity of available geospatial data. To store and analyze these colossal data sets obviously demands more storage space and computers more powerful than ever for data mining and research. So paradoxically, the age of ubicomp will also simultaneously create new demands for more powerful mainframe and personal computing as well. The theoretical foundations and functional capabilities of GIS in data acquisition, storage, analysis/modeling, and visualization need to be expanded to accommodate the new demands created by ubicomp.

Data Mining, Knowledge Discovery, and Geographic Profiling

The growing availability of massive amounts of geocoded information has contributed to rapid development of a variety of new data mining and knowledge-discovering techniques. These techniques are capable of conducting integrated analysis of heterogeneous data sets to detect meaningful structure and patterns. In addition to techniques for handling quantitative data, recent developments have also led toward breakthroughs in text mining and photo synthesis (http://photosynth.net).

The increasing availability of geocoded data, coupled with our improved capabilities in data mining and knowledge discovery, has resulted in new spatial practices called geographic profiling. Geographic profiling originally developed as a criminal investigative methodology that analyzes the locations of a connected series of crimes to determine the most probable area of offender residence. Geographic profiling helps police prioritize information in major crime investigations that often involve hundreds or thousands of suspects and tips. Most recently, techniques of geographic profiling were used to zero in the possible location for Osama Bin Laden. Although typically used in criminal investigation, such as in cases of serial murder, rape, arson, bombing, robbery, and other crimes, geographic profiling techniques can also be used in several other areas such as marketing, location-allocation analysis, political campaign/fund raising, real estate development, environmental health, archaeology, and so on.

One very important fact that must be kept in mind is the existence of a massive infrastructure (such as Echelon) that is classified and controlled by the government for surveillance purposes. Although the project for total information awareness (TIA) was stopped due to strong public opposition, the government's capability to conduct surveillance has vastly improved with the passing of the Patriot Act following the events of September 11, 2001.

The vastly improved technical capabilities in real-time tracking have led to diverse applications, such as tracking children, the elderly, Alzheimer's patients, animals,

employees, students, and those on parole. It is these diverse applications that have created many new legal and ethical issues for us to ponder.

Geospatial Technologies and Society: Legal and Ethical Issues

As demonstrated by several high-profile lawsuits and news reports involving the wide-range applications of geospatial technologies in society, legal, and ethical issues have increasingly been on the public radar screen. There have been calls for a broader public debate and dialogue on these issues in order to develop new legal and ethical guidelines for geospatial technology practices in this new, pervasive computing environment with massive surveillance capabilities. To begin with, a distinction between legal and ethical issues should be helpful.

Legal versus Ethical Issues

Human conduct in society can be classified as legal or illegal (the circle in Figure 1). We also judge people's conduct as ethical or unethical (the rectangle in Figure 1). Under normal circumstances, a clear distinction can be made between legal and illegal and usually also between ethical and unethical conduct in society. Each society has set up its own rule of laws that bans certain behaviors. Violations of laws are subject to sanctions imposed by the judicial system. Ethics refers to values that deal with human conduct or practices with respect to the rightness of certain actions and to the goodness or badness of the motives and ends of such actions. Each society has its rule of ethics and morality, which are widely accepted by that society but not clearly coded into law.

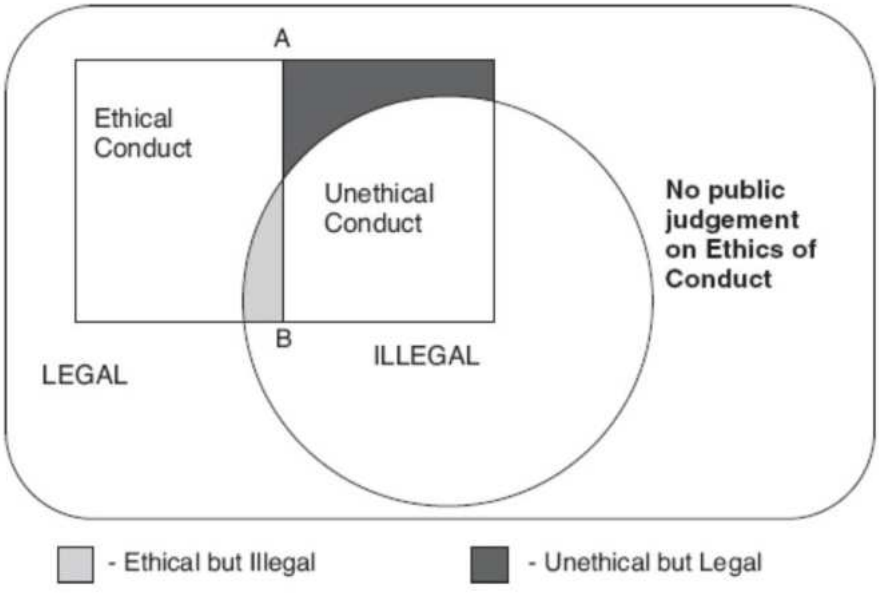


Figure. 1: Legal and Ethical Dimensions of Societal Conduct

Two grey areas complicate the legal versus ethical behavior issue in society. Certain human behaviors are illegal but ethical, whereas some others are legal but unethical. For example, to prevent a murder from happening, one may break the speed limit or break

into somebody's house. To some pacifists, the use of geospatial technologies on the battleground is regarded as unethical, but its use is legal in most cases except when geospatial technologies are used in war crimes such as committing genocide or purposefully targeting civilians. Similarly, to some environmentalists, using geospatial technologies to facilitate oil drilling in environmentally sensitive areas (such as Alaska's wildlife refuge) may be legal but unethical. These distinctions are helpful when we discuss the legal and ethical issues of geospatial technologies. But in reality, as Olson (2006) so vividly documented, there exists a vast murky terrain of moral limits in spying for the purpose of national security. The same moral dilemmas, although perhaps at a different intensity level, also exist for the general use of geospatial technologies in society.

Major Legal Issues

Recent media coverage on legal issues relating to geospatial technologies has focused predominantly on tracking people and invasion of privacy, but the legal issues of geospatial technologies are broad and complex. In general, all legal issues related to applications of geospatial technologies are concerned with collection, ownership, access, retention, use, and dissemination of georeferenced data at either individual or collective levels. Major legal issues relating to geospatial technologies can be roughly grouped into three categories:

(1) privacy and data accessibility issues;

(2) intellectual property, copyright, and data licensing issues; and

(3) international law issues.

Privacy and Data Accessibility Issues

At the individual level, the possible invasion of privacy has been a growing concern owing to the growing use of geospatial technologies to track people and commodities in real time. Traditionally, privacy has been defined as an individual's right to be left alone. Over the past century, extraordinary technological development has dramatically redefined the boundary and the domain of what is normally considered as a private realm. The meaning of privacy has also changed from the right to be left alone, to the right to enjoy anonymity, to the right to control information about oneself, and so on. The recent development of geospatial technologies has moved locational (spatial or geographical) privacy to the forefront of privacy concerns. Purely locational information in terms of latitude/longitude or other types of coordinates (site information) may not be that meaningful, but people can make a reasonable inference about the surroundings of a particular location (situation information), which could be embarrassing or harmful. This is in large part why most people would prefer their whereabouts to remain private. For example, each year, one million American women and half million American men are being stalked (http://www.ojp.usdoj.gov/bjs/abstract/svus.htm), and geospatial technologies can play a very important role in stalking.

In terms of legal protections, the Fourth Amendment of the US Constitution provides that: "The right of the people to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures, shall not be violated, and no Warrants shall issue, but upon probable cause, supported by Oath or affirmation, and particularly describing the place to be searched." Constitutional protections for privacy, derived primarily from the Fourth Amendment, restrict government intrusion into our personal life through searches of persons, personal space, and information. For law enforcement officials, a search warrant is usually required before a private property can be search or seized. Although, in general, the fourth Amendment places restrictions on government intrusions into the private realm of ordinary citizens, it has not been interpreted to provide an effective means of protecting physical and locational privacy outside of the home or other quarters. In the seminal case Katz v. United States (1967), the United States Supreme Court held that government eavesdropping of a man in a public phone booth violated a reasonable expectation of privacy because the Fourth Amendment protects people, not places (Herbert, 2006). The Supreme Court has interpreted the Fourth Amendment as protecting individuals from government intrusions without a warrant only where the individual has an objectively reasonable expectation of privacy. The reasonable expectation standard has been adopted by the state courts when interpreting state constitutional and common law protections of privacy. However, in a recent case involving Google™ , a Pennsylvania judge recently dismissed a law suit against Google™ for posting some very private photos on Google Earth™ Street View.

As a worst-case scenario, some scholars have also contemplated the possibility of geoslavery in this age of ubiquitous computing. The growing applications of geospatial technologies, especially through the development of human tracking devices and various kinds of LBS, has introduced a new potential for real-time locational control and monitoring that extend far beyond privacy and surveillance per se. Scholars have warned that society must address a new form of slavery characterized by location control – geoslavery, now looming as a real, immediate, and global threat. According to Dobson and Fisher, geoslavery refers to "a practice in which one entity (the master) coercively or surreptitiously monitors and exerts control over the physical location of another individual (the slave)". With the current geospatial technologies readily available and affordable (US300–500), an individual can routinely control the time, location, speed, and direction of another individual for each and every movement, even without the permission of the individual being monitored. The fact that child slavery, sex slavery, and other abusive behaviors (such as stalking) are still rampant worldwide (e.g., http://www.iabolish.com/ slavery_today.htm) begs one to ponder where the increasing use of geospatial technologies and location- aware computing will lead us in the near future. The potential of geoslavery has raised the issue of whether locational privacy should be universally protected as a fundamental human right. Although legally speaking, the Thirteenth Amendment of the US Constitution, which states: "Neither slavery nor involuntary servitude, except as a punishment for crime whereof the party shall have been duly convicted, shall exist within the United States, or any place subject to their

jurisdiction," has clearly outlawed slavery since 1865, recent incidents involving individuals serve as painful reminders of the potential for geoslavery.

Although the Fourth (and possibly the Thirteenth) US Constitutional Amendments have been invoked in legal cases regarding the use of geospatial technologies, legal scholars have argued that it is unlikely that workable limitations on the use of human tracking devices will grow out of criminal appeals under these Amendments. Many legal issues, such as who can track whom, under what circumstances, and whether a warrant is needed (in the case of police tracking citizens) also have to rely on other federal and state laws.

Several federal legislations have been cited in recent legal cases. While the Electronic Communication Privacy Act 1986 protects against unauthorized interception and disclosure of electronic communications, it excludes tracking devices. However, the Wireless Communication and Public Safety Act 1999, explicitly protects location information in wireless devices, requiring customer approval for disclosure. This protection does not extend to deriving location information from communication devices. Transaction information such as telephone numbers is not protected (Smith v. Maryland, 1979), but providers are prevented from releasing information that discloses the physical location of an individual (CALEA, 1994/2000; US Telecom v. FCC, 2000). However, using mobile communication devices as tracking devices to derive location information is not constitutionally prohibited (US v. Meriwether, 1990; US v. Knotts, 1983; US v. Forest, 2004), as courts have ruled that individuals using cell phones, beepers, and pagers do not have a reasonable expectation of privacy when moving from place to place (although this interpretation continues to be challenged). Several related federal regulations, however, have been enacted:

Telecommunication Act 1996; Children's On-line Privacy Protection Act; Children's Bullying law; Privacy for Consumer and Workers Act 1993; and the Video Voyeurism Prevention Act, as well as other legislations aimed at eavesdropping and Internet websites.

Recently, however, the Patriot Act 2001 has nullified some of these protections, granting broad authorities for government surveillance, including the ability to use roving wiretaps, which has caused grave concerns to both the public and legal scholars. The Patriot Act has vastly increased government power for surveillance (in some cases even warrantless). Taipale (2007) describes the nature of modern communication networks and certain related technology developments, and examines how three situations – transit intercepts, collateral intercepts, and automated monitoring – cannot be accommodated by the Foreign Intelligence Surveillance Act (FISA) as currently constituted. It remains a legal challenge to fix foreign intelligence surveillance so that it preserves existing Fourth Amendment principles and protections while still addressing these failures. To get beyond backward looking recriminations, we need to craft new progressive consensual solutions.

Invasion of privacy due to the use of geospatial technologies can also be dealt with through common law and state constitutions. Tort laws are often invoked. A tort is a

wrongful act or damage (not involving a breach of contract) for which a civil action can be brought. Following the doctrine established by Warren and Brandeis (1890), there are four kinds of privacy torts:

- Misappropriation of one's likeness – use of a person's name, likeness, or identity for trade or advertising purposes without consent.
- Intrusion upon a person's seclusion – a physical, electronic, or mechanical intrusion into someone's private space. This is an information-gathering, not a publication, tort. The legal wrong occurs at the time of the intrusion; no publication is necessary.
- Public disclosure of embarrassing private facts – publication of non-newsworthy, private facts about an individual so intimate that they outrage the public's sense of decency, or that would be highly offensive to a reasonable person (true defamation).
- Publicity in false light – publication of false, highly offensive (but not necessarily defamatory) information about an individual.

However, the public disclosure tort is limited by the clause that if an event takes place in a public place, the tort is unavailable. The courts have generally ruled that a person traveling in public places voluntarily conveys location information. But courts have also recognized that a person does not automatically make public everything he or she does merely by being in a public place. Most states give common law or statutory recognition to some or all four of the privacy torts.

According to Herbert and Tuminaro (2008), case law has interpreted these locational privacy rights more specifically, examining intrusions of technology into the private sphere, government searches that are technologically enhanced, and the use of mobile devices and telecommunication information to derive locational information. While Fourth Amendment protection does not extend to that which is knowingly disclosed to the public, the courts have ruled that the use of technologies not available to the general public can violate the privacy one reasonably expects (Kyllo v. US, 2001). However, the courts have also shown a willingness to allow law enforcement to use technologically enhanced means for searches, including flying over properties such as a fenced backyard (California v. Ciraolo, 1986), a greenhouse (Florida v. Riley, 1986), or an industrial plant (Dow Chemical v. US, 1986), suggesting that the open fields doctrine brings no reasonable expectation of privacy.

In summary, legal protection for location privacy in the USA is inconsistent and sectoral, providing coverage only under certain situations and for specific technologies. Recently, legal public privacy issues raised by Nissenbaum (1998) and the further development of geospatial technologies have certainly added quite a bit of urgency to this issue. Conflicting rules exist, such as the need to obtain a warrant for police to start tracking somebody, despite the lack of legal protection for privacy in public.

Intellectual Property, Copyright, and Data Licensing Issues

In addition to privacy issues, recent advances in geospatial technologies have also raised many challenging issues related to copyright, liability, and intellectual property rights on diverse geographic information. Under the current culture of mashing-up practices, which is part of the larger emerging remixing culture, "who legally owns the geospatial data" emerges as a burning issue for further discussion and clarification. The recent development of VGI poses new interesting questions about data ownership,

intellectual property rights, and copyright, as recently demonstrated by the FacebookTM data ownership dispute (see http://www.japantoday.com/category/technology/view/facebook-does-about-face-in-content- ownership-dispute).

Licensing of geographic data and works has increasingly become a common practice because of the limited protection afforded by copyright and other intellectual property doctrines in the digital environment. License or licensing of geographic data or a geographic work means a transaction or arrangement (usually a contract, in which there is an exchange of value) in which the acquiring party (e.g., the licensee) obtains information with restrictions on the licensee's rights to use or transfer the information. More and more data providers also have turned to technological means to control access and copying, measures that are reinforced by the Digital Millennium Copyright Act, for works that have at least some copyright protection. Moreover, courts have upheld contracts or licenses that limit the uses that a licensee can make of data, or that prohibit further distribution. Data providers' rights are likely to be further strengthened if Congress adopts database protection.

Federal agencies almost always distribute geographic data at or below marginal cost of distribution. Cost recovery has been the norm in dealing with spatial data in Europe and it has held GIS development back. In the USA, Landsat pricing has also attempted to follow the cost recovery path, which has held back the development of remote sensing. Since the 1990s however many state and local governments have experimented with the distribution of data using licenses to generate revenue from them. As we move further into the ubiquitous computing age of the twenty-first century, many of these entities have concluded that fee programs (1) cannot recover a significant fraction of government data budgets, (2) seldom cover operating expenses, and (3) act as a drag on private-sector investments that would otherwise add to the tax base and help grow the economy. The use of licenses to provide data to users may, however, be useful to enforce proper attribution, minimize liability, enhance data security, and formalize collaboration.

Licensing has become commonplace because of the realization that many geographic data, as opposed to geographic creative works, are difficult to protect through copyright alone. There have been growing concerns over potential liability and a desire to limit liability through explicit license language. Sharing costs through various data maintenance partnerships has also become common practice.

This has facilitated a shift away from supplying distinct datasets to providing access to databases, and the rise of business models that stress multiple subscribers despite the reality of digital networks and media that allow others to distribute perfect and inexpensive copies.

Confusion and uncertainty have arisen in recent years as a result of a proliferation of nonstandard licensing arrangements. The geospatial community has recognized the difficulty of designing licenses that can (1) track the legal, economic, and public interest concerns of different levels of government, and (2) accommodate all sectors of the geographic data community. There also exist no effective license tracking and enforcement mechanisms. Different sectors of the geospatial community also have different practices and standards in the licensing process.

The wikification of GIS has also raised another important legal issue on who is qualified to create geospatial data. In January 2007, the Management Association for Private Photogrammetric Surveyors (MAPPS) filed a lawsuit seeking to limit competition for federal mapping contracts of nearly every type, including GIS services, to firms of licensed architects, engineers, and surveyors alone. In June 2007, Judge T.S. Ellis III of the US District Court in Alexandria, Virginia, ruled against MAPPS, finding that MAPPS failed to "establish that an injury in fact was suffered by the individual [licensed] surveyors or their firms" (http://www.ucgis.org).

This is a significant legal victory for the continuing democratization of GIS, which will hopefully ensure all qualified professionals – not just licensed engineers and surveyors – can compete for government contracts related to mapping and GIS activities. Recent innovations in technologies have drastically flattened the learning curve for geospatial and mapping technologies. The development of Google Maps™/Google Earth™ and Microsoft 's® Virtual Earth® , along with their precursors Mapquest, Yahoo Maps, Multimap, StreetMap, and so on, have democratized the application of massive online geospatial information. Additionally, the new wave of technological innovations has even democratized the production of maps and online geospatial information. The accelerated democratizing process for mapping and GIS has put powerful mapping technologies into the hands of the masses, which now can perform rather complex mapping tasks (once requiring years of training) with little or no training at all. Although Judge Ellis' ruling in the case of MAPPS v. US Government has been widely applauded by the geospatial community, the fast growing collaborative mapping by amateurs (or citizen cartographers) does raise new questions and concerns about the authority and trustworthiness of geographic information production.

Drawing on an analogy of the tragedy of the commons in the environmental domain, Onsrud (1998) warned of a possible tragedy of the information commons unless innovative mechanisms for sharing information and licensing geographic data are developed. The recent democratization of geographic data collection and dissemination in the age of Web 2.0 further complicates the liability issue of geographic data information. Obviously, the wide-ranging applications may be disadvantageous to some people, such

as users of the software or data or those affected by decisions taken on the basis of GIS applications. Liability is a creation of the law to support a range of important social goals such as avoidance of injury, encouraging the fulfillment of obligations established by contracts, and the distribution of losses to those responsible for them. Generally speaking, liability of GIS is related either to contract liabilities (warranties/implied vs. defined) versus tort liabilities (negligence, fraud, and product liability).

Liability in data, products, and services related to GIS is likely to be determined in most instances by resort to contract law and warranty issues. If decisions are made based on geographical data or products produced by someone other than the user, there will always be liability exposure. Minimizing losses for users of geographical data products and reducing liability exposure for creators and distributors of such products is achieved primarily through performing competent work and keeping all parties informed of their obligations. But new data-licensing practices, value-added operations, plus volunteered geographic information via mashing up and wiki sites have made it increasingly difficult, if not entirely impossible, to track the creators and distributors of geographic data. Establishing liability in case something goes wrong is thus becoming even murkier. Recent road accidents also raised the issue of whether GPS or navigation systems should be blamed for fatal crashes.

International Dimension

When Google Earth™ was first launched in 2005, several countries, including India, China, Pakistan, and Israel, immediately expressed security concerns posed by the high-resolution satellite imagery taken over their sovereign territory, which renewed discussions on the legal issues of geospatial technology at the international level. In fact, such have been a concern of the international community since the early days of remote sensing technology in the 1960s, as geospatial technologies have always played an important role in international affairs.

The basic legal framework for all space activities is provided by the 1967 Outer Space Treaty, signed by major countries in the world with space technology capabilities. This treaty ensures the freedom of exploration and use of outer space by all states, including for satellite remote sensing. The treaty further articulates the principle of non-appropriation of outer space by any single state. This treaty also makes it clear that any limit to the freedom of exploration and use can be established only at the international level, that is, by the community of states via treaty provisions or, as the case may be, by customary international legal rules. Finally, the treaty provides for the application of general international law to outer space, in particular by establishing general principles such as the freedom of information gathering from outer space.

The United Nations Declaration on Principles Relating to Remote Sensing of the Earth from Outer Space, Resolution 41/65, adopted on 3 December 1986, sets out the main legal principles (15 in total) specifically pertinent to remote sensing. Resolutions passed by the UN General Assembly do not per se constitute binding legal documents; however,

they may over time evolve into reflections of customary international law. Resolution 41/65 was adopted by consensus, and in any case UN General Assembly Resolutions carry considerable weight in the political/moral sphere, so that this resolution may indeed be considered customary law.

The key principles contained in the resolution deal with the issue of access to data gathered by remote sensing activities for land-use purposes, in particular, by states other than the one(s) generating the data in the first place. Here, Principle IV provides for the conduct of activities on the basis of respect for the sovereignty of so-called "sensed states." Principle V calls for offering opportunities of cooperation to sensed states, and Principle VII requires so-called "sensing states" to make technical assistance available to other interested states on mutually agreed terms. Most importantly, however, Principle XII provides for a right of access by the sensed state to data concerning its territory "on a non-discriminatory basis and on reasonable cost terms." While these two qualifications already allow for considerable flexibility for sensing states ultimately to disallow sensed states access to certain data, it is also clear that the sensed state has no right of precluding its territory from being sensed, nor any right of exclusive, or even priority access to such data. In the last resort, freedom of information-gathering has thus prevailed over a principle of sovereign control over data regarding one's own territory.

In terms of obligations binding on states concerned, Principle X lays down the need for states to convey relevant information regarding threats to the "Earth's natural environment" to other states concerned; and Principle XI calls upon states in the possession of relevant information regarding natural disasters to duly inform other states concerned. Principle VIII furthermore envisages a key role for the United Nations: it "shall promote international cooperation, including technical assistance and coordination in the area of remote sensing." Once again, freedom of information-gathering reigns supreme over data control.

The above framework, being very general, already raises a number of legal issues at the highest level when it comes to applying it to the "real world" of satellite earth observation. Two of these will be briefly touched upon as generic issues requiring treatment before moving on to legal details. Such details would namely also involve particular intellectual property rights issues pertaining to satellite data, compensation for damage caused by erroneously interpreted data, the potential value as evidence in court cases, and a number of other matters, all involving specific legal regimes and questions.

The two "real world" issues concern international responsibility and liability, respectively in specific cases of involvement of intergovernmental organizations and private entities as categories of players in addition to that of the states. First, under Article VI of the Outer Space Treaty, states are responsible for national activities in space, even if conducted by non-governmental entities, and for ensuring that these activities conform to the law. Second and along similar lines, under Article VII of the Outer Space Treaty and the 1972 Liability Convention, states are specifically liable for damage caused by space objects.

Both are, therefore, clearly focused on states as "undertakers" of space activities, a focus which made sense historically but is increasingly subject to discussion.

The role of intergovernmental organizations results in some particular ramifications of responsibility and liability. As to state responsibility, it also applies when activities are carried on in outer space by an international organization, although in such cases jointly with the responsibility of the international organization itself. As a result, member states of intergovernmental organizations are effectively prevented from hiding behind these organizations in the case of their earth-observation activities violating applicable rules of international law; it is their duty and responsibility to ensure that the organizations themselves do not undertake any such violating activities.

As to liability, under the 1972 Liability Convention, intergovernmental organizations equally enjoy a secondary status effectively allowing them to qualify to some extent as liable entities, and a similar construction under the 1975 Registration Convention allows them to themselves register satellites and exercise concomitant competencies over them. The European Space Agency (ESA) actually enjoys the relevant status, as it has deposited relevant Declarations in respect of both conventions, but for most organizations, any liability would revert directly to individual member states.

As far as the liability stemming from geospatial data is concerned, this is still a murky terrain in international law. Some legal scholars have argued that international liabilities regarding geospatial data are most likely handled by international agreements and frameworks such as the General Agreement on Tariffs and Trade (GATT) developed by the World Trade Organization (WTO). Dispute resolution over international liabilities of geospatial data may also be addressed by various existing and proposed EU laws regarding electronic databases, or other bi-lateral/multi-lateral agreements such as the North America Free Trade Agreement (NAFTA) or the Mercado Común del Sur (MERCOSUR).

Critics argue that the existing rules of international law regarding geospatial technologies are outdated and no longer can deal with the complexities of their international dimensions. Both the Outer Space Treaty and the UN Resolution of 41/65 reflect the legacy of the Cold War with heavy emphasis on states as players. Their dominant concern is military/national security instead of commercial goals. They have also been criticized as overtly favoring those developed countries with space capabilities, whereas the rights of developing countries are not properly respected according to the international rule of law.

Ethical Issues

As indicated earlier, not all of the social issues brought about by the advances in geospatial information science and technology can be resolved according to the rule of law. Some of these issues fall into the realm of ethics and moral judgment. Ethics deal with society's moral code on human behavior and practices in terms of right and wrong, which varies greatly according the culture, history, and customs of the country concerned.

Generally speaking, discussions on ethics can be conducted at three levels: normative, meta-, and descriptive/applied. Normative ethics deals with issues related to what should be considered as right or wrong behavior/practices in society, whereas meta-ethics is concerned with the ontological foundation and justification for the normative practices. Descriptive/applied ethics concentrates primarily on what specific actions we should take under specific circumstances. Some scholars have raised and discussed ethical issues pertaining to GIS from normative and meta-ethical perspectives, but for the general public, the applied/ descriptive perspective on ethics is perhaps more relevant. We have yet to define what actions are acceptable and under what circumstances our use of geospatial technologies is ethical and moral.

One particular ethical dilemma we face is the so-called exterior surveillance vs. interior sousveillance. Recent technological advances seem to point to a paradoxical trend involving the general public and the rapid diffusion of geospatial technologies. On the one hand, millions of Internet users worldwide voluntarily contribute very large amounts of information by the hour (if not by the minute) using Web 2.0 technologies in different formats of user-generated content. The blogs, photos, videos, and twitss contributed by users on the Web often expose people's lives in excruciating detail. There is a vast literature in psychology about this aspect of human nature, which is closely related to exhibitionism and voyeurism. In fact, most people not only want and enjoy surveillance, but also play with it and use it for comfort (McGrath, 2004). On the other hand, we have repeatedly seen headlines in various news media on the growing public concerns and outcry about the danger of surveillance, invasion of privacy, and a looming geoslavery on the horizon. Although fragmented studies and reflections have been reported, there exists no comprehensive study so far linking these two separate lines of inquiry to address this love–hate reaction by the public to surveillance in general, and geosurveillance in particular. We need more research and attention to this area, which may facilitate the development of applied ethics for geospatial technologies.

The dilemma seems to derive from the fact that human existence is often characterized by the paradoxical desires of trying to be both private and public. The question is when, where, how, and whether the parties involved have the choice of disclosing or not disclosing. On the one hand, we are all afraid of the darker scenarios of repressive obsession and the invasion of privacy through the relentless logistics of data gathering and database linkages. Dystopian depictions of a future totalitarian state run by a super-panopticon is also too Orwellian to be real. On the other hand, the seemingly new fascination with certain forms of surveillance as a source of pleasure and entertainment is manifested in the increasing popularity of webcams, the proliferation of claims to real-time/live broadcasting, and the global success of the reality TV genre, which has resulted in the dramatic proliferation of surveillance both as subject matter and as narrative structure in contemporary cinematic production. The risks of aestheticizing surveillance can potentially trivialize its irreducible and all-too stark political dimensions.

Another ethical issue is related to the so-called first law of geographic information: information is often the most scarce when it is needed the most. Have the applications of geospatial technologies helped to narrow or widen the digital divide? The new surveillance infrastructure, of which geospatial technologies are an integral part, mediates the production of social knowledge and action toward individuals. The potential uses of locational infrastructure redistribute the power to negotiate the meanings and uses of public places. Non-reciprocal visibility is one of the greatest inequities in contemporary surveillance. Who is being constantly surveilled? The news reports seem to point to the young, the sick, the elderly, and the vulnerable.

The on-going war on terrorism raises another ethical dilemma. High-resolution satellite images available on Google Earth™ have reportedly been used by terrorists in Yemen in 2006 and insurgents in Iraq in 2007 to plan attacks on allied troops. True, committed terrorists could find all this information in most public libraries, but the increasing availability of online geospatial databases has made some of the sensitive information a lot easier to access. In other words, by making more geospatial information available online, we have inadvertently created an infrastructure that can be used counterproductively by terrorists to plan and launch attacks against us.

In his classic essay "The Tragedy for the Commons," Hardin (1968, p.1243) somberly warned "ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all." This raises the question, should society impose certain limits and guidelines in terms of who can collect, access, use, retain, and disseminate geospatial data?

Seeking Remedies: Discussions and Prospects

Evidently, the recent developments in geospatial technologies and their wide-ranging applications have raised a series of challenging legal and ethical issues. Although existing laws and regulations can be applied to some limited extent, we need a combination of legal, ethical, and technical approaches in order to address these issues effectively.

New Legislation

Most legal issues regarding the use of geospatial technologies in society revolve around the issues related to geospatial data/information at the individual or collective levels, and include: (1) data collection; (2) data retention; (3) data access; (4) data use and integration with other information; (5) data dissemination; and (6) data ownership and licensing. Comprehensive legislation is needed to clearly address these issues at local, national, and international levels. The European Union framework, as implemented in the Netherlands, strikes a balance between protecting consumer privacy versus offering adequate services, while at the same time the new legal frameworks are also widely accepted by the general public. In the USA, former North Carolina Senator John Edwards initiated new federal legislation on locational technologies in 2003, but the new law was not brought to the Senate floor for a vote due to his subsequent vice-presidential nomination in the 2004

presidential campaign. Generally speaking, the USA has taken a more laissez-faire approach to markets, which tends to restrain government, whereas EU tends to regulate third parties.

A core concept that much of the new legislation hinges upon is locational privacy, which suggests individuals have rights to their signature in space and time and can determine when, how, and to what extent location information is communicated to others. For further legal protection Sui (2006b) proposed that location be treated as an integral part of a person's identity, as where we are often reflects and defines who we are. By treating location as part of identity, Sui (2006b) argued that many existing laws regarding identify theft can be invoked when a person's location information is collected, used, and disseminated without the person's permission.

In recent years, more than 13 US states have passed laws restricting RFID adoption and application. Texas, for example, passed laws prohibiting school districts from requiring students to use an RFID device for identification. Wisconsin made it illegal to implant RFID chips into human bodies. Also, New Mexico and Tennessee require the disclosure of RFID chips to consumers and the removal or deactivation of tags at the point of sale of RFID-chipped merchandise (http://rfidprivacy.mit.edu/access/happening_legislation.html).

There also have been efforts in recent years to develop measures of self-regulation by industry. Although industry self-regulation is a welcome step toward protecting personal privacy, these rules and regulations by service or data providers often focus on relieving themselves of legal liabilities, thus avoiding potential law suits in case something goes wrong. It is also hard to enforce those industry self-regulations.

Many businesses offering LBS or geospatial information have increasingly realized the importance of the legal and ethical issues that a suite of powerful geospatial technologies has brought to individuals and society. Industry leaders have recognized that safeguarding sensitive personal information is not only important to consumers, but also of paramount importance for the sustainable growth of their business. Most LBS or geospatial data providers have developed their own privacy policies and protocols posted on their web sites, most of which warn users of the potential risks of using their data or services.

One particular area that has attracted much public attention in recent years is the legal limit of an employer's right to conduct surveillance on employees. As the boundary between work and non-work is increasingly blurred in the digital economy, how to track employees for their productivity, although understandable and legitimate, has caused considerable privacy concerns in recent years. Furthermore, inspired by Garrett Hardin's tragedy of the commons thesis, Onsrud (1998) argued for the existence of what he called the information commons. Drawing from experiences in developing laws to protect the environmental commons, he proposed to develop new legal frameworks for the information commons.

New Ethics

Legal remedies are expensive and notoriously slow, and not every potential problem caused by geospatial technologies can be litigated. Therefore, in addition to legal solutions through new legislation, scholars have also been calling for the development of new ethics rules and social norms at both the individual and societal levels suitable for the age of pervasive computing. In addressing many of the social issues brought by new technologies, new ethics and moral practices are perhaps more effective, because as humans we are more likely to be seduced by new ethics rather than coerced into compliance with new laws.

To resolve many social problems, Dodge and Kitchin (2005) advocated a new ethics of forgetting, which clearly articulates a new set of rules on "how" and "when" to "forget," and even "delete," the massive electronic information in the age of pervasive computing. The rapid development of pervasive computing in general and geospatial tracking in particular has led to the widespread sousveillance, which complements surveillance, through the development of life-logs. We now have a new cyber-infrastructure for socio-spatial archives that can document every action, every event, every conversation, and every material expression of an individual's life. A new ethics of forgetting needs to be developed and built into the development of life-logging technologies. Rather than seeing forgetting as a weakness or fallibility, Dodge and Kitchin (2005) argued that the new ethics of forgetting could be an emancipatory process that will free pervasive computing (of which geospatial technologies are part of) from burdensome and pernicious effects.

Recently, Google™ has already started a new business of blurring or deleting sensitive targets on Google Maps™ or Google Earth™. Although the benefits of a new ethics of forgetting cannot be denied under certain circumstances, it is not always possible, or even desirable, to adhere to forgetting as a new social norm. Inspired by Asimov's "Three Laws of Robotics" (Table 2), Durocher (2002) formulated a set of three laws of LBS (Table 3), which he contends that the LBS industry should adopt. Overall, LBS should have ethical laws regarding (1) its use during emergency situations; (2) its voluntary status; and (3) the appropriate/beneficial use of the locational data.

Table 2: Asimov's Laws of Robotics

First Law of Robotics:
A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
Second Law of Robotics:
A robot must obey orders given to it by human beings, except where such orders would conflict with the First Law.
Third Law of Robotics:
A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

Table.3: Durocher's Laws of LBS

First Law of LBS:
Location, through its availability or non-availability, must not allow a human being to come to harm.
Second Law of LBS:
The availability of one's location must be in one's complete control, except where such control would conflict with the First Law.
Third Law of LBS:
The providers of location-based services must be allowed to create a profitable business from these services as long as such business does not conflict with the First or Second Law.

Since its original publication in a short story called “Runaround” in 1942, Asimov's three laws of robotics have been continuously debated and fine-tuned. Although still controversial, several extensions have been made, Asimov's laws have been widely accepted as a reasonable guide to discuss the moral issue of robotics. Even Asimov himself admitted that “there was just enough ambiguity in the three laws to provide the conflicts and uncertainties required for new stories, and to my great relief, it seemed always to be possible to think up a new angle out of the sixty-one words of the three laws”.

Although significant fine-tuning is needed, Durocher's three laws of LBS offer a reasonable guideline for the use of LBS in the near future – provided that an enforcement mechanism can eventually be established. The first LBS law addresses the requirements of LBS in emergency situations. It is consistent with enhanced 911 (E911) services as mandated by the new FCC regulation. It is reasonable to expect improved emergency services if all 911 calls are locationally explicit. The first law of LBS also requires that no services should put mobile users in danger.

The second law would ensure that LBS services are voluntary, and therefore that privacy should be preserved for individuals subscribing to these services. Under normal circumstances, a subscriber should be able to prevent others from locating him or her. But totally complying with this could also put the user at risk, since in emergency situations it might be impossible for the user to provide all the necessary life-saving authorization- Alaso, in some cases, the police will want to (and already do) track cellular phone usage to locate dangerous criminals.

Finally, the third law stresses the fact that providing location information alone is not sufficient to sustain business growth. Service providers must find a way to develop the right business models and charge the appropriate fees for the right services. Applications must bring real value that consumers and business users will be willing to pay for. However, the third law also ensures that no business should be able to benefit from the

availability of location data to the detriment of a LBS user's right to complete privacy and safety.

As Fisher and Dobson (2003) illustrated in their seven different scenarios regarding the use of LBS (Table 4), the legal and ethical implications of LBS are complex and contingent upon many uncertain parameters in the real world. Nonetheless, I believe that the three LBS laws provide reasonable guidelines for most civilian applications, as tested by the Fisher and Dobson's seven scenarios (Table 4). The ethics of forgetting is only one of the seven possible real world scenarios defining practices that may be viewed as desirable.

Technical Solutions: Steps toward Trustworthy Geospatial Technologies?

Legal and ethical strategies for remedying the problems brought about by geospatial technologies are trust- based mechanisms for delimiting unacceptable uses of location information. However, trust can be breached, making sensitive information still vulnerable to unintentional and intentional disclosure. Therefore, the research community also suggests development of technical solutions. A range of previous research on location privacy has addressed the issue of adapting the level of spatial detail in location information as needed to protect an individual's location privacy. This concept is termed spatial generalization by Mascetti and Bettini (2007), but has also been variously termed in the literature as “spatial cloaking”, “obfuscation”, the “need-to-know principle”, and the “principle of minimal asymmetry”.

Table. 4 Surveillance Scenarios and Laws of LBS

Scenarios	Examples	Legal/Ethical Issues	Laws of LBS
They didn't know where you were	Normal life for ordinary citizens	Personal privacy/ ethics of forgetting	Obeyed (violated if the person is suicidal?)
They know and you want them to	On call, emergency, alibi	Consent	Obeyed
They don't know but you thought they did	Faulty signal, signal blocked, physical density	Ignorence	Violated
They know and we wanted them to	Criminal activity, unethical conduct	Public interest	Ambiguous
They know and you didn't want them to	Nuisance calls, stalking, monitoring	Geo-identity Theft	Violated
They know and we thought we wanted them to	Abusers, hostage takers	Coercion	Violated
They know and can physically keep you there	Forced labor or domestic abuse	Geo-slavery	Violated

Generally, two major strategies have been well-developed and adopted: anonymity and obfuscation. Anonymity is often regarded as one of the privacy-sympathetic technologies (PST). Anonymity detaches or removes an individual's locational information from electronic transactions. Anonymity is normally quite effective in protecting individual privacy. However, with recent advances in data mining techniques, GIS can integrate locational information with other data such as remotely sensed imagery, georeferenced social, economic, and cadastral data, point of-sale data, credit-card transactions, traffic monitoring and video surveillance imagery, and other geosensor network data, allowing identity to be inferred. Obfuscation techniques deliberately degrade locational information, using error and uncertainty to protect privacy, which is part of the privacy enhancing technologies (PET). They also include geographic masking for static data (Armstrong et al., 1999). Duckham and Kulik (2006) extend the obfuscation approach to mobile objects. They also consider ways to counter potential threats from third parties who can refine their knowledge of a mobile object and compromise the obfuscation.

Reactions by the International Community

Facing the threat of freely available high-resolution satellite images in various digital globes such as Google Earth™, Microsoft'®s Virtual Earth® , NASA's WorldWind, and so on, many countries have taken a variety of steps to protect their national interests. According to a confidential report recently issued by the CIA's Open Source Center and made public by the Federation of American Scientists (http://www.usatoday.com/ tech/news/surveillance/2008-11-06-googleearth_N.htm), the following reactions have been reported by the international community in response to the recent advances of geospatial technologies.

• Negotiation – some nations have asked Google™ and other companies to keep certain images off the market. For example, Google Earth™ uses older imagery for several areas of Iraq based on British concerns about exposing its military sites. Some commercial imagery providers – typically those providing pictures from planes, not satellites – blur sensitive images before they are provided to Google™, usually in accordance with local law or at the request of local authorities.

• Bans – China issued a new government regulation barring websites selling "unapproved" commercial imagery in 2008. Similar rules were also implemented in Bahrain, but the move has been mainly to prevent exposure of elaborate residences and land holdings of the country's rich and powerful.

• Buying in – several countries, such as China and Thailand, are getting into the satellite imagery business themselves, and India sells its spy photos commercially. Many countries without their own satellites have become enthusiastic purchasers of commercial imagery to meet intelligence and security needs, and international demand for high-resolution satellite imagery has been growing steadily in recent years.

• Evasion – many countries have stepped up efforts to conceal sensitive facilities, either by putting them underground or camouflaging them. Others, such as India, have improved their ability to discern when satellites pass overhead, which allows

them to conduct sensitive military activities when cameras are not watching. (For more details, see http://www.fas.org/irp/dni/osc/google.pdf).

However, these actions are ad hoc. There is an urgent need for the international community, perhaps under the umbrella of the United Nations, to update the rules and resolutions regarding the use of geospatial technologies at the international level in order to narrow the global digital divide between the information rich versus the information poor countries.

Summary and Conclusion:

It is abundantly clear that recent technological advances in geospatial technologies have created a complex set of legal and ethical issues that deserve a broader dialogue in society about their short- and long- term implications. Mark Poster (2004) argued that networked digital information "humachines" should be understood as the central part of the evolving, unavoidable aspect of globalization. The new technological cornucopia tends to erode privacy, create new forms of inequality, and diminish the mechanisms of accountability. Indeed, a broader dialogue is needed to awaken humanity from its technological somnambulism. Whereas these humanchines bring with them countless risks and afford considerable resources for highly dangerous agglomerations of power, they also offer serious points of resistance to those powers and may serve as a base for developing auspicious, decentralized, multicultural global networks.

Technological advances provide us with hope for trustworthy computing that is capable of giving users more secure control of their own personal information, but technical remedies are not sufficient for the legal and ethical challenges discussed in this chapter. We also need broader legal and ethical frameworks that can effectively deal with issues at individual, institutional, and international levels. Similar to the dilemmas brought by bio-tech innovations, how to capitalize on the benefits of geospatial technologies and deter (even diminish) the emergence of a dystopia of Orwellian, or a monster of Frankenstein, proportions remains one of the grand challenges for our technological society. Obviously, we all want to savor the fruits of the latest advances in geospatial technologies without succumbing to their most dangerous temptations. Whether this delicate balance can be achieved is far from clear at this point.

Geographers have long been interested in studying complex issues at the intersection of geography and law, geography and ethics, geography and morality, and the education of the next generation of geographers. The widespread applications of geospatial technologies in society and our individual lives have opened new avenues for intellectual inquiries that will have far-reaching impacts. Geographic information scientists need to work closely with other geographers and with scholars in other disciplines facing similar legal and moral concerns in order to address many of challenging issues reviewed in this part.

Legal Issues Regarding Spatial Data:

The main legal issues regarding the spatial (geographic) data, information and GIS technology supported databases in general are related to the three prevailing problem domains:

− Intellectual Property Rights and GIS technology - copyright issues on spatial data sets, topographic and thematic maps, GIS databases, GIS software and applications etc.,

− Privacy Protection and GIS technology - confidentiality protection in GIS databases versus enabling public access to spatial data, personal integrity data and political sensitive data, policy for restrictive disposal and limited access to spatial data etc.,

− Liability and GIS technology - warranty and (legal) responsibility for specified spatial data quality, liability contract problems, negligence, torts and damages, limited recovery strategies for spatial data etc.

GIS Data Dissemination and Intellectual Property Rights

Introduction

Digital spatial data likely to be available in huge quantities that too for countries like India where a billion-plus human population interacts with environment, and its dissemination over the network is a complex and gigantic task in scale and dimension. Integrated information and communication technologies provide tremendous opportunities as well as challenges in data storage, retrieval, analysis and dissemination. Current technological advancements and future forecast that computer networks will be powerful in gathering information rapidly and inexpensively. This leads to the tremendous integration and development of third party- products and also secondary use of transactional data. Geographical Information Systems (GIS) are concerned with spatial data collection, analysis and their use. These inputs are primarily from topographical/ thematic maps, GPS/ ground based observations and aerial and space- borne sensors. Such a digital spatial data generation and dissemination will be effective through convergence of information and technologies from geo-spatial technologies as well as Communication technologies which are broadly grouped into (a) non-spatial (b) spatial and (c) networking/ communication technologies and sub-segments listed below;

(a) Non-Spatial Data Sets (for ex Land Records, MIS and Miscellaneous)

(i) Computerised MIS, Relational Data Base Management Systems

(b) Spatial Data Sets (Basic Digital Vector Data, value- added data Services)

(ii) Remote Sensing/GIS Technology based products

(iii) 3 D GIS and Digital Photogrammetry based products

(c) Networking/Communication Technologies(Dissemination/ administration)

(v) Networking, Wireless technologies

(vi) Computer Integrated Telephony, Real-time applications

Digital Data Ownership and Related Copyright Liabilities

It has been primarily Survey of India, the authenticated government agency all the way responsible for survey, publication and dissemination of printed topographical maps and later spearheaded by National Atlas and Thematic Mapping Organisation (NATMO) through thematic maps. Recent developments indicate that both these agencies have gone

the digital way, thus by making available digital data to the interested users. Recent decade witnessed mushroom growth of private agencies/ companies digitizing and selling these map products in the open market. Incidentally the source data is either from SOI/NATMO (in exceptional cases, town guide maps). In some cases (like Eicher city maps) these large- scale maps larger than 1: 25,000/10,000 the source of data were supplemented by limited ground surveys as well as recent satellite images. Then came the authorisation of nine government agencies by the government of India for digitizing/ incorporating the detailed information like heights, contours etc in the commercially available digital map products. Legal ban anyway existed for publication/ dissemination of restricted category topographical maps and large-scale vectorised digital spatial data. Web based digital spatial data dissemination (digitised vector) had to depend upon the client-server computer capabilities and this enabled the user to have indirect access to the digital vector data. Bitmaps or JPEG format maps appear on the users screen with minimal manipulation capabilities, while the original data lies in the server and processing happens in the host-server or web-server that distributes the data.

Legal obligations include applicable sections of official information act, official secrets act and cyber-crime act amended from time to time. Under such scenario, ownership of geographic information, liability issues, legal rights and duties, limitations, responsibilities, code of conduct had to be promulgated and adopted under the legal framework within each countries, worldwide by users, system developers and data custodians. GIS system per se do not fit into any of the specific categories of works whether literacy, dramatics or artistic but yet these are products of human creativity and of great value to the society in all its applications. It has been projected that thin copyright for GIS map products give the ease of copying digital data. Court of law examines the process as well as data as an asset in GIS systems within the framework of the concerned (Cho, 2000).

Digital Data: Current Intiatives and Future Prospects

National Spatial Data Infrastructure (NSDI):

The Survey of India primarily has the task of evolving digital vector data (DVD) standards for creation of digital spatial data which forms the back-bone of the proposed national spatial data infrastructure (NSDI). Private entrepreneurs have much more challenging role in terms of data generation, data dissemination, value-added services and so on. With NSDI initiative becoming a near reality within few years, it is paramount to identify the private entrepreneur role within the overall framework and to propagate the efforts. Even though attempts have been made for the past two decades, its necessary to point out that inconsistency still exists in databases generated across India, (especially established by separate agencies like National Informatics Centre through its state and district centres: NIC: DISNICs) by various studies/ research. As a part of initiatives from Indian space research organization (ISRO) and department of science and technology (DST) progress is being reported to evolve a National Spatial Data Infrastructure (NSDI). NSDI focuses on decentralized approach with main emphasis on:

- Develop and maintain standard digital collections
- Develop common solutions for discovery, access and use of spatial data
- Build relationships among organizations
- Increase the awareness and understanding of the vision, concepts and the benefits

The overall framework that is being planned in NSDI is shown in Chart. 1.

On the basis of approaches for evolving NSDI standards at domain servers, dedicated thematic map server expected to be established for meta-data bases and available for users on demand through single window mechanism or data clearing house for each region/state across India. It is expected that the development of National Spatial Data Information Infrastructure (NII) in USA will enable the convergence of computers and telecommunications on a massive scale and dimension whereas in Japan it will handle voluminous data across network with bi-lingual capabilities of which major contribution comes from private entrepreneurs through NSDIPA. Under such scenario, patents, copyright and IPR issues related to digital spatial data assumes greater relevance and significance.

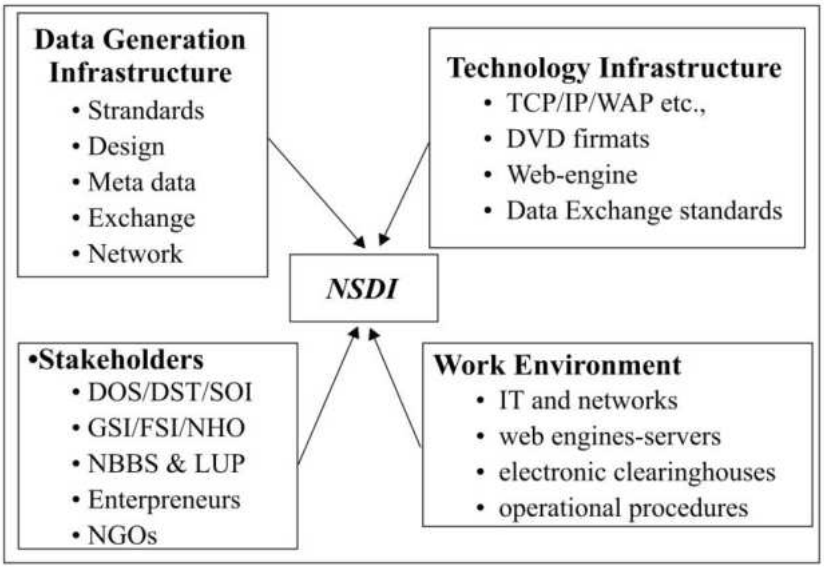


Chart. 1 NSDI functional inter-linkage components

Copyright and GIS

A major reason for singling out copyright for an in-depth treatment is that it imposes on nearly every aspect of GIS as we know it. GIS as applied to geographical data will involve a system of hardware, software and iterative procedures that are designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data.

The present task is to analyse the copyright issues as they relate to GIS by examining each functional step in the system where a perceived intellectual property right (IPR) might subsist.

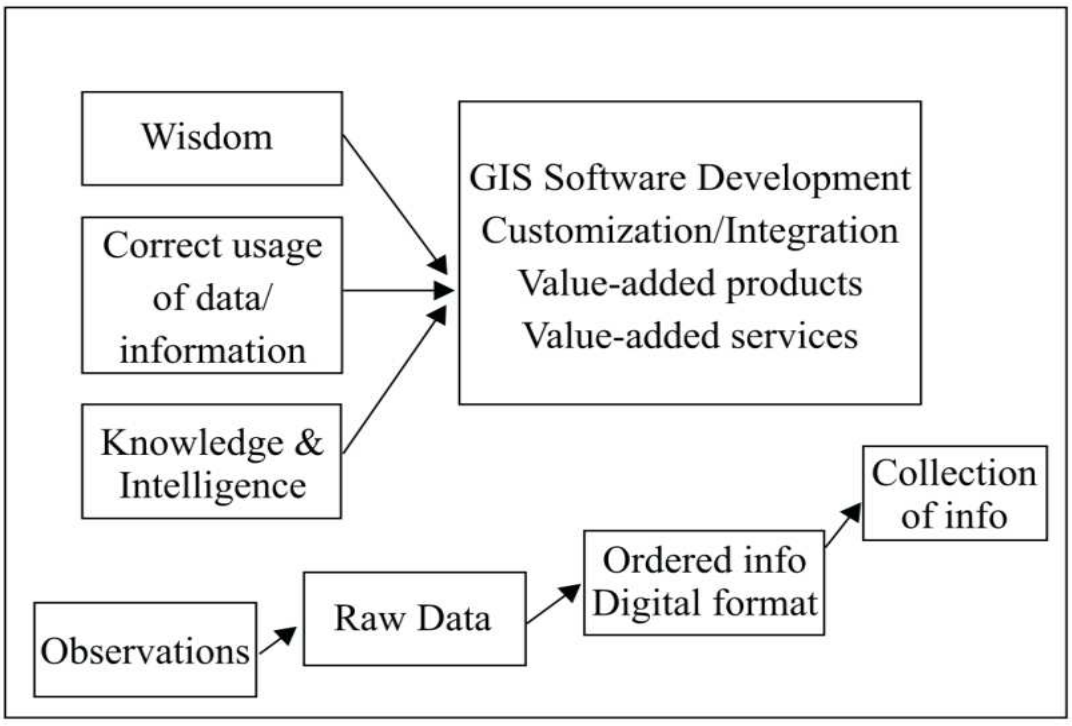
Risk management principles in GIS data/ services and products:

In a general way, the development of GIS involves creation and modification of databases, purchase of GIS software, hardware and other peripherals. Selection of data including topographical/ cadastral data, satellite data and other collateral data. The GIS techniques enable us to derive multi-tasking, e.g., preparation and presentation of maps, reports, and considered expert opinion on the analysis/ strategies to assist in the decision-making process. So it is essential to agree that it is experts commitment to provide reliable and accurate and integrated information and analysis. Some of the risk include failure to secure intellectual property rights for GIS and liability for IPR infringement; failure to secure accountability for a defective GIS and liability for breach of privacy or confidential obligations. Legal uncertainties are involved in contracting out either by or to a government agency. However if products of GIS are considered for provision of services, then different aspects of law come into play, namely liability arising from negligence - a duty of care, the breach of duty of care, causation or proximate cause, and damages. Liability in contract terms may be more limited and narrower in scope.

Guidelines for costing and provision of spatial data:

Such policies do not over ride limitations imposed by privacy, confidentiality, liability, intellectual property, national security, other co-operative arrangements, international agreements or statutory obligations.. The development and applications of GIS in a commercial context may involve several legal risks, if ignored could result in a liability and loss for a business or government entity that develops GIS and/or sells, distributes and resells or provides GIS services.

Chart 2: Process of data/information conversion into IP



India Needs IPR Courts

Cyber Law and IPR compliance will be the guiding factors in this complex yet rewarding process. The security and technological risks, involved in this process of transformation, too, will need to be well addressed. Ignorance and non-compliance of Cyber Law/ IPR, thus, can attract persecution in a court of law, making it imperative for every member of the corporate world to learn its technical and critical components. In an effort to create awareness and knowledge sharing regarding these issues, The Centre for Intellectual Property Rights, Research and Advocacy (CIPRA) was established in 1998 by The National Law School Of India University (NLSIU), Bangalore. CIPRA has developed the following website http://www.iprlawindia.org/iprlaw/ with the support of NISSAT (National Information System for Science and Technology). It provides comprehensive coverage of Indian intellectual property resources.

India needs to set up exclusive judicial courts to deal with intellectual property rights (IPR) issues, which are on the rise, according to the noted legal expert and patents judge, Mr Michael Fysh, who states that India has moved from the developing to a developed country status as far as IPR is concerned. Mr Fysh advocates that these courts should have at least two assigned judges who have experience in practice of IPR work and also a science degree. The IP Court should not be a tribunal as in the case of environment, consumer or labour courts because of the nature of the issues involved. The life of a patent is technological risks, involved in this process of transformation, too, will need to be well addressed. Ignorance and non-compliance of Cyber Law/ IPR, thus, can attract persecution in a court of law, making it imperative for every member of the corporate world to learn its technical and critical components. In an effort to create awareness and knowledge sharing regarding these issues, The Centre for Intellectual Property Rights, Research and Advocacy (CIPRA) was established in 1998 by The National Law School Of India University (NLSIU), Bangalore. CIPRA has developed the following website http://www.iprlawindia.org/iprlaw/ with the support of NISSAT (National Information System for Science and Technology). It provides comprehensive coverage of Indian intellectual property resources.

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around 14 years and that of trademarks and designs is 15 in the Indian context, and therefore protracted litigation does not help, as told by Mr. Fysh, currently judge, patents county court in London, to Business Line magazine to be assisted by independent assessors, qualified in science, the IP courts could deal with patents, designs, trademarks,

copyrights and breach of confidential information among other issues, he said. The British legal expert, who is the last of his countrymen to be a member of the Bar in India, represents foreign and Indian companies in cases in the country and the sub- continent through his juniors. Mr. Fysh expressed skepticism about the efficacy of police courts, which seek to control copyright, piracy and counterfeit cases. They can be a deterrent, but not very effective, since the police are not IP lawyers, he argued. The police, customs and the judiciary should play a proactive role in curbing the menace of piracy that is threatening to kill the culture industry in the country. India needed an IP court like the ones in Thailand, Korea, Germany, UK or the US according to former Deputy Director-General, World Intellectual Property Organisation (WIPO). Source: Technology, Information, Forecasting Assessment Council (TIFAC), Department of Science and Technology, Government of India. In this context Tables 1 & 2 are relevant.

Country	Agency	Cost	Uses allowed
Denmark	Danish Data Archive	No cost For non-commercial use.	May not be redistributed. May only be used for stated purpose after which data must be returned/destroyed.
Ireland	Ordnance Survey Ireland	Varies with intended use	Uses are licensed according to categories of activities (e.g., for architects, solicitors, Internet, etc.)
New Zealand	Crown Research Institutes	Recovery of direct costs is allowed	Open, except where use is not to the benefit of New Zealand
UK	Ordinance Survey	Cost recovery is allowed	Uses are licensed according to categories of activities
USA	United States Geological Survey	Reproduction and handling	Unlimited

Table 1: World wide data use or ownership policies of mapping or data agencies

Patenting Geographic Information Systems, Software/Products and Services

While it is indeed a valuable proposition that intellectual property rights need to be protected for a persons/ companys business strategies, future growth and service to the humanity, it is equally necessary that concerned team of groups or individuals are aware of such IPR issues. Table 3 below shows typical ideas/ products/ services/ inventions that are being patented recently in USA/Japan/China. For details please browse through the Internet. Only sample listing is shown, for authenticity and details of patents, one needs to go into details of each patent). Glancing through such patenting table throws light on each of us who are involved in the development/ deployment/implementation of such technology/ innovative idea that more awareness needs to be created among us on how to proceed on each and every stages to patent an invention or development of algorithm and value-added services/ products related to GIS and allied spatial technologies like remote

sensing, GPS, digital image processing and networking. It becomes even more critical in a network sharing work environment (say futuristic NSDI infrastructure) whereby every individual efforts needs to be rewarded/rights are to be protected and any such negligence is challengeable in court of law.

Table 2: Analysis on comparison of basic features of different mechanisms for protecting intellectual property

S.No	Mechanism	Applicable to data per se	Database	Software	Geographic coverage	Comments
A	Copyright	No	Yes	Yes	Respected across jurisdictions.	Only protects form of expression, not ideas or data.
B	Patent	No	No	Yes	Requires application in each country.	Not all countries allow patents on
C	Database protection	Yes	Yes	No	Only vailable in certain countries	Concepts of fair use remain to be established.
D	Written License	Yes	Yes	Yes	Terms used in licenses vary with country (for ex., workservice")	If well written, provides perhaps the least risk of misunderstanding. Especially useful when dealing with agreements among diverse organizations.
E	Shrink-Wrap	Yes	Yes	Yes	for hire" vs. "contract of/for uncertain	Validity of such licenses is still bein tested in courts.
F	Trademark	No	No	No	Requires application in each country.	Used only for names and logos.
G	Trade secret	Yes	Yes	Yes	Laws protecting secretsvary greatly	Requires that deliberate efforts be made to keep information or product secret.

Table 3. Examples of recent US patents related to Geographic Information Systems.

The assignee is the individual or entity to whom ownership of the patent was assigned at the time of patent issue, typically the business that employed the inventor(s).

Patent No	Title	Assignee
6411899	Position based personal digital assistant	Trimble Navigation
6408107	Rapid convolution based large deformation image matching via landmark and volume imagery	(information not available on USPTO database)
6404920	System for generalising objects and features in an image	(information not available on USPTO database)
6389356	Geographic information system	Matsushita Electric Industrial Co
6353832	Selectivity estimation in spatial databases	Lucent Technologies
6337693	Vector-based geographic data	Autodesk
6321158	Integrated routing/mapping information	Delorme Publishing Company
6308177	System and method for use and storage of geographic data on physical media	(information not available on USPTO database)
6307573	Graphic-information flow method and system for visually analysing patterns and relationships	(information not available on USPTO database)
6282362	Geographical position/image digital recording and display system	Trimble Navigation Limited
6262741	Tiling of object-based geographic information system (GIS)	PRC Public Sector
6247019	Object-based geographic information system (GIS)	PRC Public Sector
6240424	Method and system for similarity-based image classification	NBC USA
6240360	Computer system for identifying local resources	Multipmap.com
6229546	Rapid terrain model generation with 3-D object features and user customisation interface	Geosoftware
6216130	Geographic-based information technology management system	InGeo Acquisitions
6115672	Method for measuring and quantifying amounts of carbon from certain greenhouse gases sequestered in and by grassy and herbaceous plants above and below the soil surface	Environmentally Correct Concepts
6107961	Map display system	Kokusai Denshin Denwa, Japan/USA

Conclusion

While authors appreciate the efforts taken by the government of India in creating awareness on IPR and related issues , especially by CSIR, TIFAC, DST etc, it is yet to draw comprehensive IPR policy covering the entire business processes and value-added services. In fact our attempt is one of the first of its kind to create such awareness within the paradigm of geo-spatial solutions and services industry, especially GIS and related systems development. The paradigm of intellectual property rights and its role in development of GIS systems/ applications/value-added services are of immense value with reference to the growing GIS industry segment coupled with expected availability of high to very-high resolution satellite data products through traditional means or over Internet. Indian geo-entrepreneurs are yet to make headway into this arena.

A set of guidelines for managing spatial information related IPR and other interesting details could be seen from the CAS web-site and other listed web references.

Privacy Issues in Geographic Information Technologies

Introduction

The concept of privacy varies widely between societies, across time and even between individuals. Therefore, providing a succinct definition of privacy is difficult because one person's concept of what constitutes privacy intrusion can be very different from another's. An extensive survey of personal privacy (Rotenberg and Laurant 2004) was carried out by Privacy International as part of the Global Internet Liberty Campaign. The original report is now revised and extended on a yearly basis and identifies four broad privacy categories:

Information privacy:

protection of data containing personally-identifiable information; examples of personal data include medical records and bank statements.

Bodily privacy:

protection of people from physical invasion; examples of bodily invasion include drug tests, cavity searches and genetic testing.

Privacy of communications:

protection of all forms of communication from interception; examples of interception include monitoring telephone, email and written correspondence.

Territorial privacy:

protection of domestic, work and public space from intrusion; examples of intrusion include search warrants, video surveillance and identity checks.

Gavison (1980) took an alternative approach and defined privacy in terms of three commonly asserted moral rights connected with privacy:

Solitude:

the right to control access to a personal space; examples include undisturbed reading of a book in a park or enjoying a meal with family and friends at home.

Secrecy:

the right to control the collection and onward distribution of sensitive personal information; example types of information include medical records, family photos and private communications.

Anonymity:

the right to remain anonymous and unnoticed in social interaction; examples include shopping for goods and services without identification and the ability to speak freely with anonymity.

In many traditional social structures, individuals experienced relatively little solitude, secrecy or anonymity; gossip could spread intimate personal details and actions of other members of the community quickly. Such information was rarely spread outside a community since the method of communication was often by word-of-mouth and the information transmitted would generally have little relevance to remote communities, except where it concerned a famous or wealthy individual. As most events were committed to memory rather than written down, past events were tempered by time since recent actions of an individual allowed the community to subconsciously re-evaluate an individual's previous behaviour.

At the dawn of the industrial era, large metropolitan areas developed and people gathered together in much greater numbers. This enabled the general populous to enjoy much greater levels of anonymity than was possible in a small and relatively closed community. During the same period the reading and writing skills of the population improved as better education became available to the masses. Writing enabled individuals to record and distribute an immutable record of current events; this, together with the development of the printing press and instantaneous photography, enabled invasion of the secrecy and solitude of an individual on a much larger scale than was previously possible.

Developments in science and technology over the last century continue to provide individuals, companies and governments with new and more invasive ways to intrude on the privacy of individuals and communities. Since the latter decades of the 20th century, computer systems have developed their capacity to collect, analyse and distribute sensitive information at an exponential rate. This, together with advances in medicine, transportation, finance and communication have resulted in the recording and preserving of many more private facts.

Globalisation has also accelerated the analysis and distribution of private data through the development of high-speed computer networks and the growing number of interoperability standards. Examples include the Internet Protocol, facilitating ubiquitous

network connectivity, and standardised data storage formats and meta-formats such as XML.

There are many reasons for recording and distributing personal information. Most governments, while wildly varying in political constitution, now demand some personal information from citizens; examples include earnings, family make-up, religion and qualifications. The stated goal of data gathering is that of collective good for society; in many cases the benefit is clear, for example, the regulation of medical practitioners, but in some cases the societal benefits are less obvious.

Commercial organisations are primarily concerned with profit, yet companies are often much more invasive than their governmental counterparts. Traditionally, marketing, advertising or brand loyalty have been suggested as the major motivation, but more recently price discrimination–the act of charging individuals a personalised price based on the amount they are prepared to pay–has been suggested as a strong motivating factor.

Discriminatory pricing works best in markets with large, fixed, up-front costs and low marginal expenses. With the centralisation of services and reduced cost of communication and transportation, more industries fit this model. Price discrimination is not a new phenomenon: it was used extensively throughout the early development of the railways in the US and Britain until a customer backlash introduced extensive regulation. Traditionally its use has been limited by the lack of technology to perform detailed customer profiling, however recent developments in computer systems make such techniques relatively simple and cost effective.

Recent price discrimination examples include flights, computers and even DVDs. The region coding scheme on DVDs was (in part) motivated by the desire to enforce a price differential on discs sold in different areas of the globe. In September 2000, Amazon experimented with price discrimination on for customers buying otherwise identical DVDs; this practise was quickly discovered by Internet users and was widely reported in the press. The situation had the Amazon community split–some thought the practise was fair, others abhorred it.

Specific GIS privacy issues

The development of the Geographic Information Systems (GISs) mirrors the technological development of computers and the globalisation of government and industry. Traditional GISs ran on mainframe computers with relatively little computational power and data were often entered manually by the users of the system. Desktop GISs widened the market and, with the development of computer networks and cheap, removable media, increased the ability of individuals to copy and distribute geographic information. Recent developments in GISs have seen further growth in distributed processing and real-time data sharing over the Internet.

The types of data stored in a GIS are not restricted to solely topological facts; rather, the aim of many GISs is to spatially index and cross-reference multiple datasets containing a wide variety of information, and much of this data may well be of a personal and private

nature. Therefore, the potential for privacy invasion of spatially-indexed personal data can be at least as problematic as a generic computer database.

Due to the expense of mainframe computer systems, early GISs were predominantly used by governments and large corporations. Typical government uses include tax assessment, zoning and planning, environmental impact analysis and maintenance of transportation and utilities. Businesses with a direct involvement in the exploitation of natural resources have an obvious need for recording and processing spatially-indexed data, yet the spatial indexing of personal data has many other uses for commercial enterprise.

Geodemographic software systems are a particular type of GIS used to categorise individuals living within a particular geographical region with a common set of socio-economic attributes. Such databases are popular with a wide variety of businesses. For example, mass marketeers use demographic data to direct advertisements to specific regions and thereby reduce postage costs on sending adverts to areas deemed unlikely to be responsive to a particular product. Other businesses use location data to determine the best location for retail outlets or to offer a potential customer a personalised price for house and motor insurance.

Traditionally, companies producing geodemographic software believed the accuracy of the system depended on the size of the region associated with a particular demographic, the quality and variety of the data used to generate the demographic for each area, and the number of possible socio-economic attributes. Therefore, by reducing the size of the geographical region, a geodemographic system should select a more socially homogeneous group, and this, together with more detailed and accurate input data about the group, combined with a greater number of possible attributes, should produce more accurate geodemographics. There are, of course, limits to the accuracy of such an approach; nevertheless the continued existence and popularity of geodemographic systems in the business community demonstrates their utility.

Recent technical innovations such as GPS and mobile telephone location systems show the potential for dynamic geodemographics. With this technology, geodemographic analysts can use the set of locations an individual visits during the day rather than just their permanent home address. Proponents of geodemographics anticipated that this set of data will provide better insights into the socio-economic groups of individuals. This concept can, of course, be extended to allow fully fledged location-based services where advertisements or products are offered to potential customers based on their current geographic location.

Geodemographic software encourages the practise of “redlining”, where business avoid offering services such as mortgages or insurance to geographic areas considered to be a poor economic risk. Such practises represent a form of discrimination, but may also be interpreted as form of collective or territorial privacy violation, since personal data is gathered from a community and used to generate a, perhaps unfair, or at least generalised viewpoint of the population.

Indigenous people have also expressed concerns over the use of GISs. Worries about GISs stem partly from a cultural desire for collective territorial privacy, where certain regions are considered sacred and private and as such should not be visible to outsiders. GISs can be used to determine regions rich in natural resources and therefore indigenous populations are concerned that recording such information may lead to pressure from governments and commerce for exploitation. The data does not even have to be collected locally, and this reduces the ability of the local population to control the access to, and dissemination of, information about their land. Satellite imaging systems integrated with GISs can be deployed remotely by governments and commercial organisations to intrude on territory without the consent of the local population.

GISs raise both information privacy and territorial privacy concerns. Protecting the set of movement data from a specific individual is a form of information privacy, whereas protecting the information concerning personal or collectively private spaces is an instance of territorial privacy.

Future directions of computing and GISs

The price of computers continues to fall dramatically, following the downward price trend which started almost as soon as computers entered mass production. Astoundingly, as the price of computing has dropped, the performance and portability of computers has increased immensely. Most people in richer nations no longer own just one computer, but a dozen. If the price, performance and portability trend continues for much longer, the average consumer will soon be able to afford a hundred or a thousand small and powerful computational devices. Many of today's computers operate independently, however as the deployment of wireless technologies takes hold, devices will soon start to inter-operate.

Weiser noticed these trends over ten years ago and used them to provide some predictions about computing in the 21st century. He coined the term ubiquitous computing to describe a world in which computers "weave themselves into the fabric of everyday life until they are indistinguishable from it" and claimed that "the most profound technologies are those that disappear." He noted that other technologies have done this before, and envisioned computing becoming sufficiently embedded into our world that users would often interact with computers at a subconscious level, much like we do today with the written word on signs, billboards, books and magazines; "in essence...only when things disappear in this way are we freed to use them without thinking and so to focus beyond them on new goals."

Most individuals are incapable and unwilling to manage a thousand devices in a similar fashion to the control and configuration required for a typical home PC today. Therefore, if ownership of a thousand computers is going to be productive, methods will be needed to automate the vast majority of the tasks these new devices are designed to perform. At the same time, techniques for reducing the cognitive load placed on users through improvements in human-computer interaction will be required.

Context-aware computing(Schilit et al. 1994) or sentient computing (Hopper 2000) augments computers with sensors and actuators in order to achieve a better understanding of, and interaction with, the physical environment. Such systems collect sensor data to build a model of the environment or world model (Adly et al. 1997). Human-computer interaction can then be improved, since individuals can use their five senses to interact with the computer within their real environment, rather than through a screen, mouse and keyboard. A computer system can also make use of the rich and diverse set of sensory inputs to trigger actuators and therefore automate tasks on our behalf. Effective context-aware systems should be easier to use than the traditional computing infrastructure commonplace today and it will therefore enable the average individual to make use of a much larger number of computers than would otherwise be possible. In many respects context-aware computing provides a way to realise the goal of ubiquitous computing.

Researchers in the field of ubiquitous computing have struggled to provide a precise definition of context, yet, from a privacy perspective, it is important to consider what types of information may be required to enable the successful operation of a context-aware system. López de Ipiña describes some of the common attributes, which include identity, location, time, features of the natural environment, such as temperature, light level, air quality etc., physiology, activity, social interaction and nearby resources (López de Ipiña 2003). Dey and Abowd claim there exist four primary context types which characterise any particular situation of an individual or object (Dey and Abowd 2000):

Identity:

the identity of relevant entities.

Location:

the geographical position of relevant entities.

Activity:

the activity or activities being performed.

Time:

the time period at which the entities perform the activity.

All other types of context information are declared secondary because they require association with one or more pieces of primary context to be meaningful. For example, a phone number, address or date of birth is usually associated with an identity; similarly temperature information is only useful when combined with a location, time and possibly activity. It is usual for secondary context to require more than one piece of primary context in order to identify unambiguously a single piece of information; in database parlance, the primary contexts must be combined to form a composite key.

A large amount of research in the field of ubiquitous computing has focused on enabling location-awareness and location-based services. In many cases the scale of these research projects is small in comparison to both the geographical size and data richness of

commercial GISs. However integrating serious GIS systems will become a necessary component of ubiquitous computing systems as the technology is transferred from research groups and into commercial deployment.

Providing computers with knowledge of the context of users means that computers will gather, collate and distribute much more personal information about individuals than they do today. Such personal information is often considered private. Therefore, there appears to be a fundamental conflict between personal and collective privacy and the needs of context-aware computing. The next section outlines some possible methods which can redress the privacy imbalance between the deployment and use of GISs. Particular focus is given to future issues which arise when real-time location information of individuals becomes available for use by GISs and ubiquitous computing systems.

Protecting privacy

Lessig (1999) describes the four basic constraints which regulate the behaviour of individuals: architecture, social customs, market and law. Each constraint poses a distinct but interdependent cost on the individual. Constraints can be complementary or opposing, yet all can ultimately be governed by the rule of law. Architecture and the market regulate behaviour before an action can take place: a locked door prevents unwanted entry and the cost of cigarettes deters consumption. Social customs and law regulate behaviour after the event: diners may scorn if you smoke while eating and the police may arrest you for trespassing on private property. Most individuals feel the threat of social customs or law before the action even though social customs or law cannot actually prevent the act, unlike architecture or market forces.

Law is able to directly regulate behaviour through statute, and indirectly by regulating architecture, social customs and the market; examples of indirect regulation include building codes, sex education in schools and cigarette taxation. Such indirect regulation does raise questions of transparency, particularly in the regulation of architecture. For example Lessig describes how Robert Moses commissioned the bridges constructed on Long Island to prevent the passage of buses–the primary transportation of African Americans–preventing the progress of public transport to the beaches.

There are occasions when breaking a regulation may be morally justifiable, for example, speeding to hospital with the seriously ill; law and social customs are good at adapting in this situation, but architecture and the market are not; for example, a vehicle's speed limiter always limits. Therefore architectural and market forces are arguably more powerful but less adaptable regulators.

This distinction has important implications for the regulation of privacy. Law alone is not sufficient as it is not the most efficient method to prevent unwanted intrusion into the private lives of individuals because: firstly, privacy is very subjective–what is acceptable to one person is unacceptable to another; and secondly, post-action retribution through law may not be able to provide any good remedy— "the cat may already be out of the bag." This does not mean law-makers provide no aid in protecting privacy; quite the

opposite is true–law has a crucial role to play in controlling architecture, market forces and social customs to foster privacy.

Legal instruments

Almost all countries now recognise privacy as a fundamental right and have attempted to codify privacy in law. The first known piece of privacy legislation was the 1361 Justices of the Peace Act (England), which legislated for the arrest of eavesdroppers and stalkers. In 1890 Warren and Brandeis argued that citizens should have the right to prevent disclosure of personal information as a separate right to that of copyright law or of slander or libel (Warren and Brandeis 1890). More recently, the 1948 Universal Declaration of Human Rights (United Nations 1948, Article 12) states everyone has a right to privacy at home, with family and in correspondence. This declaration was reaffirmed in The European Convention on Human Rights (Council of Europe 1950, Article 8) and the International Covenant on Civil and Political Rights (United Nations 1966, Article 17).

Many other more recent pieces of legislation aim to protect citizens 'privacy; some modern constitutions even go as far as expressing the specific rights of access and control of personal information. Lessig argues that we should go further than just protection and recognise (certain pieces of) information about individuals as "real property" in order to provide individuals with the ability to control the dissemination of their data.

The legal protection for personal privacy differs markedly across the globe. Some countries, such as Europe, Australia, New Zealand and Canada, have a comprehensive regulatory model. For example, the European Union regulates the collection of and access to all personally-identifiable information. The 1995 Data Protection Directive (European Union 1995) harmonised data protection law across all member states and embodies Westin's principles of privacy (Westin 1970), namely openness and transparency, reasonable security, accountability, collection and limitation, data quality, usage limitation and individual participation.

Accountability, openness and transparency is ensured through the supervisory authority which has the power to investigate, intervene, temporarily or permanently stop processing and ban the use of, or order the erasure of data. Further, the supervisory authority has the power to initiate legal proceedings in cases where the directive has been violated. All companies and individuals collecting and processing personal data must notify the supervisory authority of their intention to process data.

The directive demands that personally identifiable data are, firstly, collected for explicit and legitimate purposes, and not further processed in a way incompatible with the original purposes; secondly, accurate and kept up-to-date– inaccurate data must be either erased or rectified; thirdly, relevant and not excessive with respect to the purpose of collection; and finally, only stored for as long as is necessary for the purposes for which the data was collected.

The directive also requires explicit consent or a demonstration of necessity of processing– this can include a legal or contractual requirement where the data subject is a party, or for the protection of vital interests of the data subject, for example, emergency recovery of medical records in the event of an accident. Furthermore, data subjects are also entitled to access their personally identifiable information "without constraint, at reasonable intervals and without excessive delay or expense."

The comprehensive model proposes an architecture, backed by legal punishment, to regulate and control data processing of personally identifiable information. It is worth noting that, at least in the case of the European model, regulation only applies to personally identifiable information, and as such does not necessarily provide protection against territorial privacy violations. In addition, the directive does not require consumer choice; as Langheinrich notes (Langheinrich 2001), notice and consent are of little good if consumers have no choice.

Other countries take a broadly sectorial approach to privacy legislation by enacting statues when specific privacy problems arise. Specific regulation often lags behind current developments in technology, and can leave vast areas of commerce insufficiently regulated. The United States, for example, does not have a comprehensive regulatory model, and the US constitution does not specifically mention privacy at all, although the Supreme Court has interpreted certain passages in the Bill of Rights to protect a person from government surveillance when they have a "reasonable expectation of privacy" and has recognised a right to anonymity in the context of free speech. In addition some states have incorporated a more general right to privacy into their own constitutions.

The US Federal Privacy Act of 1974 attempted to introduce some of Westin's principles to protect the privacy of citizens from invasion by the government; however, the act did not limit or control the behaviour of private industry. The effectiveness of the legislation has been limited by poor enforcement and a broad interpretation of "routine use" which permits data collected for one purpose to be reused for other similar purposes.

In 1977 the Supreme Court ruled that individuals do not have constitutional protection for private data once it has been transferred to third parties. To date, the federal government has not provided comprehensive legislation to regulate private industrial use of personal data. Instead it has enacted a series of laws to cover specific cases, with the result that, for example, video rental records are better protected than drug purchases.

Various industries have attempted self-regulation through codes of practice, however many of these bodies suffer from a lack of effective enforcement and therefore have less impact than primary legislation; furthermore, industry-wide consensus does not necessarily result in good consumer privacy, although the threat of government intervention for poorly performing industry codes of practise may have some positive effect.

Liability in the use of geographic information systems and geographic datasets

Introduction:

Liability is a subject of great interest and concern in the geographic information system (GIS) community. Use of GIS data and software inevitably results in some action or decision. If errors or shortcomings have resulted in inappropriate actions or decisions and parties are harmed, the specter of liability arises for dataset and software producers as well as for all other parties involved in handling geographic information.

As a general proposition, legal liability for damages is a harm-based concept. For instance, those who have been specifically hired to provide data for a database or those who are offering data for sale to others are responsible for some level of competence in the performance of the service or for some level of fitness in the product offered. If others are damaged by mistakes that a producer should not have made or by inadequacies that should not have been allowed, the courts have reasoned that producers should bear some responsibility for the damages. But for their mistake or defective product, the damages would not have occurred. In commercial settings, liability exposure often may be reduced through appropriate communications, contracts, and business practices. However, liability exposure may never be eliminated completely. Nor as a society would we want it to be. Modern societies generally support the proposition that individuals and businesses should take responsibility for their actions if those actions have unjustifiably caused harm to others.

However, the law does not require perfection. The law exists and responds to a realistic world. No general purpose dataset will ever be complete for all potential purposes that users might desire. Nor will the accuracy of data ever meet the needs of all conceivable uses. It is also inevitable that errors and blunders will be contained in any practical database. Thus, the law holds that those in the information chain should be liable only for those damages they had a duty to prevent. Establishing the nature and extent of rightful duties has traditionally been accomplished under theories of tort or contract law. Legislation may impose additional or alternative liability burdens. Legislation affecting liability for spatial datasets and software typically might be found in statutes addressing such issues as intellectual property rights, privacy rights, anti-trust issues, and access rights.

The liability in data, products, and services related to computerized geographic information systems is complicated by legal theory uncertainties surrounding liability for maps. This is compounded by the complexities and uncertainties in liability for information system products and services generally. Liability in GIS is further confused by the wide array of current and potential applications of geographic information technologies. Each application requires integration of information specific to the application and often will involve different attributes, analytical methods, spatial features, and accuracy requirements. The specific software and end users will also vary depending on the application to which the technology is being applied.

Thus, the complexity of the legal questions surrounding geographic information system liability combined with the diversity of problems to which geographic information technologies are being applied has tended to create diffuse, changing, and often undefined liability concerns for all parties involved in geographic information production and use.

People purchasing GIS software, datasets, products, and services are often disappointed in their expectations. Representations that software will accomplish certain tasks or that a dataset is complete or sufficient to accomplish specified tasks may be false or misleading. Datasets may contain errors and software may achieve inconsistent or wrong results. In these instances the disappointed purchaser or user usually has a contract relation with the technology product or service provider upon which to assert their claim. Thus, any discussion of liability with regard to GIS should probably begin with consideration of liability in the context of contract and licensing arrangements. Whether GIS products or services are custom-developed or software and datasets are sold prepackaged for the general consumer market, the relationships between the producer and purchaser or user will probably be affected foremost by contract law principles.

In disputes based on contract principles, the issue of warranty, either express or implied, will typically be raised as a basis of claim. In addition to warranty claims, the disappointed party may attempt to pursue a parallel tort claim, such as negligence, in order to expand the types and extent of damages that might be covered or to raise a broader range of duties on the part of the technology product producer. Also, statutes of limitations may vary.

Tort theories come to the forefront when the goal of the law is to prevent harms to the public generally. Thus, tort concepts such as negligence and strict liability may often be invoked by third party users outside of and independent of contractual considerations. Certain geographic information technologies and products if found defective may be held by public policy to be unreasonably harmful to persons or property if offered on the market to the public. In these instances, the tort theory of strict liability will be important.

In some instances, at issue may be an attempt by a dominant party to restrict the entrepreneurial activities of those entering into a contract with it. In such instances, antitrust (or noncompetition principles in a European context) may be relevant. Infringement of rights to intellectual property, personal privacy, and access to government information may also give rise to responsibility for damages.

Specific laws in regard to liability are dependent upon the specific laws of individual nations. This chapter uses as its foundation primarily U.S. legal principles. However, in an attempt to remain more general, the chapter focuses on "fundamental" legal principles and policies that remain germane regardless of the national jurisdiction. In a U.S. context, many of these fundamental principles are best illustrated through reference to the various Restatement of Law documents and the Uniform Commercial Code.

Contract liability concepts

A contract may generally be defined as a mutual assent between competent parties, usually manifested by an offer and acceptance, upon a legal consideration to do or to abstain from doing some act. The mutual assent may be express or implied and the legal consideration is often cash in a GIS context. Once a contract exists, a party to the contract may recover for breach of contract by showing the other party failed to perform as promised. It is not necessary to prove fault on the part of the breaching party. It is necessary only to show that the terms of the contract were not met. As a general proposition in regard to damages, parties are entitled to the benefit of their bargain and thus damages are calculated by determining the amount that would place the damaged party in the position that party would have been in had the contract been fully performed.

In the United States, contracts for the sale of goods are subject to Article 2 of the Uniform Commercial Code (UCC) which generally applies to all goods offered for sale in interstate commerce and has been adopted in entirety or large part by most states. If no explicit contract exists between a supplier of goods and a consumer, the law applies the provisions of Article 2 to the sales relationship. If an explicit contract for the sale of goods exists but is quiet in respect to certain items that were not addressed by the contract but that are now in dispute, the UCC fills in the gap to clarify the relationship between the parties. GIS software, hardware, and datasets typically qualify as "goods" and thus their sale often would be subject to UCC provisions. Of course, the parties to a contract have leeway to develop and agree to alternative provisions to those contained in the UCC. Contracts for the performance of services are not covered by the Uniform Commercial Code. Other nations often have similar default statutory provisions that apply when a sale is not governed by explicit contract language.

Warranties:

Warranties are often the issue in dispute in cases involving computer product contracts. The most basic warranty provided by a seller of goods is that the "(a) the title conveyed shall be good, and its transfer rightful; and (b) the goods shall be delivered free from any security interest or other lien or encumbrance of which the buyer at the time of contracting has no knowledge." Such a warranty may of course be negated by specific language that the person selling does not claim title to the product or modified to claim only partial title in the product being sold. Because geographic data sets may sometimes be acquired through a string of successive sources that may each alter the data set, a seller's ability to sell or license full interests in a geographic dataset may be an issue in some cases. Additional warranties may be express or implied.

Express warranties by the seller are created by the following:

(a) Any affirmation of fact or promise made by the seller to the buyer which relates to the goods and becomes part of the basis of the bargain creates an express warranty that the goods shall conform to the affirmation or promise.

(b) Any description of the goods which is made part of the basis of the bargain creates an express warranty that the goods shall conform to the description.

(c) Any sample or model which is made part of the basis of the bargain creates an express warranty that the whole of the goods shall conform to the sample or model.

"It is not necessary to the creation of an express warranty that the seller use formal words such as "warrant" or "guarantee" or that he have a specific intention to make a warranty, …"

Implied warranties are of two fundamental types, implied warranties of merchantability and implied warranties of fitness for a particular purpose. Under §2-314 UCC, a warranty that goods are merchantable "is implied in a contract for their sale if the seller is a merchant with respect to goods of that kind."

(2) Goods to be merchantable must be at least such as

(a) pass without objection in the trade under the contract description; and ….

(b) are fit for the ordinary purposes for which such goods are used; and

(c) run, within the variations permitted by the agreement, of even kind, quality and quantity within each unit and among all units involved; and

(d) are adequately contained, packaged, and labeled as the agreement may require; and

(e) conform to the promise or affirmations of fact made on the container or label if any.

(3) .... other implied warranties may arise from course of dealing or usage of trade.

Implied warranties of fitness for a particular purpose are established under the language of §2- 315 UCC. "Where the seller at the time of contracting has reason to know any particular purpose for which the goods are required and that the buyer is relying on the seller's skill or judgment to select or furnish suitable goods, there is unless excluded or modified under the next section an implied warranty that the goods shall be fit for such purpose."

Language in the contract tending to negate or limit an express warranty is construed whenever reasonable as consistent with the express warranty but where consistent construction is unreasonable the negation or limitation is inoperative. Implied warranties of merchantability and implied warranties of fitness may be waived in the contract. Warranties "whether express or implied shall be construed as consistent with each other and as cumulative …"

Warranties in GIS Cases

Scenario 1 - Let us assume that an individual has purchased off-the-shelf GIS software from a merchant. The purchaser leaves the store, tries the software, and is disappointed in her expectations of the capabilities of the software. The product carries with it an implied warranty of merchantability as well as potential express warranties that might be included, for instance, on the packaging. Whether the purchaser may receive return of her purchase price will depend on whether these warranties have been breached. Software,

system and data sellers typically are able to avoid damages for breaching implied warranties of merchantability by meeting the requirements of §2-314(2) of the UCC listed above and are able to avoid damages for breaching express warranties by not blatantly overstating or misrepresenting the capabilities of their products. Thus, in the typical business-like sale of prepackaged software or data it is unlikely that these warranties have been breached. Of course, further consumer laws in some jurisdictions or custom in the trade may allow return of undamaged products within specified time periods with no need for explanation. There is also considerable case law authority supporting the invalidity of "shrink-wrap license" provisions under U.S. law and therefore a waiver of merchantability contained in a license inside of a software or dataset package probably would be unenforceable against a consumer.

Scenario 2 - In another instance, let us assume that an individual is engaged in the business of selling health care products by mail. She reads sales literature about a GIS database and software system that will allow her to better profile her potential customers and their physical relationships to a wide range of environmental hazards. Updates of information on the purchasing patterns of households and environmental hazard ratings are provided on a regular bi- weekly basis under the terms of her license with the system supplier. Her signed standard-form license supplied by the system supplier states that "the software system and data are supplied AS IS without warranties of any kind, either expressed, implied, or statutory, including but not limited to warranties of merchantability and fitness for a particular purpose." After suffering greatly decreased sales through her latest mailing efforts, as evidenced by her worst sales in ten years, she discovers that a recently introduced non-intentional defect in the latest version of the GIS software has resulted in her mailings going to the least likely purchasers of her health care products rather than the most likely purchasers. From her perspective, the software did not do what the sales literature promised and resulted in very substantial losses to her business.

Unless she lives in a jurisdiction that bans the exclusion of implied warranties, she may have little chance of prevailing on a contract claim since all warranties were explicitly waived in the contract. She might argue that the contract as a whole was so one-sided at the time it was made that it was unconscionable under the circumstances. However, let us assume for the sake of argument that the court finds otherwise, perhaps because the contract was among reasonably sophisticated business parties of relatively equal bargaining power and the parties freely negotiated the terms of the contract or had a reasonable opportunity to do so. This raises the question of whether a tort action based on negligence, misrepresentation, fraud, or strict liability might be brought in lieu of or in parallel with the contract claim.

Tort liability concepts

A tort is a private or civil wrong or injury to a person or property, which does not arise as the result of a breach of contract. There are no fixed and rigid classifications for torts. Two major policies supported by tort law are punishing wrongdoers for their conduct and compensating injured parties. If both policies can be supported by transferring money

from the wrongdoer to pay for the damages of the party harmed, the rationale is strong for granting tort relief. Although there are no rigid classifications for judge-made tort law, there are some traditionally recognized or classic tort situations. Three traditional classes of tort liability have been for intentional harms, negligence, and strict liability. Additional classes of claims that may be relevant to disputes involving GIS products and services include products liability, defamation, wrongful invasion of the right of privacy, and misrepresentation. The primarily judge-made law of torts has been summarized in the U.S. in Restatement of the Law (Second) Torts. Legislation relative to tort law in individual states has often mirrored the provisions of this document.

Negligence

Negligence is conduct that breaches a duty of care for the protection of others against unreasonable risk of harm. Each person owes a duty to act as a reasonable person would under the same or similar circumstances. Thus, negligence does not involve intent to cause harm but only failure to meet a sufficient degree of care. The greater the risk of harm involved, the greater the care that a reasonable person can be expected to take. Under negligence, the duty to act reasonably to avoid foreseeable risks of physical injury extends to any person. If this duty is breached, a plaintiff can recover for personal injury or property damage caused by a product. However, purely economic loss is not typically recoverable in a negligence action. The duty to avoid foreseeable risks of solely economic injury runs only to those with whom the product producer has a special relationship.

In some situations the defendant is able to present a defense that the plaintiff's own actions failed to provide sufficient self-protection. In such cases, a combination of the plaintiff's and defendant's actions may have caused the injury and, if so, liability for damages is distributed among the parties using the doctrine of comparative negligence or the older doctrine of contributory negligence.

In most instances, those whose cause of action against a GIS product or service provider is based solely on economic damages will have a contractual relationship with that provider. For instance, even under principles that support extension of contract warranties to other reasonably foreseeable users of the product, those parties without a contractual relationship would typically be excluded from claiming for economic loss unless they were also injured in person. Since negligence claimants seeking only economic damages would in most cases also have a contract with the GIS product provider, this raises the issue of whether they might bring a parallel action in negligence or bring such an action in lieu of a contract claim. Remember that plaintiffs often desire to pursue tort claims such as negligence because of the possibility for expanded damages and a broader range of duties imposed on the defendant.

The traditional test in allowing a negligence action in parallel with the contract action for breach of a duty established by the contract was whether there was misfeasance (improper performance) as opposed to nonfeasance (failure to perform.) In nonfeasance or nonperformance, one may only resort to contract damages.

Another possibility for maintaining a parallel negligence action would be through a claim of "professional malpractice." Malpractice occurs when an individual does not perform to the expected standards of one's profession. Professional standards of care are higher than those imposed on the average citizen. Under this approach the plaintiff would argue that a duty independent of the contractual duty arose in the specific instance. The plaintiff would argue that a "special relationship" existed between the parties. Proving such a relationship would involve showing that the plaintiff was relatively unsophisticated, the plaintiff needed to depend on the defendant's expertise, the plaintiff did depend on that expertise, and the defendant held itself out as having the required special expertise. If shown, the plaintiff could maintain both breach of contract and negligence claims.

Negligent and Fraudulent Misrepresentation:

Liability for negligent misrepresentation is established by Restatement (Second) of Torts § 552 as follows:

> One who in the course of his business, profession or employment, or in any other transaction in which he has a pecuniary interest, supplies false information for the guidance of others in their business transactions, is subject to liability for pecuniary loss caused to them by their justifiable reliance upon the information, if he fails to exercise reasonable care or competence in obtaining or communicating the information.

Liability for fraudulent misrepresentation is established by Restatement (Second) of Torts § 525 as follows:

> One who fraudulently makes a misrepresentation of fact, opinion, intention or law for the purpose of inducing another to act or to refrain from action in reliance upon it, is subject to liability to the other in deceit for pecuniary loss caused to him by his justifiable reliance upon the misrepresentation.

Perritt argues that in a contract setting establishing the duty in a misrepresentation case above and beyond what the contract requires of the parties is often very difficult. He additionally argues that "the modern law of fraudulent misrepresentation is only subtlety different from the modern law of breach of contract." He makes this argument both in regard to damages recoverable and in establishing the elements of the case. As such, when a contractual relationship exists there would appear to be only infrequent situations where it would be beneficial to pursue a misrepresentation claim over a contract claim. One instance might be where the time to bring a cause of action has passed the statute of limitations for bringing tort claims but not a longer statute of limitations for contract claims.

Fraud in the Inducement

The complexities and confusion caused by bringing a tort action within a contract setting and the tendency of courts to defer to the written contract as the final agreement between the parties sometimes may be overcome by claiming "fraud in the inducement" of the

contract. The objective of the plaintiff in such an action is to focus the courts attention solely on the events that occurred prior to and separate from the contract. Alleged fraud, such as evidenced by fabricated testimonials or test results, that occurred before consideration of a contract could justifiably be considered as tortious conduct separate from the contract. The wrongful conduct led the party into a contract which directly resulted in damages. Fraud in the inducement may be pursued independent of contract claims. Thus, by this approach the plaintiff advocates disposition of the dispute by establishing duties and breach of duty standards through tort concepts and ignoring the contract language, except perhaps in evidencing the amounts and kinds of damages suffered.

Strict Products Liability

For public policy reasons, suppliers of defective products are often held strictly liable to consumers and other product users for injuries caused by defective products. The primary objective of strict products liability theory is to provide an incentive to manufacturers to keep unsafe defective products off the market. The incentive is provided by reducing the burden of proof on harmed parties and making the manufacturer and others in the supply chain responsible for damages caused by unsafe defective products. If only negligence theory applied, suppliers could often escape liability for defective unsafe products by showing that industry-wide standards for design and manufacture were reasonably met. A product might be unsafe, yet still meet usual industry standards for quality control and design.

Restatement of the Law (Second) Torts §402A states that:
(1) One who sells any product in a defective condition unreasonably dangerous to the user or consumer or to his property is subject to liability for physical harm thereby caused to the ultimate user or consumer, or to his property, if

> (a) the seller is engaged in the business of selling such a product, and
>
> (b) it is expected to and does reach the user or consumer without substantial change in the condition in which it is sold.

(2) The rule stated in Subsection (1) applies although

> (a) the seller has exercised all possible care in the preparation and sale of his product, and
>
> (b) the user or consumer has not bought the product from or entered into any contractual relation with the seller.

Under a strict products liability approach there is no need for the harmed party to show that those with a financial interest in placing the product on the market were negligent in the design or manufacture of the product. Showing the defective condition, that it was unreasonably dangerous, and that it caused the physical harm suffered is sufficient. The duty of a product provider in such an instance is to any reasonably foreseeable member of the public that might be harmed by the good. Fault is not a required element of the cause of action under strict liability and therefore waivers and disclaimers of fault that might be contained in a contract between the supplier and the consumer are ineffective because

they are irrelevant to the cause of action. Other courts have held such disclaimers not to be irrelevant but to be invalid in consumer transactions as against public policy.

Although liability is strict in such instances, it is not absolute. There is no award of damages for purely economic injuries. There must be physical injury and the plaintiff must prove that a defect attributable to the defendant caused the injury. Defects may be due to manufacture or design. A manufacturing defect results when the finished product is not in the condition the manufacturer intended it to be when it left its control. A design defect is one that causes the product to carry an inherent risk of harm in its normal use.

If a physical injury occurs only to property, the question often arises whether the physical injury is of such a nature that the claim warrants inclusion under strict products liability theory. The clearest cases appear to be those in which property damage involved a safety hazard that could readily have caused personal physical injury to a consumer or other user even though in the case at issue it caused only physical injury to property. That is, the nature of the defect and the type of risk involved in causing the physical injury to property are so closely associated with potential physical injury to persons that the underlying goal of preventing such hazards would be frustrated if the physical injury to property is not included within the ambit of strict liability.

Other courts determine whether physical injury to property without physical injury to persons falls within the ambit of tort law primarily by looking at the relationship among the parties. A "garden variety" consumer has very little bargaining power and therefore some courts, on public policy grounds, allow consumers to sue in tort rather than restrict them to breach of warranty actions. Thus a consumer with little bargaining power that has suffered physical harm from a defective product should be able to pursue a strict liability cause of action in these jurisdictions. This may be true even for a commercial consumer assuming the commercial consumer has little expertise in the product and the product was offered "as is" with little or no bargaining involved. If a party has little bargaining power, sound public policy also indicates that the consumer also has no power to disclaim their right to seek redress under strict liability principles.

Several court cases in the U.S. have indicated that the imposition of strict liability should be allowed in electronic maps and charts. The language of these cases justifies including electronic charts and maps while excluding how-to-do books from the realm of strict liability by distinguishing charts and maps as technical tools whereas how-to-do books are more in the tradition and nature of providing ideas and expressions. At least one commentator suggests that this distinction is not very useful. He suggests that distinguishing practical works that lead people to depend on a work product for taking direct physical action is a more reasonable way to determine which products should be considered within the ambit strict liability. Whether treated as a technical tool or a practical work that leads people to take action, electronic charts and maps seem to be well within the bounds of the type of information product reasonably considered under strict liability principles.

Damages are recoverable for direct injuries such as medical expenses, lost wages, property damages, and pain and suffering. Losses which are solely economic without physical injury are generally not recoverable under strict liability.

Tort Liability in GIS Cases

Scenario 2 - In scenario 2 discussed previously, the only damages alleged by the health care products distributor are economic. In that case the clear showing of a defect in the software that resulted in the system malfunctioning rather than not working may be sufficient to meet the requirement of misfeasance. If so, this would allow the parallel action in negligence and raise the possibility of recovering damages beyond those allowed under contract liability principles. However, even if negligence is found in failing to meet the requisite duty, the fact remains that the waiver of express and implied warranties in that specific contract might still be upheld.

Scenario 3 - Let's assume that a small two person "timber finding" business reads about the possibilities of finding pockets of hardwoods through the use of GIS and image processing software in combination with satellite imagery. A large GIS consulting firm advises the timber finding business that they have already developed the system that the timber finding company needs, they have numerous clients using the system, and those clients have all increased their hardwood finds by at least 200% over conventional ground cruising methods. The timber finding business enters into a contract with the GIS consulting firm for delivery of a fully operational system including the imagery they need for the large land mass that they are interested in investigating. The signed contract between the parties states that "damages recoverable by the purchaser in the event of a breach of this contract by the seller are limited solely to return of the price of the contract." The GIS consulting firm fails to provide the system and in fact no system has ever been developed. The timber finding company relies on the consulting firm's promise to deliver the system on time and suffers substantial reliance damages due to timber finding contracts it was forced to breach because the new capabilities were not delivered as promised.

Discussion: In this case the claimed losses are solely economic. They are arguably the result of nonperformance as opposed to improper performance. Thus, the traditional test for allowing a negligence action in parallel with the contract action is not met. Yet, the plaintiff would still prefer suing in tort since tort actions may allow the possibility for a greater range of damage recoveries.

One approach that the timber finding company might take is to argue the malpractice claim that a duty independent of the contractual duty arose in this specific instance. In arguing the "special relationship" elements of such a case the timber finding company would argue that their company is relatively unsophisticated, they needed to depend on the expertise of the consulting company, did in fact do so, and the consulting company held itself out as having the required special expertise to implement the complex technological system for them. If the court rejects these arguments, defers to the contract

as the final agreement between the parties, and holds that the contract is not unconscionable, the provision limiting the contract damages is likely to be upheld.

Negligent or fraudulent misrepresentation may also be potential causes of action in the case. If the plaintiff can prove through a preponderance of the evidence the misstatements of facts as alleged, they probably have a good case for fraudulent misrepresentation. For instance, evidence of fabricated written testimonials of the other purported clients of the GIS consulting firm would be solid evidence of fraudulent intent and misrepresentation of facts. If the only evidence of fraud is oral, the danger exists that oral statements prior to the contract will be treated as "puffery" on the part of the seller which any reasonable purchaser should have treated with caution and the court may lean toward the contract as evidencing the full and final agreement between the parties.

A claim for "fraud in the inducement" of the contract also offers possibilities for success by the plaintiff. Here the objective is to convince the court that the alleged fraud involved separate and distinct actions prior to and extraneous to the contract. If the court is convinced that the fraud was a sufficiently separate occurrence there is less likelihood of deferring to the contract language to resolve the matter. This would undoubtedly be to the plaintiff's benefit as it would avoid imposition of the contract language limiting damages.

Scenario 4 - Assume that a farmer buys a "precision farming" system consisting of software, computer hardware, and computerized variable rate farming equipment from a large equipment manufacturing company. The new computer controlled system tracks the location of farm machinery very precisely through the use of a global positioning system receiver mounted on the farm equipment and is able to apply fertilizers, pesticides, and herbicides at variable rates in order to match the needs of the soil and groundcover conditions as identified in a digital spatial dataset for the farmers fields. The system is also able to measure the productivity of each square meter of soil as crops are harvested. The farmer hires a local engineering consulting firm to accomplish soil tests in a dense grid over his fields and to insert this information along with other physical data specified by the manufacturer into the computerized system. The farmer implements precision farming of his fields. After one of the best growing seasons on record, the farmer experiences one of the worst crops he has ever had. Through an investigation the farmer discovers that chemical fertilizers, weed sprays, and insecticides were sprayed by the automated machinery in reverse locations to where they were needed due to a software error in the latest version of the software. The inappropriate spraying resulted in poisoning of the ground in some areas, killing off the crop in other areas, and allowing insect infestations in other areas. Evidence shows that the engineering firm made no errors in data collection and inserted the required information as directed by the manufacturer's instructions. The farmer's standard form contract supplied by the instrument manufacturer states that "the software system and data are supplied AS IS without warranties of any kind, either expressed, implied, or statutory, including but not limited to warranties of merchantability and fitness for a particular purpose." The

software component of the system containing the defect was developed and distributed by a very large GIS software company with whom the farmer did not have a direct contract.

Discussion: Under contract principles, the farmer might pursue breach of implied warranties of fitness for use and merchantability as well as any express warranties that might have been made. However, to pursue these warranties the farmer would have to overcome the clause in the contract stating that the "software system and data are supplied AS IS without warranties of any kind ..." The farmer might argue that the contract clause on its face is unconscionable since application of the disclaimer clause would allow the system producer to provide useless and harmful systems to consumers without any responsibility for the harm caused by the systems nor any contract benefit for the consumer. If the court as a matter of law finds the clause to have been unconscionable at the time it was made, the court would probably limit the clause as to avoid any unconscionable result. Resort to normal contract principles in deterring damages would then seem appropriate. Deeming the entire contract unconscionable with resort in entirety to negligence principles for resolving the liability issues would appear to be inappropriate, except perhaps if the court found from the evidence an extreme disparity in bargaining power between the parties.

Because the dispute involves improper performance as opposed to nonfeasance, the possibility of pursuing a parallel negligence claim with the contract claim exists. Negligence in this case arguably involves both physical harm to property as well as economic damages. It appears reasonably foreseeable that a software error could cause physical damage to farmland and crops if the software was used in conjunction with computer controlled farm equipment as intended by the suppliers and as used under normal conditions as was done in this instance. Although pursuing a negligence claim in parallel with a contract claim is complex and gives rise to difficulties in meeting the conflicting underlying objectives of tort law versus contract law, protecting the public against the hazardous harms caused by this type of defect and the argument that suppliers are in a better position than users to insure against the losses caused by defective products may be reason enough to allow the parallel action.

It is also interesting to explore whether a strict products liability claim might be successful in the instant case. Although no person was physically injured by the defective product, the fact situation seems to meet the requirements of Restatement of Law (Second) Torts § 402A of being "unreasonably dangerous" to a user's property. The software defect is arguably more in the nature of a "manufacturing defect" than a "design defect" in that the defect was unintended and didn't meet the software developer's own standards. The cost and feasibility of testing the software to see if it worked properly and to correct it prior to its release to consumers seems very small compared to the risk of physical injury and the gravity of potential harms that might be caused by the malfunctioning of the system. The software developers and the machinery manufacturers were fully aware that their products would be used in the application of dangerous farm chemicals. Although the physical harm was to property only in this instance, the hazard

and defect represent a significant safety hazard to humans as well. Because of the inherent safety hazards and because of failing to establish safety conditions designed to avoid unreasonable risks of harm, the type of physical damage involved seems to be of the type that should be allowed to be included within the ambit of strict liability.

Section(1)(b) of §402A additionally requires that the product "is expected to and does reach the user or consumer without substantial change in the condition in which it is sold." Although a complex combination of farm machinery, computers, software, and data contributed by various parties was required to make the system operational, the individual components were not altered by the user. The software containing the defect remained unaltered by the consumer. Thus, those in the chain of generating income from the sale of the precision farming system should not be able to escape their duty to provide a safe product by claiming that the system was changed when applied to a specific farm site. The system was implemented in conformance with the manufacturers instructions and the application of the system to a particular site did not involve substantially changing the condition in which it was sold to and received by the farmer.

Scenario 5 - Assume that a car manufacturer installs a vehicle routing system in its latest line of automobiles. Drivers are able to insert a CD containing detailed street, address, and business information for a community and are able to have the computerized system select a travel route for them based on selected criteria such as shortest time, shortest travel distance, or all streets of a certain type. The location of the vehicle is tracked as it travels primarily through use of a global positioning system receiver and the system uses oral voice commands to inform the driver when an exit is coming, features of interest along the route, turn right, turn left, etc. An engineering firm has collected street and business data for a local community, has placed it on a CD, and the CD is now being used by consumers in routing themselves through the metropolitan area. It appears that all data collected by the engineering firm is spatially accurate and all other information such as street names, street directions, names of businesses, locations of traffic lights and signs, and similar physical features was accurate when collected. The owners manual for the system indicates that the system is provided solely as an aid for determining routes and warns that drivers should rely primarily on their own observations to check the oral routing instructions against potentially conflicting traffic and street conditions. A similar abbreviated notice is provided on the dashboard.

A thirty year old male driver bought the CD at a local discount store and has been using it for several months to aid him in routing himself through the city to deliver flowers in his part-time job with a small florist. After typing in the addresses of his deliveries for the day, the system calculates a route. Half way through his deliveries the system gives him oral instructions to turn right at the next street. He turns right and drives down a major one-way street in the wrong direction. This results in a head-on collision with another vehicle and he receives major physical injuries. Upon investigation, it is determined that no data was entered into the system wrongly nor was there a malfunction in the software.

Rather, it is determined that the street recently was changed from a two-way street to a one-way street by the city.

Discussion: Under the facts, there is no manufacturing defect in the provided vehicle routing software nor in the separately purchased dataset. However, the injured party may argue that the system was defectively designed and poses too great a threat to physical injury from a safety hazard perspective as designed and implemented. Any reasonable system designer should have known that the directions of streets, locations and kinds of traffic controls, and similar physical features affecting safe routing decisions could be expected to change over time and the system and data providers should have provided a means to update the information when it changed. It may be argued that the system is so unreasonably dangerous with the current design defect that it should never have been placed on the market. Placing it on the market should have been delayed until such time as remote data upgrades to such systems could have been reasonably and responsibly provided or the CD should have been sold under a license agreement with data upgrades going to the address of the currently registered owner of the vehicle. The gravity and likelihood of harm due to the inability to provide reliable data upgrades far outweighs the social benefits of such systems.

Counter arguments are that the system is unavoidably unsafe in certain very limited situations but the overall social utility of vehicle routing systems is so great that they should not be kept off the market simply because the technology hasn't advanced to the point where the systems are able to be made fail-safe. Unavoidably unsafe products are not "defective" when the danger is reasonably apparent and the danger of full reliance on oral directions from a computerized system should have been obvious. Adequate warnings were provided. It was the plaintiff's unreasonable misuse of the product that caused the "defect" and therefore no defect exists and no cause of action exists without that unreasonable misuse.

In the U.S., courts typically would resort to one of three risk-utility analysis methods to determine whether the design should be deemed to be defective. Depending on the jurisdiction, plaintiffs and defendants would couch their arguments to address a pure negligence standard, a state-of-the-art analysis, or a consumer expectations test. If the jury did find the system to be in a defective condition unreasonably dangerous to the user and found the defect to be the cause of the injury, those jurisdictions following comparative negligence approaches for determining the distribution of damages probably would reduce the award to the plaintiff by the plaintiff's proportionate share of responsibility in causing the injury as determined by the jury.

Summary:

Liability is a creation of the law to support a range of important social goals such as avoidance of injurious behavior, encouraging the fulfillment of obligations established by contracts, and the distribution of losses to those responsible for them. If decisions are made based on geographic data or products produced by other than the user, there will

always be liability exposure. Minimizing losses for users of geographic data products and reducing liability exposure for creators and distributors of such products is achieved primarily through performing competent work and keeping all parties informed of their obligations.

Liability in data, products and services related to geographic information systems is likely to be determined in most instances by resort to contract law and warranty issues. This is true whether geographic data products are custom developed for specific clients or mass produced for the general consumer market. Tort theories, such as negligence and strict liability, come to the forefront when preventing harms to the public generally arises as an issue.

In this part, fundamental contract and tort liability concepts were reviewed followed by illustrations of how liability issues might arise and be addressed in a range of GIS conflict scenarios. Liability burdens arising under legislation relating to specific substantive topics such as intellectual property rights, privacy rights, anti-trust laws, and open records laws were not addressed by the chapter. Assessing liability exposure arising under statutory law requires consideration of the specific language of the legislation in each nation or other jurisdiction. In addition, this chapter did not address the potential immunity of government agencies from liability for their geographic information products. Again, the availability of immunity for government agencies from damages varies among nations. Finally, even though many geographic information products are being transferred across international boundaries and geographic data forms a significant component of the global information infrastructure, this chapter did not address the likely effects of international agreements on liability for injuries resulting within world trade contexts. All of these additional issues should be considered when relevant to geographic information supplier and consumer relationships.

Some legal concerns with the use of crowd-sourced Geospatial Information:

Introduction

Spatial law and policy occupies a fascinating phase in technological development as new legal relationships and operational imperatives arise. The ‘grey ’areas of interpretation and respective responsibilities are set to become more prominent. Geospatial information has been transformed by ‘disruptive ’technologies (‘innovative’) that have dictated a new modus operandi, from the collection of spatial data, storage, analysis to its use in information systems. The previous use of the floppy disk and compact disc (CD) to exchange data and information has given way to the universal service bus (USB), flash drives and cloud computing (CC). The displacement of CDs and digital video discs (DVD) as a storage media by CC has potentially made these physical media redundant. The information technology evolution has also witnessed innovative uses of the Internet from Web 1.0 to Web 2.0. In its latest guise, many new possibilities have emerged including the sharing of maps and spatial information in one common storage medium – the ‘cloud’.

This paper outlines some preliminary findings and concerns that are caused by disruptive technologies. The literature has prominently focused on technology and apart from Scassa (2013), little attention has been paid in previous studies to legal concerns. This paper posits the view that there are many uncertainties that may need to be resolved before the operational and technological innovations may be deployed on a large scale. In part 2 of this paper the Web 2.0, crowd-sourced maps and produser environment is described. This discussion leads to parts 3, 4, & 5 that raise concerns with the quality of data and information, ownership especially of intellectual property rights, and legal liability in contract and tort respectively. The potential risks for each of these concerns have to be appropriately managed. Part 6 examines current legal frameworks and the legal governance of the collection and dissemination of geospatial data. The final part 7 summary and conclusion identifies five observations and suggested actions that may be taken to resolve the practical problems for produsers. Many of the findings reported and discussed here are preliminary ones but nevertheless provide a basis for proposing a governance framework for all parties.

Web 2.0, Crowd-sourced Maps, VGI and Produsers

This section lays the groundwork for a common understanding of the Internet environments beginning with Web 1.0 through to the collaborative milieu of Web 2.0 with innovative ways of harnessing the myriad applications. In particular, the spatial dimension and its mapping and recording is of particular interest especially with volunteered geographic information (VGI) and the different producers and users as participants in crises, emergencies and disaster management.

In the Web 1.0 environment, the World Wide Web (WWW) known synonymously as the Internet was envisioned by Sir Tim Berners-Lee as “a collaborative medium, a place where we [could] all meet and read and write”. Recent developments on the Internet and especially within Web 2.0, have extended the range of use – from the desk-bound to the mobile device. However, the more ubiquitous ‘application ’(apps) of mobile electronic devices has produced new legal concerns in general and liability in particular. More specifically, net-citizens (netizens) who contribute to the collection, use and dissemination of geospatial information have triggered a re-evaluation of traditional legal frameworks. The legal and policy framework is continually being cajoled to adapt the law to provide novel solutions for the digital age.

In the Web 2.0 environment the static pages of websites are used and updated by collaborative and cooperative means by users for dialogue, creation of content, and the online meeting of virtual communities. The new environment and other mobile technologies have opened up the landscape for nearly everyone to access the Internet, to create and share content. There is a democratisation in the production of information.

In this environment communication takes place anytime and anywhere. However, the management of such activities will invariably be a place-based where ‘jurisdiction ’ becomes pre- eminent and the law of the land prevails. In the absence of specific laws to

govern electronic-based activities in a jurisdiction, existing law and regulations may have to be adapted to cater for and address new challenges of technology. The adaptation of the law could be by way of analogising case by case or re-writing rules and regulations for 'special or exceptional cases'.

Furthermore, innovative ways of collaborating and disseminating information have been created to harness the dynamic power of Web 2.0. Paper maps have made way to electronic maps together with the so-called 'crowd-sourced 'maps. Ushahidi ('witness 'in Kiswahili) is the interactive map that was developed by concerned citizens during the disputed Kenyan elections of 2007. The interactive maps provided eyewitness accounts of violence across Kenya. The maps were accompanied by written text in Ushahidi and images were displayed on Google Maps. This example demonstrates the potential applications that could assist first responders and humanitarian organisations in the wake of natural disasters, crises and violent conflicts.

Volunteered geographic information (VGI) is "the widespread engagement of large numbers of private citizens, often with little in the way of formal qualifications, in the creation of geographic information". VGI is part of a broader trend of "user-generated content" (UGC) that is becoming commonplace in Web 2.0-based applications. The VGI community is set to play an influential role in modern map making and they have sometimes been described as produsers defined below.

Produser is a portmanteau of two words combining 'production 'and 'usage – 'a word popularised by Axel Bruns (2008). The word refers to the type of user-led content creation that takes place in a variety of online environments such as Wikipedia. There is the blurring of boundaries between producing and using, hence the produser.

Examples of other VGI include need for information and maps in crisis situations, for example, during the Haitian earthquakes of 2010. Volunteer mapping efforts that assists in relief efforts have since been used in the context of forest fires, floods, hurricanes and other disasters. Volunteers capture and record information using mobile devices and submit these to a website or central agency that analyses, reviews and then publishes the data on base maps, for example, those provided by OpenStreetMap or GoogleMaps. Most of these contributors are novices and non- professional map creators. While reliability and accuracy of VGI might be questioned, the timely production of near-instantaneous maps during times of crisis has proven invaluable. Further examples of VGI include the Libyan crisis map in 2011; the United Nations Organisation for the Coordination of Humanitarian Affairs (UNOCHA) maps; Transparency Morocco; Mamdawrinch; and Syrian Tracker 2013.

Scassa (2013) identified a series of potential risks from the perspective of the operator of a VGI site, the contributor of VGI and user of the product, service or application that is created using VGI. The article gave an overview of emerging issues of which developers, contributors and users should be aware when engaging in VGI-related activities. The lessons for all are timely.

The digital environment has made nearly everyone with a mobile device a map maker and a digital recorder. Nearly every phenomenon that is observable may be captured and mapped. Using cell phones, global positioning system (GPS) devices and placing information on the Internet using social media has elevated the importance of the spatial context. The newly discovered cartographer may be untrained in geographic information systems (GIS) technology but are now enabled to contribute to location-based services and bringing GIS to the masses.

While expectations are on the rise, so are the legal risks. Legal liability questions have been raised where the subscribed data might be biased and wrong leading to an endangerment to life. VGI service providers on their part have to ensure that they do not engage in conduct that is deemed "negligent" and to verify volunteer contributions.

The ubiquity of location-aware devices that automatically record personal movements, habits and other information linked to one's location raise other concerns such as privacy. Equally important are those relating to the ownership of geospatial information and the kinds of tacit agreements between producers and users.

Many of these questions have remained largely in the background, lightly discussed and seldom highlighted. In the following three sections, issues of quality of data and information, of ownership and of legal liability are reviewed to help prepare a proposed legal framework.

Concern # 1 Quality of data and information:

Amongst the range of potential risks is the concern with the quality of the data contributed by the 'crowd 'relative to those produced by professional mapping agencies. Data authoritativeness is closely linked to the background and training of the contributors. Traditional government sources of GI have always been considered more 'authoritative ' because of the professional training and other quality checks in place. What is considered authoritative geospatial data may be debatable and appropriate criteria may be necessary.

However, what is not in dispute is that the production of authoritative geospatial data is costly, time consuming and usually undertaken by the public sector. Evidence suggest that many government mapping agencies might be struggling to obtain continuing funding to maintain geospatial data or the mandate to keep geospatial databases current. As a result it it seems that there may be a growing reliance on VGI data. While on the one hand, VGI data sources could be highly accurate, complete, in time and at a practical useable scale, the potential risks are still largely unknown and little understood.

The life cycle of GI from the collection of data, cleansing, and assembly of results are prone errors and inaccuracies. Without careful editing and ground-truthing inaccuracies might creep in through misinterpretation of observations, digitising errors, resampling and the use of incorrect map projections as well as the inexpert final assembly of results. For VGI data to be readily acceptable the issues of quality control and monitoring of VGI contributions are a prerequisite as the risks are neither hypothetical nor inconsequential. Tragic consequences could ensue from using 'bad 'data.

The Canadian the Centre for Topographic Information, a division of Natural Resources Canada, has begun assessing the potential of a collaborative mapping model that combines contributions from provincial and municipal organisations as well as those from its citizens. In Australia, the state of Victoria's Department of Sustainability and Environment has developed a Notification and Editing Service that encourages crowd-sourcing of GI. The OpenStreetMap Collaborative Prototype (OSMCP) project of the U.S. Geological Survey (USGS) and swisstopo [sic] Revision Service of the Swiss Federal Office of Topography are experimenting with similar ideas.

In the U.K. OpenStreetMap (OSM) is one of the better known examples of collecting and leveraging VGI. Initiated in 2004, the project was a response to the strict copyright laws that apply to Ordnance Survey maps and geospatial data. With OSM any interested party may view and edit geographic data in a collaborative way. Registered contributors may make additions, modify inaccurate features, delete stale or invalid data and generally edit features to improve the quality of the geospatial database. In addition to individual contributions, organisations have donated complete data sets to OSM. Ironically OSM does not use quality control experts to vet contributions. The quality of the data is refined over time through iterative corrections of the submitted data by subsequent contributions.

The concerns about the quality of data also raises issues about who owns the contributed geospatial data in the mix. The rights to ownership of the intellectual property can be a 'real 'issue especially when the end use is transformed from the altruistic ideals to the for-profit motives.

Concern #2 Ownership: Intellectual property and moral rights:

Intellectual property rights (IPR) including the ownership of copyright is a pressing concern with VGI data. In most common law jurisdictions copyright is vested in the author of an original work that is the expression of an idea that also involves a degree of skill and judgement in the work.

In the U.S. 'originality 'focuses on a creative spark, rather than on the 'sweat of the brow', whereas, in Canada 'originality 'requires skill and judgement and not copied from a previous idea.

With electronic databases, concerns have been raised about whether the 'arrangement 'of data qualify as sufficiently original. The views here may be contrasted to database protection laws in the EU especially the sui generis regime where protection is afforded not just to an original selection or arrangement of the data (similar to copyright law) but to the underlying data itself. In VGI applications and its products there may be independent rights in the underlying base map. Given the nature of any map is made up of layers of information there can conceivably be multiple copyright holders in any given work.

With many contributors adding to the volunteered geospatial database, there can be difficulties in tracing the heritage of the data and hence the ownership of the copyright. The 'confected 'or synthetic data may 'lose 'copyright status because of the difficulties

associated with tracing the current and original owners of the data. It has been suggested that Creative Commons licences could assist in alleviating such a problem and to avoid what Scassa (2013) has described as the 'Wiki 'effect – where data are combined from thousands of disparate sources to form one or more coherent works. The perverse outcome may be that the confected data may become more inaccurate, corrupted with further errors and there may be no one to blame because there is no copyright holder or there may be too many owners to be held accountable.

The Australian Copyright Council has proposed several steps to manage and minimise potential liability risks when posting data on websites. These include terms and conditions that state that the host service provider will not infringe copyright. In addition to indemnities, service providers must ensure that the agreements are legally binding. Service providers have also to educate users not to post material without the relevant copyright owner's consent, to retain the right to remove material if copyright is infringed, to monitor sites for potentially infringing material, and to moderate the process of accepting contributions with a clear statement as to how to complain and how to assert one's rights.

In cases where the VGI contributed data contain material that infringe copyright whether advertent or otherwise, efforts should be made to remove such material and steps put in place to prevent further infringement. Also the use of disclaimers to alert users to the limitations of the data can help mitigate and prevent litigation.

Other service provider-contributor agreements include the terms of service to be provided by the website, disclosure of information to third parties and data protection protocols including indemnities and warranties regarding the data in storage.

Traditionally geospatial data produced by government agencies have copyright vested in the Crown even in cases where the agency is the first publisher of VGI contributions. In these instances it is important to communicate the intention of the Crown to contributors and to emphasize the terms and conditions of use. In turn, VGI contributors may surrender ownership and use of their data and to limit the extent of the permitted uses.

There may be a binding agreement between the contributors and the websites using the contributed data to ensure that they have not infringed the rights of third parties and that they will indemnify site operators for any damages arising from any such infringements. Such an agreement could include a statement that unequivocally states that the contributors themselves have the rights to the contributed data. On the other hand, contributors may request attribution and acknowledgement of their materials. In most jurisdictions moral rights clauses in the legislation enable the assertion of such rights.

Moral rights, recognised by Australia, Europe and the Berne Convention – droit moral -- protects the integrity of a creator's works in terms of the right to attribution (claim to ownership of a work), right not to have authorship of a work falsely attributed and a right to integrity (a right to object to distortion, mutilation or other modification which might be prejudicial to the creator's honour or reputation).

Ownership issues in terms of the consent to release the data containing private, confidential and sensitive information are also pertinent here. The website may have implicit access to all data found on its servers. However, there is the danger that the data could be disclosed to third parties innocently, advertently, inadvertently by accident, and deliberately by unauthorised persons. The key to such security risks hinge on the contractual relationship between the user and the service provider and how these are managed.

In some cases, there may be jurisdictional prohibitions on the transfer of data across international borders. The EU Data Protection Directive, for example, regulates the processing of personal data within the European Union. Important components of this Directive include privacy and human rights. On 25 January 2012 the European Commission unveiled a draft of the EU General Data Protection Regulation that will supersede the Data Protection Directive which may have direct implications on geospatial cloud computing usage and deployment of crowd-sourced geospatial information on websites.

The potential for the deployment of poor/bad data on VGI sites, misuse of the data, and innocently 'illicit 'data can lead to a number of potentially unpredictable consequences. Examples of such use of innocent illicit data include the unauthorised use of copyrighted data contributed by a third party data supplier, and the inappropriate use of personal information by VGI user organisations that may contravene privacy and data protection legislation.

There may also be ethical considerations in the release of private information on public documents such as published maps. Scassa (2013) gave the example of Proposition 8 Maps – a mash- up of Google maps and Prop 8 donors to a campaign in support of a ban on gay marriages in California. The map revealed names, addresses and donation amounts of donors. Such revelations were unforseen by the donors and for some who may not have consented to the use of the information in this manner. The potential for mischief, subsequent harm and tort liability as a result of posting of the information could affect the VGI host, contributor and innocent bystander.

A breakdown in contractual relationships and the likely impact of tortious damage from using inaccurate and/or sensitive data point to a discussion of legal liabilities and personal responsibilities that follows next.

Concern #3 Liability: contractual and tortious:

While appearing to be a semantic one, there may be difficulties in determining whether a VGI website is the source of a product, service or mere provision of information. In general, legal liability in common law attaches to negligent behaviour where a duty of care was owed and was breached and where there was a causal link between the negligent act and the loss suffered.

In the case of contributors in the 'crowd 'who may not have any specialised training or expertise in mapping or geography, mistakes and errors may occur the data collection

phase itself. A threshold test for liability is whether there was an exercise of due diligence of a reasonable person engaged in that activity. Liability may be unlikely for an innocent mistake.

Tortious liability may arise in a number of other ways. As a shield against any liability VGI site operators could insist that users accept the terms of use of their data.

VGI data supplier organisations may be liable for negligent contributions of erroneous data that result in injury or damage to persons who have relied on that data. Data accuracy is a critical element that VGI organisations should guard jealously. The extent of the responsibility for user generated content could hinge on the degree of quality control in the data it receives, the editing and filtering of the data, the nature and subject-matter of the data and the degree of control asserted by the data supplier organisation in the data. Under common law tort, the greater the control the greater the responsibility and hence exposure to liability should anything go wrong.

Professional geospatial data producers assume a higher standard of care. They may be sued for providing incorrect data, misleading or negligent information as well as defamatory information. However, it would be difficult to hold amateur contributors to the same standard of care as the collection of their data may not have undergone as rigorous a process as the professionals. Their data may contain minor errors, and may be a synthesis of data from numerous sources.

Another concern with VGI activity is that of the exposure to liability of the volunteer contributor. These volunteers may be described as 'Good Samaritans'. In many jurisdictions, Good Samaritan law is not found on statute books but is a concept adopted by the courts and applied as public policy. However, practices vary in different jurisdictions.

In Australia, the various states have enacted Good Samaritan laws that protect professionals providing assistance at the scene of an accident or any emergency. Most of these provisions define a Good Samaritan (rescuer) as a person acting without expectation of payment or other consideration who comes to the aid of another. Hence, a Good Samaritan should not be liable for assisting in an emergency if all reasonable care and skill has been taken.

However, the laws in much of Europe criminalize a failure to help people in an emergency. Indeed in Germany, the failure to provide first aid to a person in need of help is punishable under § 323c of the German Criminal Penal Code.

In the U.S., courts have taken a view that there is no duty to rescue. Robson's (2011) discussion of the so-called Good Samaritan laws in the U.S. unequivocally demonstrates that a person is not required to rescue another, even if the person could do so safely. The discussion suggests that:

- A volunteer group that undertakes to rescue others exposes itself to liability.

- A duty to rescue arises only when a person puts another in danger but has a responsibility to mitigate the harm and danger.
- A duty to rescue is required where there exists a special relationship between the parties.

Emergency services using crowd-sourced geospatial information are in an invidious position. The 'Good Samaritan 'duty of emergency services could be mitigated by not undertaking rescue services and in the case of collecting geospatial data in situ of the emergency, by not providing the crowd- sourced data and maps. It would be ironic to note that, the digital volunteers could be considered to assume the role of a passive observer and not communicate with the victims. Or, the digital volunteers could discourage reliance on the use of information with disclaimers and other notices with statements to the effect that the information are not to be relied upon in life threatening situations.

Other worries about legal liability, however, remain in the sense that crowd-sourced data might be misused; volunteers could get hurt in collecting the data; the legal responsibility for the data are unascertained and unascertainable; and the legal status of the volunteers themselves, as a loose collective of like-minded people who wish to help, is uncertain. The U.S. Federal statute Volunteer Protection Act of 1997 (VPA) offers some protection to a broader range of volunteers such as operating under organisational structures of a particular kind and imposing limits on volunteer compensation.

In the case of contractual liability – relationship between the VGI website service provider and users – the 'duty 'is expressed in the "Terms of Use" posted on the web page. Thus, for contributors, particular care must be exercised by not giving or promising any type of warranty or guarantee for the data submitted. To do so might expose and heighten the risk of legal responsibility for any errors. Contributors could refrain from providing any indemnification for the data and information submitted to the website.

From the preliminary findings of the above review, a legal framework may be needed to manage the viewpoints of the three major actors in the piece – the service provider as host, the 'crowd 'as volunteer contributors, and the disaster manager both as contributor and user.

Current Legal Frameworks and Governance

A preliminary conclusion is that the VGI community in general, and crisis mapping community in particular, may need to develop general standards that address issues of quality, ownership and liability. Each of these issues come about where crowd-sourced maps are deployed whether in a disaster situation or in the calm surrounds of a planning studio. It seems that the consensus is that laws that regulate the use of technology, the governance of volunteered information and protection for all is undoubtedly a looming challenge for policy makers and governments. One view is that if the legal questions are not properly managed, tort liability might have "the potential to destroy the model before it realises its potential".

Given the need for large-scale data and the ubiquity of geospatial data, technology has been developed to make these available anywhere, anytime and in any way. The Internet and sharing on the cloud and its use for geospatial applications promise a lot but many unresolved legal issues remain.

Since 2010, the Ordnance Survey (OS) GB, the National Mapping Agency in the U.K., has made available geospatial data to the public to encourage innovation and government transparency. OS is by far the largest public sector agency that makes use of cloud computing as part of its web mapping service that deploys geospatial data to customer websites and enterprise systems, services that are hosted on the Amazon Web Services (AWS) platform.

Increasingly one platform that is being used to host VGI and crowd-sourced maps is the 'cloud'. Cloud computing provide a means to undertake computing tasks, software, data access, data storage resources. Users of cloud computing (CC) take advantage of computing infrastructure but are not involved in the detailed technical setup.

The advantages, offered by CC generally and to geospatial cloud computing (GCC) in particular, to analysts, users, data providers and others, are unlimited. The benefits include lower costs, provide enlarged access to products and services and be able to do so online theoretically from anywhere in the world. The need for geospatial software may be leased or paid for on the basis of use and data used acquired on a needs basis through web services. This is indeed neo-geography par excellence and the 'cloud 'is poised to radically change the way geospatial analytics are performed.

However, geospatial cloud computing raises other concerns such as the security of information and data in terms of unauthorised use of the services, the protection of personal, confidential and sensitive data, intellectual property rights especially of copyright and licensing the use of geospatial data and legal liability.

The Natural Resources Canada's Primer on Cloud Computing discusses a survey that lists ten different security risks. Among these risks include abuse and malicious use of cloud computing by spammers and hackers, weak application programming interfaces (API) that expose cloud computing users to confidentiality and integrity risks, technological vulnerabilities arising from shared technologies, data leakage, service and traffic hijacking, delegations of authority to the vendors and encryption issues.

While the risk concerns appear credible especially with reports of data security lapses, helpful advice is available, for instance, from the European Network and Information Security Agency (ENISA). In addressing some of these concerns an understanding of the roles and responsibilities of both the vendors and users are as important as assessing the threats and mitigating losses. Where these rights and duties have been established, the sharing of liability as well as the burden of the liability may be apportioned by mutual consent through arbitrators and mediators.

The International Bar Association (IBA) has been in the forefront of thinking in attempting to meet the challenges of technological developments. The IBA's proposed

International Geoinformation Convention focuses on the reliability of information for the particular application and the limits the law should seek to impose on the undoubted power of the information. By addressing the many conflicting and overlapping existing rules and regulations associated with the collection and processing of GI, a new industry may develop with commercial certainty about rights and obligations of its many participants and also the confidence in moving in conformity with public opinion. It may be posited that such an industry will not spontaneously blossom without the trellis provided by a robust international legal framework.

Summary and Conclusions

This part has reviewed several concerns with the use of VGI-generated geospatial data. Five conclusions may be made in summary.

First, the Web 2.0 environment has witnessed a new wave of data collection methods, data use and data analytics. The challenge is how to manage this new world of geospatial data collection and dissemination. Cloud computing, the Internet of Things (IOT), open standards and open source all challenge traditional means of ‘professional ’data creation, collection and storage. With public sector funding of the collection of geospatial data becoming more restricted in straitened economic times, the public and private geospatial industry may have to turn to use shared crowd-sourced data. Protection by way of licencing and new methods of data ownership will have to be developed. In turn standards and new usage policies may also have to evolve. Yet, there remains tort liabilities related to questions of data assurance, integrity and ownership.

Second, there seems to be an acceptance of the terms of use of VGI data as well as the consequence of the negligent contributions of erroneous data. Also with amateur collectors and contributors of the data, there is an apparent lowering of the standards of care. The use of volunteered and crowd-sourced geospatial databases has highlighted the tensions with Good Samaritan laws especially for rescuers who may not be shielded legal liability. But the laws are mixed for different jurisdictions from the hard line U.S. position to the more benevolent Australian states. The challenge here for policy makers is that if there were to be no legal protection for volunteers, the ensuing litigation may destroy the VGI model before it reaches its full potential.

Third, cloud computing is the next ‘storage ’media that appeals to the needs of the neo-geography par excellence. Cloud computing is changing the way geospatial information collection and geospatial analytics are undertaken. However, the issues of security of information, the protection of personal, confidential and sensitive data, intellectual property and aspects of tort liability hover in the background.

Fourth, the record and reception of crowd-sourced geospatial data among different jurisdictions is mixed. For example, newly developed countries like China and India, and developing countries like Indonesia are very ‘security conscious ’and sensitive in so far as geospatial information and data are concerned. The fear of threats of invasion and border incursions persist.

Indonesia provides an extreme example where all geospatial data are collected by a central agency and no one else may collect such information. The Indonesian Geospatial Information Act No. 4, 2011 provides the legal framework for acquiring accurate geospatial data and creates a regulatory framework for the administration of national geospatial information. Criminal sanctions are attached to deter the collection of geospatial data by private persons.

Fifth, radical changes are needed to reduce geo-liability. This is because legal liability theories governing geospatial information at least in the common law world are largely under-developed and there is a tendency for the law to lag behind technology relative to resolving the growing problems and issues presented by technology and neo-geography. The disparities between legal and policy frameworks are evident.

Technological development in relative terms is without boundaries. Legal and policy frameworks tend to 'lag 'and are not developed in a consistent manner. Such under-development leads to a degree of uncertainty and perhaps a 'chilling 'effect on venture capitalists who might refrain from new and innovative investments for 'fear 'of unknown legal repercussions.

On the other hand, addressing the legal and policy challenges head-on may lead to greater developments in geospatial information production and use. A legal framework that provides 'security 'in all ways could also lead to long-term benefits to those concerned.

Given the three-way interlocking network of interests, the governance of VGI activity can be fiendishly difficult because of the various competing interests and tensions between each of the actors. This preliminary work has only focussed on the legal issues. The difficulties of legal analyses become more apparent in the absence of litigation and/or specific legislation in the field. Yet, the distinctiveness of the problem-set may warrant particular policies to address competing rights and interests and to emerge with solutions to practical problems in the use of geospatial VGI.

The final analysis suggests some kind of a 'relational 'law is required within a framework where technology, networked governance and legal protection of geospatial information are woven into place. In such a scenario, it would be possible for volunteers to craft a code of practice that can be universally practised. Such a softly-softly self-regulated environment could prove fruitful and more easily acceptable and accepted by like-minded geospatial professionals and by the map using first responder community – the *produsers*.

GeoICT Standards

Introduction

A standard is a reference record endorsed by a perceived institutionalization organization, for example, the Open Geospatial Consortium (OGC) or International Standards Organization (ISO). It characterizes the attributes and voluntary principles pertinent to a set of domain specific activities that requires common processes to address them or deal with them. Standards represent a consensus process among all stakeholders involved with

the domain of application. A standard is used to characterize a common role between end users and developers as well as policy-makers and clients involved in specific domain of technology, for example, the OGC standardized Web-based GIS protocols to harmonize policies and procedures involved in product development in the domain. At the same time, standards provide the level of details, quality, security, and environmental impact as well as the value of security. Standards encourage information and product exchange; internationally, it adds to better organizing the economy and encouraging the day-to-day practices of all involved. Institutionalization quickens the development of standards and thus improves the innovation process. A higher level of standardization yields reference systems and results framing a strong premise for and sparing time in the advancement process. At the end-user side, standards encourages the dissemination of creative new thoughts and cutting-edge innovations. They create an environment for mutual communication among involved parties and allow the dissemination of technology.

Adherence to standards guarantees security, unwavering quality, and environ- mental compliance. Therefore, clients see standardized products and services as being more reliable and, as a result, expanding deals and the take-up of new standardized technologies.

This part will focus on standardization from different perspectives covering the horizon of GeoICT. It will cover the OOG standards for WebGIS Interoperability as well as the emerging trends in standardization of big data, hydrographic data, and Web standards as well as well as 3D standardization.

Standardization Initiatives

There are many ongoing standardization efforts for GeoICT-related technology. These global initiatives aim at providing support to the geospatial data community to maximize the effectiveness and interoperability among different stakeholders of the geoid technology. Three major international initiatives are - the Open Geospatial Consortium (OGC), the International Standards Organization (ISO), and the International Hydrographic Organization (IHO). These three institutions provide guidance and direction in developing standards related to geospatial information technology (GeoICT) from a data perspective. There are other initiatives, such as the IEEE and W3 initiatives, which address the technology-related side of interoperability in terms of systems and platforms.

MODULE-VI

REMOTE SENSING TECHNOLOGIES AND LAWS IN INDIA

INDIAN REMOTE SENSING SENSOR SYSTEM: CURRENT AND FUTURE PERSPECTIVE

The Earth Observation (EO) satellites play a significant role in providing information in a spatial format and in determining, enhancing and monitoring the overall capacity of the earth. Satellite Observations over land, oceans, atmosphere, and during natural and human-induced hazards have become crucial for protecting the global environment, reducing disaster losses, and achieving sustainable development. Hence Earth Observation from Space has proved to be a game changer in providing valuable information on natural resources and environment at different scales. Indian Space Research Organization (ISRO), has made its mark in all facets of remote sensing and arguably has the most vibrant program, when it comes to civilian usage and outreach in general. Microwave and Electro Optical Remote Sensing programme has taken a great leap through development of remote sensing systems for both space-based and airborne remote sensing activity of ISRO. Today, India has the world's largest constellation of electro optical remote sensing spaceborne systems in operation. Passive Microwave sensors developed at ISRO are aimed at providing atmospheric and oceanographic remote sensing data from space-based platforms. Active Microwave sensors are dedicated to imaging as well oceanographic applications. Imaging sensors, which witnessed a beginning in airborne application, have, over the period, graduated to space borne platforms. Indian Remote Sensing sensors provide space-based remote sensing data in a variety of spatial, spectral and temporal resolution meeting the needs of many applications of relevance to national development. The Indian earth observation satellites specifically designed to meet country's needs can ideally meet the global needs as well, in view of the similarity of situations in India and most parts of the developing world. This paper takes the reader through various phases of Indian Remote Sensing Sensors developed at ISRO by describing each sensor along with its functioning.

Indian Earth Observation Programme:

The Indian Earth Observation (EO) Programme started with the experiment on detection of coconut root wilt disease from a helicopter-mounted multi-spectral camera system in 1970 has matured into a fully operational programme. It is self-reliant in every aspect of the technology and applications. It consists of space segment, ground segment, applications programme with particular emphasis on capacity building. The space segment deals with indigenous development of various types of sensors, spacecraft platforms and satellite launch vehicles. Setting up telemetry, tracking and command network of stations, data reception systems and generation of data products are important component of ground segment. Development of algorithms for retrieval of geophysical parameters and related utilization application are carried out for each satellite mission.

Indian EO program started from Bhaskara-1 satellite (June 1979) which had two types of sensor systems viz. television camera and microwave radiometer. Imageries of Bhaskara

at 1 km spatial resolution helped in carrying out land use, forestry and geological studies. SAMIR payload measured brightness temperature in 19 GHz and 22 GHz for study of ocean-state, water vapor, liquid water content in the atmosphere, etc. Bhaskara-1 was followed by Bhaskara-2 (Nov. 1981) with improved SAMIR instrument. The first operational remote sensing satellite IRS-1A launched on March 17, 1988 had two types of payloads with Linear Imaging Self Scanned imaging (LISS-1 and LISS-II). IRS-1A mission was followed by IRS-1B and subsequently IRS-P2, IRS-1C, IRS-1D were flown with improvement as per user needs and requirements.

Currently, thirteen operational satellites are in Sun-synchronous orbit–RESOURCESAT-1, 2, 2A CARTOSAT-1, 2, 2A, 2B, RISAT-1 and 2, OCEANSAT-2, Megha-Tropiques, SARAL and SCATSAT-1, and four in Geostationary orbit- INSAT-3D, Kalpana & INSAT 3A, INSAT -3DR. Varieties of instruments have been flown onboard these satellites to provide necessary data in a diversified spatial, spectral and temporal resolutions to cater to different user requirements in the country and for global usage. The data from these satellites are used for several applications covering agriculture, hydrology, urban planning, rural development, mineral prospecting, environment, forestry, ocean resources and disaster management.

Electro Optical Remote Sensing Sensors:

Presently, India is having the world's largest constellation of Electro Optical (EO) remote sensing satellites in operation (Fig. 1). It provides space-based remote sensing data in a variety of spatial, spectral and temporal resolutions, meeting the needs of many applications of relevance to national development. The Indian earth observation satellites specifically designed to meet country's needs is also useful in many global applications.

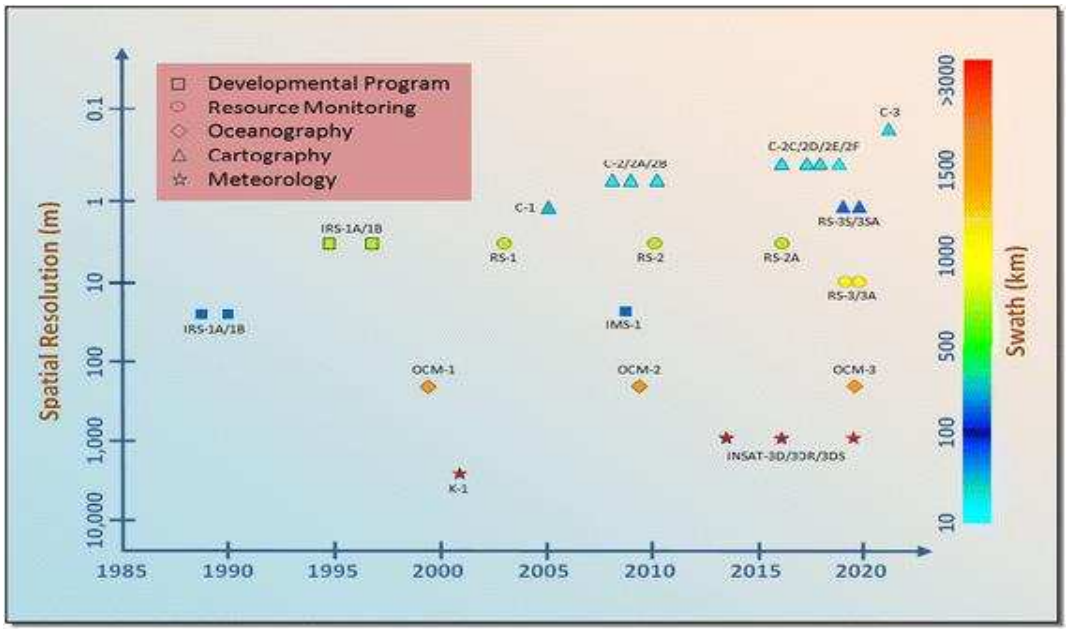


Fig:1 Electro optical remote sensing program of ISRO

Resource Monitoring

Resourcesat-1 was launched in 2003 and it changed the way agriculture was monitored and studied in India. The result has been incessant requirement of continuity of service for the series. In April, 2011, Resourcesat-2 was launched followed by Resourcesat-2A in December, 2017. The series has turned out to be one of its kind, having three tier imaging capability with LISS-4 (5.8 m), LISS-3* (23 m), AWiFS-A&B (56 m) (Figs. 2, 3). All the payloads are multispectral with SWIR bands in LISS-3* and AWiFS. This is probably the most widely accepted and popular program among the user community, world over, for its wide ranging applications covering Agriculture, Urban mapping, Forest management etc.

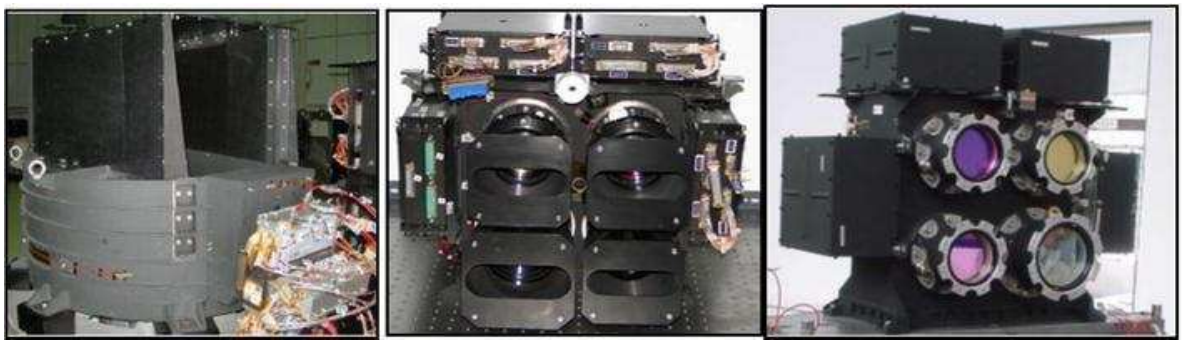


Fig. 2: LISS-4, LISS-3 and AWiFS cameras of resourcesat-2

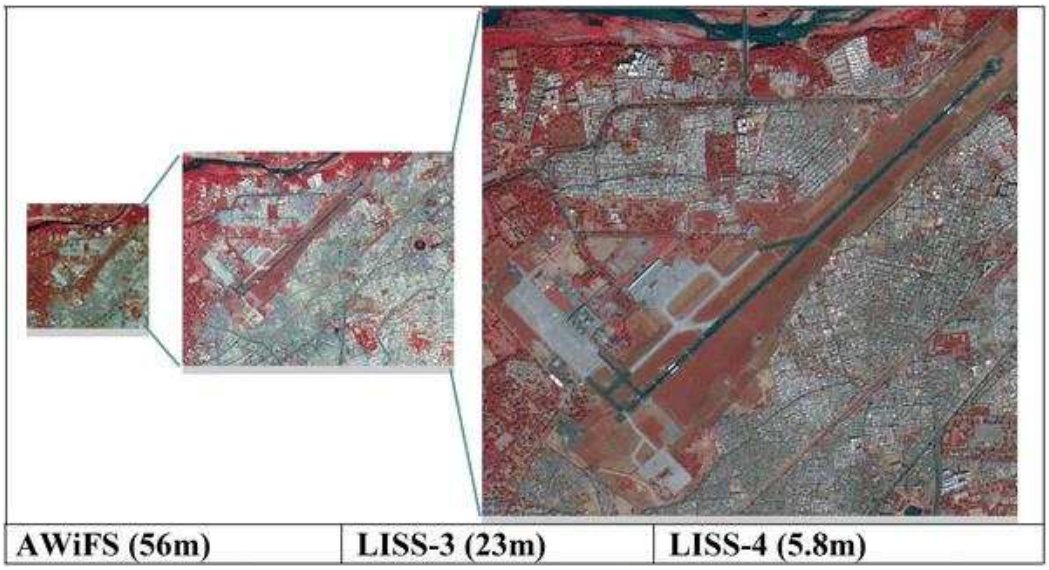
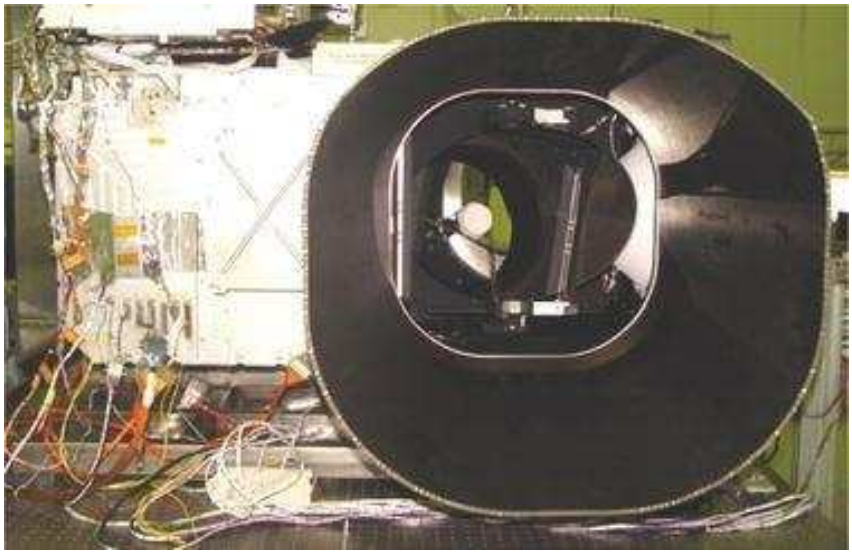


Fig. 3: Three tier imaging by resourcesat-2A, AWiFS (56 m), LISS-3 (23 m), LISS-4 (5.8 m)

Resourcesat-3 and Resourcesat-3S series of satellites, planned to fly together will be the next big step up. It will retain all the capabilities with enhancement in all aspects of observation. Resourcesat-3 will bring in a set of sensors to cover 925 km swath with a

spatial resolution of 20 m in VNIR and SWIR spectrum. This will ensure a revisit in 4 days. Additionally, the satellite also will have capability to observe 280kms from designated altitude with 10 m discriminability. Entire 925 km will also be imaged by a VNIR hyperspectral imager to improve the overall product quality. Resourcesat-3S, with multi-view panchromatic stereoscopic capability having high spatial resolution of 1.25 m will facilitate generation of fused products of great utility.

Designed and developed specifically to meet Meteorological needs, INSAT-3D and 3DR (Fig. 4) together from geostationary orbit, cover the entire Indian landmass and beyond, every 15 min. 1 km in Visible and SWIR bands, and 4kms in Thermal Infrared complement the low earth imaging capability. Geostationary orbit provides constant monitoring and beyond Resourcesat-2A, high repetivity sensor would be continued on Geostationary platform as Geo Imaging Satellite (GISAT) mission. This will provide multiple day acquisition capability and shall overcome many limitations posed by AWiFS availability. Since geostationary satellites have longer life, GISAT will assure moderately high spatial resolution (50 m VNIR Multispectral, 320 m VNIR Hyperspectral, 190 m



SWIR Hyperspectral and 1 km TIR) coverage over India for more than a decade.

Fig.4: Imager camera (INSAT-3DR)

Oceanography

Specific attention was given to realize a sensor to meet the requirements related to study of oceans. Oceansat-1 was the first satellite built primarily for ocean applications. It was launched on 26th May, 1999 on-board PSLV-C2. The main mission objective of Oceansat-1 was to gather data for oceanography, land (vegetation dynamics) and atmospheric applications. OCM-1 provided data with two day repetivity, essential for systematic coverage of the huge oceanic resources. The camera aided in determination of chlorophyll concentration, detection and monitoring of phytoplankton blooms and obtain data on atmospheric aerosols and suspended sediments in water.

Continuity in service was ensured with development and launch of follow-on satellite Oceansat-2 on 23rd September, 2009. The OCM-2 payload on board Oceansat-2 satellite is shown in Fig. 5.

Oceansat-3 is planned as next in the series. It will consist of two payloads, OCM-3 having 13 narrow VNIR spectral bands and Sea Surface Temperature Monitor (SSTM-1) having 2 bands in Thermal Infrared region. Configurations for both the payloads have been finalized and the subsystems are in various stages of development.

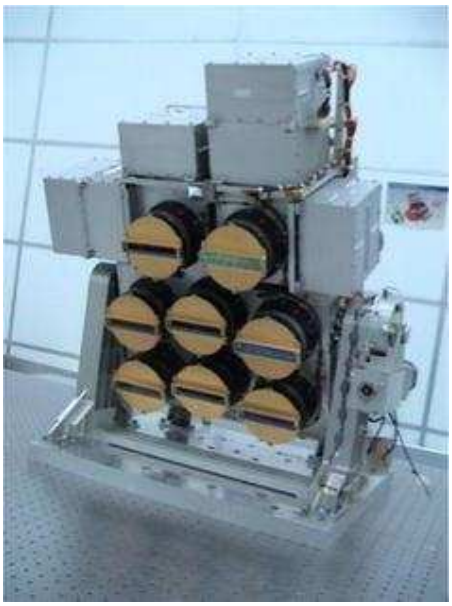


Fig.5: OCM-2 payload

High Resolution Observation

Since 1995, with launch of IRS-1C, ISRO has continuously provided High resolution images for various applications like Urban mapping, Cartography and Surveillance. From a spatial resolution of 5.8 m in IRS-1C, the capability has been contnuously improved to 2.5 m in Cartosat-1 to 1 m in Cartosat-2.

Presently, Cartosat-2S payload launched in June, 2016 offers spatial resolution of 0.63 m Panchroamtic and 1.57 m VNIR (Fig. 6) multicspectral capability with an operational life of 5 years.

In the field of High resolution imaging, next major jump will be realization of Cartosat-3 series. It will be a highly agile, advanced satellite having imaging capability with a very high spatial resolution of 0.25 m in panchromatic and 1 m in multi spectral bands. The spacecraft platform has many new technologies supporting the mission to manage and handle high data rates, agile enough to obtain more spots and strip images during a pass.

This series will also have MWIR imaging capability to meet specific user requirements.

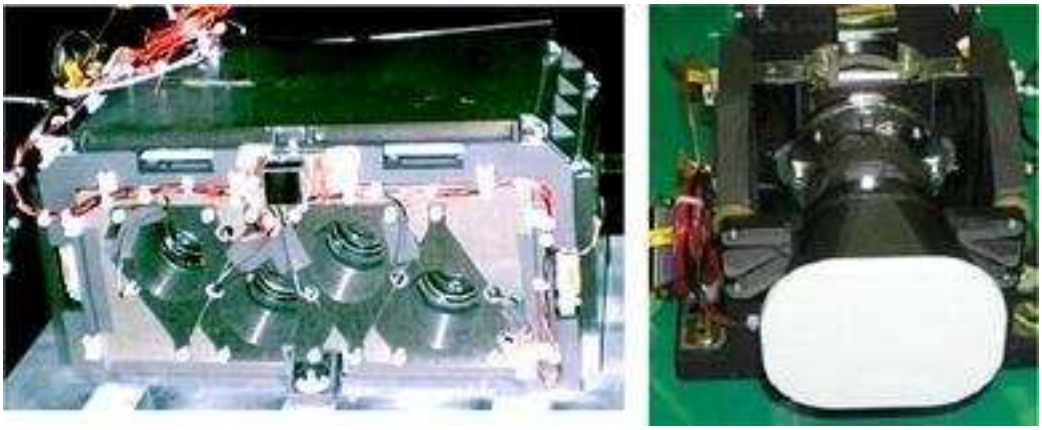
Fig.6: Cartosat-2S image of rome

To meet the ever increasing demands, HRSat series will be unique in the sense that it will provide not only high resolution imagery of 1 m, but will also have LWIR channels to cater to day and night monitoring requirements. Moreover, such three satellites will be launched together to offer specific viewing capability. The payload weight in this series will be less than 100 kg.

Small Satellite Platforms

ISRO also has taken up experimental missions that are aimed towards demonstration of technologies before they are taken up in regular missions. These missions are undertaken in small satellite platforms to reduce cost, time and associated risks. In order to facilitate systematic development, ISRO has developed standardized spacecraft bus for small satellite platforms. These fall under broad categories of 400 kg class, 100 kg class and 10 kg class of satellites.

In this category, IMS-1 satellite (100 kg class) was launched in 2008. It carried highly miniaturized multispectral camera MX-T. It had a four band imaging system that provided performance at par with LISS-2 camera of IRS-1A/1B. The weight of the MX-T camera (Fig. 7) was only 5 kg compared to LISS-2 weight of 150 kg. It also carried a compact imaging spectrometer HySI-T. This instrument provided measurement of reflected spectrum in the visible and near infrared wavelength in 64 contiguous bands.



The weight of HySI-T was only 3 kg.

Fig.7: Mx-T and HySI-T cameras on-board IMS-1

Airborne Electro Optical Sensors

In addition to providing a wide spectrum of imaging options from space, ISRO has built specific sensors to meet the exclusive requirements of high resolution and hyperspectral imaging from aerial platform as well. The present suit of sensors comprises multi-view (Fig. 8) panchromatic (ATMC), VNIR multispectral (NMx) and VNIR hyperspectral (AIMS) instruments. Both panchromatic and multispectral sensor generate imageries with approximately 30 cm spatial resolution from an altitude of 6 km. The hyperspectral sensor offers a spectral resolution of 2.5 nm.

Fig.8: NMx colour composite

Microwave Remote Sensing Sensors:

Microwave Remote Sensing (MRS) programme of ISRO has seen the development of both active as well as passive remote sensing systems for space and airborne remote sensing activities. Passive sensors (Radiometers) are aimed at providing atmospheric and oceanographic remote sensing data from space-based platforms, whereas Active sensors (SAR, Scatterometer, Altimeter) are dedicated for land as well oceanographic applications. Synthetic Aperture Radar (SAR) Imaging System, which witnessed a beginning in experimental airborne applications, have, over the period, graduated into operational spaceborne missions. The evolution of MRS programme also resulted into development of various sophisticated key technologies required for this programme.

Atmospheric and Oceanographic Sensors

Both passive and active microwave remote sensing instruments have been/are being developed to meet the requirements of atmospheric and oceanographic applications. From the modest beginning of development of SAMIR payloads for Bhaskara series of satellites for scientific understanding, payloads like MSMR and Scatterometers are designed for providing operational services. At the same time, ISRO initiated collaborative development of payloads, like Megha-Tropiques, with established space agencies, to consolidate expertise available in the development of complex technologies.

SAMIR Payload

Satellite Microwave Radiometer (SAMIR) ushered in microwave remote sensing technology. It was flown on Bhaskara-1 and -2 satellites in 1978 and 1981. SAMIR in Bhaskara-1 had 2 channels in 19.35 and 22.35 GHz. SAMIR payload in Bhaskara-2 had additional channel in 31 GHz. SAMIR provided the first glimpse of global water vapor and liquid water content with indigenous technology. Bhaskara was a spin stabilized satellite and this fact was effectively used to configure this vertically scanning radiometer. This radiometer was configured in Dicke configuration in which scan view of the open sky was used as cold calibration input. It provided a footprint of 150–250 km resolution with sensitivity of 1–2 K. Bhaskara satellites had two spinning modes namely around roll axis or pitch axis. In the first mode of spin, SAMIR provided a swath of 1500 from 777 km altitude. In second mode of spin, in every scan it provided single sample of measurement at Nadir.

MSMR onboard Oceansat-1

Multi-frequency Scanning Microwave Radiometer (MSMR) was the co-passenger payload along with Ocean Colour Monitor (OCM) onboard Oceansat-I (IRS-P4) satellite, ISRO's first satellite dedicated for oceanographic applications. The satellite has been launched on May 26, 1999. MSMR was a four-frequency, dual-polarised scanning microwave radiometer to measure brightness temperatures of the earth surface. This was used for deriving parameters like sea surface temperature, wind speed, water vapour content, etc. from the measured brightness temperatures. The system was designed for four frequencies viz., 6.6, 10.65, 18.0 & 21.0 GHz in order to cater to the above applications.

MSMR provided routinely 48 h global data product, in terms of Brightness Temperature, SST, Wind Speed, Water Vapor content and Cloud Liquid Water, on operational basis from National Remote Sensing Agency (NRSA), Hyderabad, India. The data was used for various experimental investigations like soil moisture, Antarctic ice study etc. Unfortunately, the payload was shutdown after two and half years of operation due to power starvation caused by partial failure of solar panel.

Ku-band Scatterometer On-Board Oceansat-II

Ku-band Scatterometer was being built by ISRO to gather information about the near surface winds over oceans at a global level. The scatterometer derived ocean surface wind field observations form a very important input to the global weather forecasting system. The scatterometer transmits a pulse through a dual polarized offset reflector antenna, spinning at the rate of 20.5 RPM around yaw axis. The vertical and horizontal beams are pointed at off nadir pointing of 49.4° and 42.6° respectively to cover a total swath of 1800 km with inner beam of 1400 km. All the regions within the inner beam coverage provide azimuthally divergent 4 measurements of radar cross section of capillary waves riding on the gravity waves of the sea. In the inner swath, wind direction can be measured unambiguously. However, in the outer swath, because of availability of only two measurements of radar cross section, wind direction is resolved with the help of auxiliary information like numerical model winds. It operates at 200 Hz, alternate pulses which are switched between V and H ports of the antenna. There is a provision of extensive on-board calibration of the system to provide improved accuracy in wind vector measurements.

OCEANSAT-2 Scatterometer (OSCAT) provided a global coverage of wind vector at 50 kmx50km as well as 25 × 25 km grid every 2 days with most of the earth covering daily. OSCAT proved to be an excellent instrument for oceanography. Widespread acceptance and usage of the OSCAT data by various international agencies like JPL, NOAA, KNMI, EUMETSAT and ECMWF for both research and operational purposes is a testimony to its quality and utility. OSCAT had developed snags in the transmitter subsystem system of primary chain and scan mechanism of the redundant (backup) chain during fag end of its design life period (around 4½ years from launch) forcing the ISRO to suspend its operation in April 2014. Scatterometer on OCEANSAT-2 was followed by dedicated scatterometer onboard SCATSAT-1 Mission in 2016. Various, Hydrological, Agricultural and Forestry applications are being carried out in SCATSAT-1 utilization program. ISRO will be launching OCEANSAT-3 & 3A missions with Ku-band pencil beam scatterometer in 2018/19-time frame.

Megha-Tropiques

In order to provide boost to climate research with high repetivity data over the tropical regions, a joint Indo-French collaboration resulted in Megha-Tropiques satellite with three payloads, namely

MADRAS (Microwave Analysis And Detection of Rain And Atmospheric Structures)-Imaging microwave radiometer 18.7,23.8, 36.5, 89 to 157 GHz (5 Frequencies and 9 channels); SAPHIR (Sounder for Atmospheric Humidity Profiling (6 Channels around 183 GHz) and SCARAB (Scanner for Radiation Budget)-Broadband radiation measurement instrument in shortwave (< 4 mm) and long-wave (> 4 mm)

MADRAS was configured as total power radiometer with 65 cm diameter antenna to provide observation with resolution from 67 to 10 km over different frequency bands. It

provided measurements over a swath of 1700 km at incidence angles ranging from 50°–55°. Megha-Tropiques was placed on an inclined orbit of 20° at 867 km altitude to provide repetitive coverage of equatorial region between 30°N and 30°S at every 6 h.

Planned MM Wave Sounder

Millimeter wave sounders exploit the atmospheric opacity to sense the atmospheric temperature and humidity profiles. Sounders have an amalgamation of channels at which the atmosphere is opaque for sounding purposes and at which the atmosphere is transparent for correction of the surface contamination. Already a programme to develop MM Wave sounder for measuring vertical profile of atmospheric temperature and humidity has been initiated. Two distinct sounders are being planned: (a) Temperature Sounding Unit (TSU) operating in oxygen absorption band in 50–60 GHz and (b) Humidity Sounding Unit (HSU) operating around 183 GHz. Both these units will operate in vertical scanning configuration.

Radar Based Imaging Sensors

ISRO mastered space based imaging capability two decades ago with the launch of IRS-1A on 17th March, 1988. Progressively, optical camera based imaging capability is in the path of continuous improvement both in terms of resolution and swath coverage till this date. In a programmatic approach, the scope of ISRO's remote sensing capability was extended to microwave bands after attaining successful grip over imaging technology in optical bands.

Synthetic Aperture Radar (SAR) was logical choice for Imaging Radars in microwave bands, considering its all weather and day-night capability. Further, radar response to geometric shape and distribution of features was realized to be complementary and supplementary to spectral reflectance based feature characterization available in optical imaging process. However, development of SAR needed mastering of both sophisticated radar technology and complex SAR processing algorithm. Since space borne SAR was highly cost intensive, airborne version of SAR was embarked upon as cost effective route of mastering SAR technology in all its nuances. Over the period, both airborne and space borne versions of SAR technology development have taken vibrant shape in ISRO towards harnessing their utilization potential. Summary of Airborne microwave imaging Radars is given in Table 1.

	SLAR	**ASAR**	**DMSAR**
Frequency	9.6 GHz (X-Band)	5.3 GHz (C-Band)	5.35 GHz (C-Band)
Polarisation	HH	VV/HH	VV/HH
Platform/Altitude	Dakota (2–3 km)	Beechcraft (8 km)	Beechcraft (8 km)

Pulsewidth/Chirp bandwidth	80/300 ns	20 µsec 25 MHz	20 µsec 22,575 37.5, 18.75 MHz
Resolution/Swath	50–100 m/5 km	6–8 m/25 km	<2 m/6 km 3 m/25 km 5 m/50 km 10 m/70 km
PRF	850 Hz	425–525 Hz	452 Hz
Peak power	25 kW	2 kW	8 kW
Antenna Length/Pattern	2 m/Cosine Weighted	1.3 m/Cosec2	1.3 m/Cosec2

Table 1 Summary specifications of airborne imaging radars developed in ISRO

Airborne Imaging Radar Development

X-Band Side Looking Airborne Radar (X-SLAR)

Imaging Radar development was initiated modestly with development of Side Looking Airborne Radar (SLAR) in X-band. This SLAR was basically used for development of radar technology and it was in flying condition from 1985–1989. SLAR provided imaging over 2–5 km swath with 50 m-100 m resolution. Compared to today's technology, its capability was primitive; but it acted as a test bed to test various new technologies like the radar itself, data recording system and on-board Quick Look Display (QLD) system. Further, the experience gained by experimenting with this system, acted as foundation for subsequent development of complex SAR technology.

ASAR (Airborne SAR) was the first proud foray of ISRO in SAR development (Fig. 9). The aim of this development was not only technology attainment but also demonstration of application potential. Consequently, this system was configured in C-band providing 6 m resolution over 25 km swath. Though the breadboard model was tested in 1992, the aircraft was lost in an accident in 1994. The development was continued in a new aircraft and the ASAR system was used for experimentation since 1997. For the first time, a modest narrow swath (2.5 km) Real Time Processor was demonstrated in this system.

The high point of this project was development of a sophisticated SAR processor involving motion sensing and compensation. In fact it had a novel two track motion compensation processor which added to the robustness of the system. This algorithm was implemented on a parallel processing system consisting of 8 Xeon processors.

ASAR has been used to demonstrate flood mapping and monitoring operation in 2003–2004. ASAR experience provided the impetus for development of an improved version of C-band airborne SAR, DMSAR (SAR for Disaster Management), exclusively for flood

monitoring activity. ASAR experience has demonstrated that for quick reaction to flood related emergency, airborne SAR system is more effective than its space borne counterpart. Spaceborne SARs, with their fixed orbital configuration, cannot ensure quick reaction to flood situation.

DMSAR–Airborne SAR for Disaster Management

DMSAR was developed with operational requirement for disaster monitoring. To aid flood monitoring and assessment of damage to infrastructure, four resolution modes were provided. DMSAR was test flown for the first time in Nov. 2005. It was calibrated completely and its effectiveness in flood assessment was evaluated in 2006.

To support its high resolution and wide swath capability, the ASAR processing algorithm was significantly modified. A new algorithm called *Track Steering* algorithm was developed (under process of patenting) to process in high resolution modes. The DMSAR processor is available on three platforms:

A parallel machine with 32 Itanium processors; In house developed portable Near Real Time Processor (NRTP) built around 96 TS-101 processors and *GARUDA* computing grid provided by CDAC.

Using this grid, DMSAR data can be processed simultaneously on an array of computing nodes available in academic and research institutions across India. Figure 10 shows the photograph of DMSAR in operation and also a sample of high resolution imagery obtained by it. Figure 10 depicts a typical flood region, mapped by DMSAR, over Dharbhanga, Bihar in 2007. Devastating breach of Koshi River in Nepal in September 2008 as captured by DMSAR is also seen in the Fig. 10. This breach resulted in change of Koshi river track leading to devastating flood of Bihar Plains.

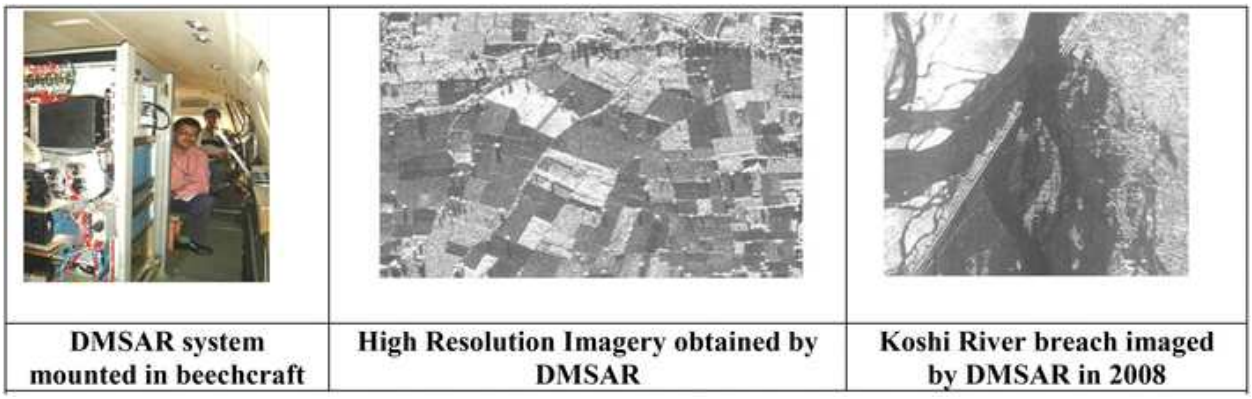


Fig.9: ASAR system mounted in beechcraft and a sample of imagery obtained by ASAR

Fig.10: DMSAR system and its applications for flood assessment in Koshi, DMSAR system mounted in beechcraft, High Resolution Imagery obtained by DMSAR, Koshi

River breach imaged by DMSAR in 2008

RISAT–Radar Imaging Satellite, ISRO's First SAR Satellite

India's first C-band spaceborne SAR onboard Radar Imaging Satellite-1 (RISAT-1) built by Space Applications Centre, launched on 26th April, 2012, has been extensively used by Indian and international users for various applications like agriculture, forestry, oceanography geology, cryosphere, disaster management support, land-use, etc.

RISAT-1 SAR (Fig. 11) is operated in the following basic imaging modes:

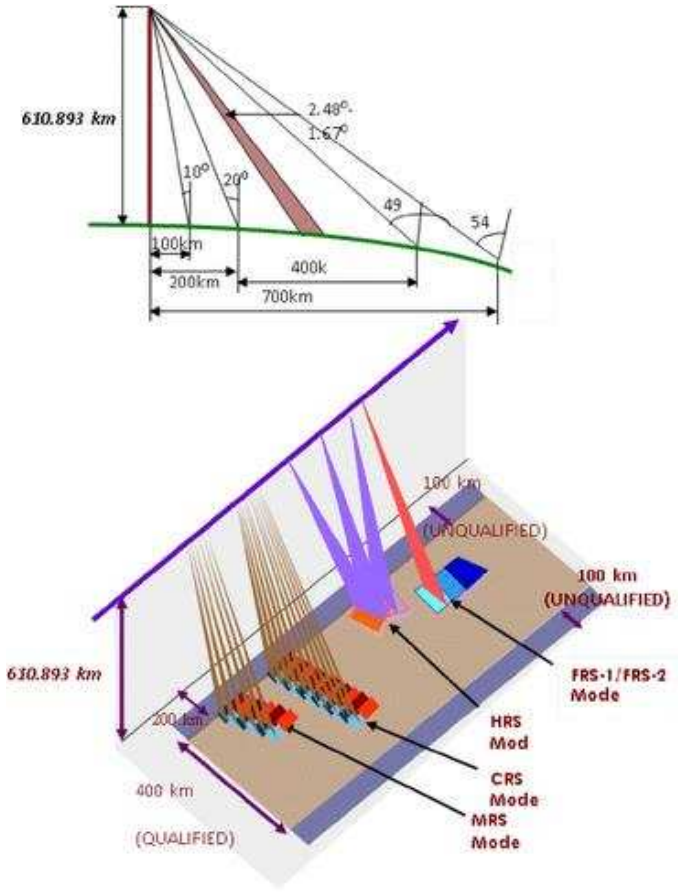


Fig.11:RISAT imaging modes

- *Fine resolution stripmap mode-1 (FRS-1)* It is based on conventional mode of SAR Stripmap imaging, providing 25 km swath (25 km) with 3-meter resolution.
- *Coarse resolution scan SAR mode (CRS)* This 12-beam ScanSAR mode provides 223 km swath with a resolution of 50 m.
- *Medium resolution scan SAR mode (MRS)* This is a 6-beam ScanSAR mode, similar to the CRS mode, providing a resolution of 25 m over a swath of 115 km.
- *Fine resolution stripmap mode-2 (FRS-2)* This mode has quad polarization capability. Philosophically, this mode is a hybrid stripmap and scanSAR.
- *High resolution sliding spotlight mode (HRS)* In the sliding spotlight mode, the antenna beam is oriented continuously to illuminate a particular 10 km × 100 km sliding spot on the ground, which can be imaged with 1 m resolution.
- *Circular polarimetric modes (C-HRS, C-FRS-1, C-FRS-2, CMRS, C-CRS)* All the modes mentioned above can be operated in hybrid-circular polarization.

There are several unique features of RISAT and the entire set of technologies associated with the payload is indigenous. RISAT-1 is the only C-band SAR in the world that is capable of giving 1 m resolution over 10 km x 100 km spot. It is the first SAR in the world with Hybrid polarimetry, which overcomes the constraint of restricted imaging below 35° incidence angle and allows RISAT-1 to operate at incidence angles as low as 12°. This feature helps the system develop new remote sensing application in soil moisture, glacier studies and better imaging in hilly regions.

RISAT-1 SAR images/data products are disseminated and utilized by the identified users on an operational basis mainly for Agriculture, Disaster Management and other ancillary applications related to oceanography, urban mapping, forest cover, etc. Hybrid Polarimetric SAR image generation from RISAT-1 SAR data is the other major capability utilized by interested scientists and researchers. Antrix, India has also entered into a major contract with M/s. Kongsberg Satellite Services (Ksat), Norway for RISAT-1 SAR direct data reception and SAR image generation at its Svalbard and Tromso stations, thereby confirming the good quality and international acceptability of RISAT-1 SAR data.

Apart from design and development of an active antenna based SAR system, the major achievement of RISAT project is extensive industrial partnership in developing critical technological elements needed for payload. This involved not only capacity building for production of space qualified hardware in the industry but also extensive qualification of production processes and training and sensitization of personnel involved. The TR module, along with all the MMICs associated with it, are designed and produced in India itself. Miniaturized pulsed EPC for powering TR module, featuring three different HMCs and planar transformer, has been a feat of Indian industry. Printed antenna aperture has been designed in ISRO and produced by Industry. The ASIC meant for controlling active array antenna elements, has been designed in-house.

ScatSAT-1

OSCAT, during its life time has demonstrated the importance and significance of the ocean wind vector data in weather modeling and prediction and laid the ground for continuation of the global ocean surface wind vector data acquisition. Based on this experience, SCATSAT-1 (Scatterometer Satellite) mission was planned as a dedicated mission to continue the global ocean wind vector data acquisition started by the OSCAT. SCATSAT-1 is configured on Indian Mini Satellite (IMS-2) Spacecraft bus of ISRO. Scatsat-1 is a Ku-band pencil-beam Scatterometer radar-only payload mission, has been launched in September 2016. The Scatterometer instrument onboard SCATSAT-1 is similar to the OSCAT flown onboard OCEANSAT-2.

Retention of major system levels specifications (altitude, scan geometry, look and incidence angles) has facilitated fast realization through the usage of hardware procured or designed for OSCAT. RF designs viz., Frequency Generator, TWTA, Front-End Switch Assembly (FESA), Receiver subsystem, have been retained while digital subsystem has been miniaturized by combining various functionalities like baseband chirp generation, radar Controller and Data acquisition and onboard processing into one subsystem. Major changes have been introduced to improve the overall instrument reliability factor through cross patching of the critical subsystems. Though the OSCAT has been designed primarily for capturing ocean surface wind vector data, it has been found that the scatterometry data has wide applications in sea ice and polar ice studies as demonstrated by both QuikScat and OSCAT.

Ground Penetration Radar

The design and development of a miniaturized ground penetration radar, operating at 250-750 MHz, has been taken up by SAC as a proof-of-concept prototype for geodetic applications on earth as well as future lunar and planetary missions, to derive information about land profile, geology and other potential subsurface resources. The frequency-stepping P-Band instrument uses a bow-tie antenna and is realized in a compact 8.4 W, 10 kg frame that is easy to use. The instrument makes use of miniature ruggedized (IP67 compliant) SSR of 64 MB (extendable to 512 MB) with UART recording interface and USB data-retrieval interface, specifically for GPR operations. Low-cost instrument has been realized which is ~ 20 times cheaper than commercial equivalent. Indian market is presently procuring GPRs from only foreign suppliers. Hence, this instrument presents a viable indigenous alternative, and is being offered for Technology Transfer.

This GPR has been a prime instrument for Antarctica snow studies (Indian Scientific Expedition to Antarctica, ISEA) over the past three years; the fourth expedition with this GPR is currently in progress. Snow and Ice profiles up to 14 m depth have been recorded at Antarctica (Fig. 12).

Follow-On Mission: RISAT-1A

To provide continuity of RISAT-1 mission, a follow-on mission called RISAT-1A has been already approved for launch by 2018-19 timeframe. Keeping in view the long lead times associated with the development of active-array electronics and other elements (like, antenna structure, spacecraft interfaces), no major changes have been planned in RISAT-1A configuration. Therefore, the system specifications of RISAT-1A are primarily the same as that of RISAT-1.

The improvements in RISAT-1A include configuration of full-polarimetric mode in lieu of quad-pol mode of RISAT-1 (termed Fine Resolution Stripmap-2, FRS-2; which basically operates with alternate bursts of H and V transmit pulses). Though the full polarimetric mode calls for high PRF (due to alternate H & V pulses) and compromises on swath, it allows extraction of the complete 4×4 Stokes 'matrix and is therefore, considered to be the gold-standard for polarimetric observations. Due to these factors, the full-polarimetric mode is an important inclusion in the RISAT-1A configuration. Hybrid polarimetry available with all the resolution modes of RISAT-1 will be retained in RISAT-1A as well. As a result, both the forms of polarimetry (hybrid and full-pol) will be available in RISAT-1A.

RISAT-1A will operate from a sun synchronous orbit at a nominal altitude of 536 km, same as that for RISAT-1. It will image from nominal 100 to 700 km off-nadir distance and corresponding look angles will vary from 10.5° to 50.6°.

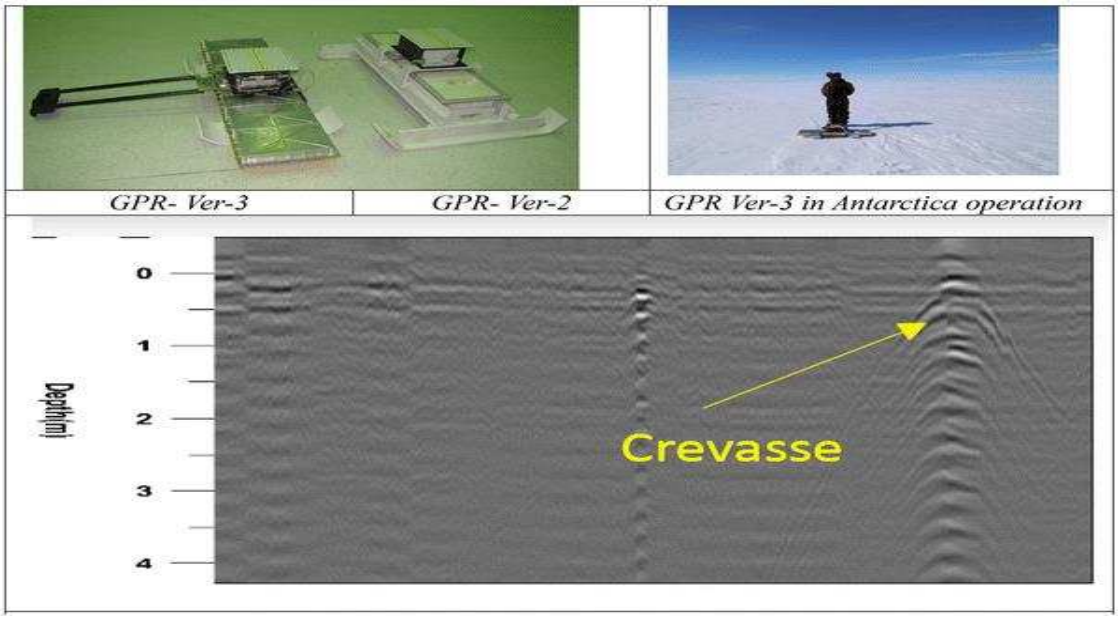


Fig.12: GPRs and crevasse observed from Antarctica

RISAT-2A

RISAT-2A Active antenna based Synthetic Aperture Radar development is initiated with the objective of providing continuity to RISAT-2 mission requirements. RISAT-2 satellite was launched in April 2009 with mission life of 5 years. The SAR will operate in X-band with centre frequency 9.6 GHz with Single/Dual/Circular Polarization capability. It will offer multimode operation with high spatial resolution. The SAR will have a high resolution mode with spatial resolution of less than 0.4 m.

All the modes (StripMap, Spot, Fine Spot and Mosaic) are available in single polarization (HH/VV), dual polarization (HH + HV, VV + VH) and hybrid-circular polarimetry (transmit circular, receive linear). Swath coverage of 200 km to 650 km will be achieved by roll-tilting of the satellite.

In order to provide greater flexibility in the selection of the look angles for different applications and to increase the effective repeatability, a region on the ground may be accessed by different look angles ranging from 23.4° to 52.8° corresponding to off-nadir distances of 200 km and 650 km, respectively. This look angle variation is implemented by roll-tilting the satellite.

Electronic beam scanning of ± 2° in elevation direction and ± 2° in azimuth direction is planned. SAR will operate with basic elevation beam limited swath of 6–10 km, over a total ground distance of 450 km, starting from an off nadir distance of 200 km and up to

650 km.

Fig.13: L-Band SAR imaging configuration

X-band MiniSAR

X-Band Miniaturized Synthetic Aperture Radar is developed with the objective of high spatial resolution imaging from an airborne platform. The SAR can operate in X-band, Single/Dual/Circular Polarization, with high spatial resolution. The system design is made such that it can accommodate altitude variation of 3 km to 10 km with on-board data storage. System can be fit in small aircrafts as it has small size and low weight.

L &S Airborne SAR

ISRO in collaboration with NASA & JPL is developing a Dual Frequency Sweep SAR (DFSS) in L and S bands. As part of this, Space Applications Centre (SAC), ISRO is realizing the S-SAR and Jet Propulsion Laboratory (JPL), NASA is developing the L-band SAR. In this process, a number of new technologies in digital and RF domains are being developed at SAC. As a pre-cursor to the space-borne SAR development, an airborne SAR in L& S band is being planned. For the airborne version, both L & S band SARs will be developed simultaneously by SAC itself, adhering to system design aspects of NISAR to the maximum extent possible. The sensor being developed is aimed to be operated in a Beech craft, currently available with NRSC, Hyderabad. The system is being designed to be operated at an altitude of 8 km with a platform velocity of 120 m/s. The centre frequencies are maintained at 3200 MHz for S-band SAR and 1250 MHz for L-band SAR, with bandwidth options of 25, 50 and 75 MHz, as in the case of NISAR. The sensor is being designed to operate in all the polarisation modes, viz. single, dual, compact, quasi-quad and full polarimetry.

L-Band SAR Satellite

Presently plans are afoot to build an L-band SAR as successor of RISAT (Fig. 13). Presently the pay load is in drawing board. This SAR will have scan SAR modes matching with RISAT. It will have stripmap mode of resolution 5 m and swath of 60 m. The interesting addition will be electronically steered spotlight mode providing 2.5 m resolution over 340×40 km spot. Compared to RISAT, it will have additional linear polarimetry mode apart from Hybrid polarimetry.

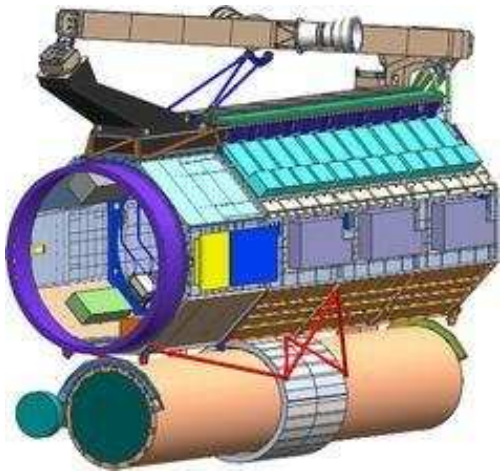
Like RISAT, the antenna will be based on active array technology to provide electronic steering in elevation and limited electronic steering in azimuth to support spotlight mode. The antenna size will be 10mx3 m, weighing 600 kg and the satellite is being planned for launch by PSLV.

L-band SAR pay load will also carry a demonstration model of Real Time Processor, for the first time, for processing the SAR raw data on the fly.

NISAR

NASA/JPL and ISRO have undertaken a collaborative programme for the joint development and launch of dual band NISAR science mission, based on JPL's patented SweepSAR concept, which helps achieve wider swath without compromising resolution (Fig. 14). NISAR will be a unique radar imaging satellite mission carrying together, JPL/NASA's L-band SweepSAR and ISRO's S-band SweepSAR. It will support 5-10 m resolution over > 225 km swath. The 12 m single reflector will serve both L- and S-band SweepSAR and will consist of 24 S-Band TR Module pairs for dual polarization operation. Payload level Baseline Design has been finalized and proof-of-the-concept development activities are underway related to various constituents like S-Band TR Integrated Module (TRiM) and RF Baseband & Digital hardware.

NISAR is optimized for studying hazards and global environmental change using advanced radar imaging that will provide an unprecedented, detailed view of Earth. The satellite is designed to observe and take measurements of the planet's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards such as earthquakes, tsunamis, volcanoes and landslides. Scheduled to be launched in 2020, the mission will also monitor the country's agricultural biomass, snow and glacier studies in



the Himalayas.

Fig.14:Schematic of NISAR payload

Terahertz Telecscope:

The vision of the Terahertz technology development program is to bridge the so-called Terahertz "technology" gap that exists between the technologies at microwave and at infra-red and visible ends of the electromagnetic spectrum. The Terahertz gap spans over a large frequency range from mm-wave (up to 300 GHz) to sub-millimeter wave (300–750 GHz) and further to far infrared (25–350 μm). The technology is entirely different as one moves from one frequency regime to another— rom Schottky Barrier diodes to Superconductor-Insulator-Superconductor (SIS) to Bolometers and their associated stringent cooling requirements. Globally, astronomical observation has been the prime science driver for THz technology development for studying the evolution of the universe by spectroscopic and continuum observations in the ISM, the circumstellar discs, giant molecular clouds, proto-planetary discs, asteroids, and Young Stellar Objects of galaxies at different red shifts.

Continuing ISRO's thrust for building and indigenizing state-of-the-art technologies for various microwave/optical payloads, for realization of a multi-frequency mm-wave/sub-millimeter wave sensor covering frequency range up to 300 GHz, various critical technologies will be indigenously developed at SAC.

Earth Observations (EO) Applications in India - A few Examples

During the past decades, Indian Space Programme has made remarkable progress in building space infrastructure to accelerate various developmental processes, and harness

the benefits of space for socio-economic development in the country. Since the early days of Remote Sensing with Landsat MSS data in the 70s, use of remote sensing for natural resources inventory & monitoring has come a long way in the country - graduating from demonstration phase to operational era, expanding scope to newer and newer areas over time. Today, remote sensing based actionable information/ products & services are supporting informed decision making in the country, in the areas of - food & water security, environment & eco-system management, cartography, ocean & atmospheric studies and disaster mitigation. The hallmark of the Indian EO programme is also the close cooperation between Government, Industry and Academia - forming a formidable EO triad.

In India, the space technology applications have helped in addressing the national developmental needs, and enabled creation of a comprehensive Spatial Data Infrastructure (SDI) as a national repository. Some examples of using such spatial data for management of natural resources, operationally, include: identifying environmentally degraded wastelands & reclaiming cultivable wastelands; identifying sources of drinking water - especially in hard-rock terrain, aw well as suitable sites/ zones for ground water recharge; watershed development in a holistic manner by linking livelihood system to soil & water conservation measures; irrigated/ command area management addressing issues like water-logging, salinity & alkalinity; assessment and forecasting of agricultural crop acreage & production; bio-diversity characterization at landscape level; and disaster management support for cyclone, flood, agricultural drought, landslides, forest-fire; etc. Following are some of the applications that highlight the use of EO data for societal benefits in the country.

Crop Forecasting

In globalised world, agricultural statistics is key information for taking crucial decisions related food security. Towards this, Ministry of Agriculture has been supporting a remote sensing based nationwide project called pre-harvest Crop Acreage and Production Estimation (CAPE) for providing in-season crop statistics with reasonable accuracy. Based on the experience gained through CAPE; ISRO has developed methodology for Forecasting Agricultural Output using Space, Agro- meteorology and Land-based Observations (FASAL), combining remote sensing, meteorology and econometrics for providing multiple in-season crop forecasting. This is one of the operational applications developed using remote sensing to provide forecasts of major crops with reasonable good accuracy well before the harvest. The effort has contributed to reducing the gaps between crop production and post-harvest technology, pricing and policy decisions. ISRO has also transferred the methodology of FASAL and National Agricultural Drought Monitoring Assessment Project to Mahalanobis National Crop Forecast Centre (MNCFC) of Ministry of Agriculture. Currently, MNCFC operationally provides multiple pre-harvest production forecasts of 8 crops, viz., Rice (kharif & rabi), wheat, rapeseed & mustard, potato, jute, sugarcane, cotton and sorghum (rabi) at National/ State/ District levels. The

Centre also assesses the progress and severity of drought in the country towards facilitating better management of agriculture in drought prone/ affected regions.

Disaster Management Support (DMS)

DMS is another key application, which takes cognizance of the convergent technologies - satellite communication, satellite remote sensing and meteorology, towards timely delivery of operational products and services for disaster mitigation, during different phases of the disaster event. The unique capabilities of satellites providing comprehensive, synoptic and multi-temporal coverage of large areas at regular intervals with quick turnaround time has been valuable in disaster mitigation efforts. The sections below give the highlights of a few specific case studies.

Uttarakhand Flash Floods: Unprecedented heavy rainfall in parts of Uttarakhand during 16-17 June 2013 had led to flash floods and debris-flow, causing enormous destruction to life and property. Pre and post-flood satellite images were analysed and information on: (i) extent of damage to structures, roads, settlements etc., (ii) formation of new channels upstream of Kedarnath, and (iii) flow of debris from northern and north-eastern sides were provided to concerned State and Central Government Agencies in a timely manner for planning relief to the affected. Post disasters, about 2400 landslides were mapped in the disaster-affected area for implementing long-term mitigation measures.

Based on request from the State, 12 mobile satellite phones were provided to local administration in Uttarakhand for deployment in deep interior locations. About 1000 phone calls were made during the initial critical ten days. Five transportable satellite terminals (one mobile van and four fixed terminals) were established on crash basis, in the affected area, to facilitate videoconference, data & voice transfer for coordinating the rescue and relief activities.

Tropical Cyclone 'Phailin': Severe tropical cyclone Phailin (9-12 Oct 2013), a significant severe weather system, which hit the Odisha coast on 12 October 2013, was monitored extensively using India's advanced weather satellite INSAT-3D. The damage to human loss due to the cyclone "Phailin" in Bay of Bengal and the States of Odisha, Jharkhand and Bihar was minimized due to satellite based timely early warning, and constant tracking of the cyclonic system.

High-resolution images and the sounder data from the satellite provided information on detailed structure of clouds near the centre of the tropical cyclone, cloud properties, rainfall distribution, etc., which helped in assessment of likely damage that could be caused due to the cyclonic winds. The track and intensity of the cyclone, as predicted, were disseminated through the MOSDAC website of ISRO.

Immediately after the cyclone hit, the State Government of Odisha was updated on the inundation due to floods in different rivers - at every 12 hours for the first three days, and then on daily basis; based on this, the State Administration could plan and implement the evacuation activities resulting in a very low casualty of human lives.

National Drinking Water Mission

In the last two decades, significant changes have taken place in the country in using groundwater for irrigation. Currently, about 60% of irrigated agriculture depends on groundwater sources; and close to 90% of rural domestic water supply is from groundwater. Remote Sensing data has proved its immense potential in identification of potable groundwater sources in terms of prospective locales, depth to water table & yield; and also, in identifying suitable zones/ sites for constructing recharge structures.

The project has been carried out in phases to cover the entire country; and the Groundwater Prospects Maps have been provided to respective State Agencies for using them in conjunction with hydro-geological and geophysical investigations for selecting suitable sites for drilling wells around needy habitations. The maps have also been used for locating site-specific recharge structures based on nature of underlying aquifer, site conditions, availability of water for recharge, etc.

Using these maps, over 300,000 bore wells have been drilled, across the country, with 90-95 % success rate; and over 9,000 recharge structures have been constructed.

Apart from these, a few States are using these maps in MGNREGA and Watershed Development Programmes of Ministry of Rural Development. In Gajra sub-watershed of Durg District, Chattisgarh, the Public Health Engineering Department (PHED) has constructed over 100 recharge structures of various types, such as percolation tank, stop dam, check dam, nala bund, etc.). Subsequently, it has been reported that, during 2002-2010, the water table in the area has come-up by 15 m on an average, and, at some places, even by 20 m.

Space-based Information Support for Decentralized Planning (SIS-DP)

Reliable information on land & water resources and their optimal management is vital in developmental planning. State level information repository comprising of natural resource database at 1:10,000 scale, coupled with stakeholder datasets and field- level information, helps in strengthening decentralized planning and decision making at grassroots level. In this regard, the recent initiative on 'Space based Information Support for Decentralized Planning '(SIS-DP) plays an important role in empowering the local bodies to prepare the action plans through a coordinated approach. For the 5 priority States (Andhra Pradesh, Assam, Haryana, Kerala and West Bengal), cadastral maps are also being integrated with the natural resources database. Taking advantage of the Information & Communication Technology (ICT), the information would be disseminated to grassroots through ISRO's Bhuvan Panchayat Geoportal.

Enhancing Area under Agriculture

About 16% of the country is characterized by wastelands, both cultivable and non-cultivable; and, reclamation of such lands is a must for enhancing agricultural productivity, improving ecology, and non-agricultural uses as well. Mapping and monitoring of wastelands for entire country has been carried out using remote sensing

data at the behest of Ministry of Rural Development for planning and implementing various reclamation activities. The remote sensing based mapping and monitoring of wastelands has provided the estimate that the total wasteland area in the country is 46.72 mha (2009). Based on this information, Ministry of Rural Development has been planning and implementing wasteland development activities across the country. These efforts have also helped in diversification and intensification of agricultural activities especially in rain-fed areas.

Watershed Development

Watershed Development Programme is one of the major initiatives in the country towards conservation of soil & water in the rain-fed areas for enhancing agricultural production, providing livelihood security to rural people, besides halting the depletion of the natural resources. Space applications have been adapted to respond to integrated development of land and water resources, and assess/ monitor the improvements of the treated watershed.

The Integrated Mission for Sustainable Development (IMSD), carried out for 25% of country's geographical area, has significantly contributed towards implementing soil & water conservation measures in drought-prone and rain-fed areas. National Watershed Development Programme for Rainfed Areas (NWDPRA), watershed development activities in 100 watersheds spread across three States viz., Andhra Pradesh (19), Uttar Pradesh (45) and Rajasthan (36), are being monitored using temporal satellite data (pre, first mid-term, second mid-term & post-treatment periods).

The Sujala Watershed Development Programme was implemented in 738 watersheds falling in 38 taluks distributed across seven drought-prone districts of Karnataka covering 5.12 lakh ha and encompassing about 1270 villages and 400,000 households. The project was assisted by World Bank to draw developmental plans at micro-watershed level using satellite data. Sujala was a community driven, participatory, holistic and integrated programme towards improving the production potential of degraded lands through land & water conservation measures and maximize the returns from per unit of land.

Combining of geospatial and conventional methods has resulted in arriving at a comprehensive Monitoring & Evaluation System to provide the up-to-date information at field level for tracking the project progress, outcome and impacts. The evidence-based monitoring and evaluation using top-down remote sensing and bottom-up participatory approach has helped decision makers to apply corrective measures and make appropriate policy changes, which resulted in positive impacts on the environment and socio-economic conditions. As outcome, various visible impacts were observed on ground, viz., improvement in cropping intensity by 12%, decrease in fallow lands by 10-15%; increase in irrigated crops by 8-14%; and improvement in crop yield by 6-15%. The project has received recognitions both at national and international levels, and become a role model in adopting innovations in the rural livelihood and watershed development programmes.

India-Water Resources Information Syastem (WRIS)

India-WRIS WebGIS provides a 'single window 'solution for comprehensive, authoritative and consistent data & information on India's water resources along with allied natural resources in a standardized national GIS framework (WGS-84 datum and LCC projection), with tools to search, access, visualize, understand and analyze the data for assessment, monitoring, planning, development, and finally, Integrated Water Resources Management (IWRM). 'Watershed Atlas of India 'has been prepared using detailed-scale drainage network at 1:50,000 scale, Digital Elevation Model (DEM) and other ancillary data.

There are 27 basins, 101 sub-basins and 4566 watersheds in the country. The atlas depicts distribution of watersheds in basins and sub-basins along with their major water resource assets, hydrological observatories, terrain characteristics and rainfall variability, and land use/ land cover. It would serve as baseline information for water resources development and management in the country.

India-WRIS WebGIS Version 4.0 has been released. The portal contains 12 major information systems, 35 sub information systems, 95 spatial layers and a large number of attributes (> 700) with 5-100 years data of the country. The portal also provides 'Automatic Map 'and 'Report Generation 'facility. Based on the National Map Policy (2005) and data dissemination guidelines of Central Water Commission (CWC), the public domain version has been developed, which complies with both. The mapping of country level base layers like river network, canal network, water bodies, location of towns/ villages, road and railway network has been completed using recent IRS-P6 LISS-IV & Cartosat-1 merged data. The Version also contains 6 modules for data visualization and analysis viz., WRIS Info Discovery, WRIS Explorer, WRIS Connect, Share Success Story, Water Resources Planning & Management and Input Data Builder. Further, the newer software features added in this version include interactive mobile application, interactive live screen, text and data sharing tool and 2D-3D linked view. India-WRIS would be institutionalized at CWC following the establishment of National Water Informatics Centre (NWIC).

Web-enabled Information Systems

ISRO/ DOS has developed many Web-enabled Geospatial Information Systems viz., NNRMS Portal/ Natural Resource Data Base (NRDB) to visualize the spatial datasets generated under NNRMS programme; 'Bhuvan 'for Indian Earth Observation Data Visualization; MOSDAC for Oceanography and meteorology data; BIS for Biodiversity Information; India-WRIS for water resources information; etc., to provide information services in the public domain. The ISRO data portal called "http://dataportal.isro.gov.in" provides unified access of all these databases to the user community. The services under ISRO data portal are organized under the category of Satellite Images, Land & Water, Ocean & Meteorology, Disaster Services and Planetary Science.

Future Perspectives in EO Applications:

The future agenda of space applications is to further spread its wings to address developmental imperatives in various core sectors of the society with synergistic use of advanced communication, earth observation and navigation satellites; and, catalysing development of innovative applications and services towards sustainable development of natural resources, location-based services and smart governance for better decision-making, protection of environment & ecosystem, improved weather forecasting and near-real time support to disaster management.

The strategy of Indian EO programme is to ensure continuity and enhanced services to operational workhorse missions; plan newer missions by adapting and assimilating advances in technologies meeting user needs; innovative technology development both for on-board and ground systems for future missions; develop actionable EO products and services and address issues on access, affordability, timely delivery, user-friendly format and style; and work towards capacity building in user agencies and decision making bodies.

Future Scenarios in EO systems:

Currently available data from various EO systems are operationally used in many national level resource monitoring programs but still many gap areas exists in observations as well applications and it need to be addressed in future. Need of high spatial resolution imaging is growing for infrastructure development including risk mapping and providing real time support for natural and human induced disasters. Multi crop inventory and detection of crop disease and pest require high revisit measurements at high spatial resolution with hyper spectral technology. The cartographic and urban/rural planning is an important thrust area. The Cartosat data has immense potential in this field. There is further need for high resolution mapping for preparation of rural development plans and creation of land information system, land parcel mapping at 1: 1000 to 1: 4000 scale cartographic maps.

It is proposed that Cartographic series be continued with launch of a very high spatial resolution camera on board Cartosat-3. LISS_III sensor would be modified into LISS-III-WS (Wide Swath) having swath around 925 km and revisit capability better than AWiFS in future Resourcesat-3/3A mission. New configuration in Resourcesat-3/3A will help in overcoming spatial resolution limitation of AWiFS. Resourcesat-3S, with multi-view panchromatic stereoscopic capability having high spatial resolution of 1.25 m will facilitate generation of fused products of great utility.

Vegetation stress, disease and pest detection using hyper spectral techniques such as red edge shift and mineral targeting are some of the important applications, which would require hyperspectral spectrometer on board IRS satellites on operational basis.

The cloud cover remains a major hurdle in optical remote sensing during monsoon season. Imaging RADAR applications are being served through RISAT-1 satellite. The C- band SAR sensor onboard the RISAT-1 satellite is found to be very useful for resource monitoring and disaster monitoring. Follow on mission with features similar to RISAT-1

(C-band and multi-polarization) with multi resolution capability is planned for service continuity. The L-band SAR is suggested on RISAT-3 mission for applications supporting soil moisture, crop and forest type discrimination. In addition, RISAT-1A (C band) and RISAT-2A(X band) are planned to meet needs of monitoring disaster situations. NISAR (L and S band), the NASA ISRO joint mission is optimized for studying hazards and global environmental change using advanced radar imaging that will provide an unprecedented, detailed view of Earth. Geostationary orbit provides constant surveillance, and 1 km imaging capability in visible and Near Infra red region already exists on INSAT 3A and additional channels available on INSAT-3D. Beyond Resourcesat-2/2A, high repetivity sensor with moderate spatial resolution would be continued on geostationary platform as a GISAT. This will provide multiple/day acquisition capability and overcome all limitations posed on current AWiFS data availability. Terahertz Telescope will start a new phase in our understanding of universe.

The Indian Remote Sensing satellite series from IRS-1A to IRS-P6/IRS-P5/Cartosat-2/2A/2B/2C/2D, Resourcesat-2/2A, RISAT-1/2, Oceansat-2, SCATSAT-1, Megha Tropiques, SARAL and sensors onboard-INSAT series of satellites like INSAT-3D/3DR have established space technology for operational applications related to areas of societal benefits. The missions planned in near future viz. Cartosat-3/3A, Oceansat-3/3A, INSAT-3DS*, GISAT-1, RISAT-1A/2A, NISAR shall enhance utility of EO data in meeting needs of societal benefit areas. Institutional framework for ensuring utilization of EO data is in place. Capacity building at different levels including decision makers is organized. Indian EO data is available to global users through the international ground stations set up and capacity building is extended to countries in the Asia–Pacific region. Continuity of EO missions with enhanced capability has been ensured. Road ahead for the EO programme has been visualized. Thus, Indian Earth Observation Programme is complementing GEOSS and adding to the remote sensing infrastructure in the world.

IRS Satellites: History, Characteristics and Applications:

Since inception, The Department of Space (DOS) has the vision to harness space technology for national development, while pursuing space science research and planetary exploration. To actualize this vision the DOS has evolved and focused on four distinct fields –

(i) to develop indigenous capability for launching vehicles and the development and operationalisation of Polar Satellite Launch Vehicle (PSLV) and development of Geo-synchronous Satellite Launch Vehicle (GSLV) are significant achievements in this field;

(ii) the multi-purpose Indian National Satellite (INSAT) programme for the telecommunication, broadcasting, development of education and meteorology etc;

(iii) the Indian Remote Sensing Satellite (IRS) programme for observation of earth surface features for various developmental purposes, and

(iv) Research, Training and advancement in Space Sciences and Technologies for better acquisition and processing of remotely sensed digital data and to convert it into information for the socio -economic benefit of the country.

India's first indigenously designed and developed experimental satellite the Aryabhata (named after the famous ancient astronomer and mathematician) was successfully launched by a Soviet Kosmos-3M rocket on April 19, 1975 from Kapustin Yar. Starting from Bhaskara-I, the First Experimental Earth Observation Remote Sensing Satellite built in India and launched from Vostok, Russia (former USSR), in 1979 to the latest Cartosat 2 Series satellite launched (by indigenous launch vehicle PSLV) in 2018 a variety of sensors are operating in visible, infrared, thermal and microwave spectral regions, including hyper-spectral sensors to acquire digital data at spatial resolutions ranging from 1 km to a meter have been built and launched indigenously along with satellites of developed nations. Indian Space Research Organisation (ISRO) on 15 February 2017 in a single launch successfully fixed 104 satellites in orbits; out of these 3 satellites were Indian and rest were of the developed countries mainly the USA. Within a limited time period indigenous PSLV and GSLV have established huge number of IRS and INSAT series satellites in orbits. The facilities to receive and process the remotely sensed data have been established in different parts of India along with various international ground stations. The focus of the present article is the Indian Remote Sensing Satellite (IRS) series along with sensor characteristics and applications. In the early experimental phase, Bhaskara-1(June 7, 1979) and Bhaskara-2 (November 20, 1981) provided data for land applications on the basis of two types of sensor systems – (i) television camera with spatial resolution of 1 km operated in visible and near infrared bands and (ii) Satellite Microwave Radiometer (SAMIR) for oceanic and atmospheric applications. Following the success of this experimental phase, India initiated an indigenous Indian Remote Sensing Satellite (IRS) programme to support national and sub national economies in the areas of agriculture, soils, water resources (surface and ground), forestry and ecology, geology and mineral resources, cartography, rural and urban development, marine fisheries, watershed and coastal management.

The IRS-1A was launched as first indigenous trendsetting operational remote sensing satellite on March 17, 1988 into a Sun-synchronous Polar Orbit (SSPO) by Vostok launch vehicle from Baikonur, former USSR. It was followed by the IRS-1B, an identical satellite, launched by same vehicle and from the same place on August 29, 1991. The IRS-1A/1B satellite sensors Linear Imaging Self-Scanning (LISS-I and LISS-II) operated in visible and near-infrared (NIR) bands with spatial resolutions of 72.5 m and 36.25 m respectively. IRS -P2 satellite was launched (after the failure of IRS-P1 mission on September 20, 1993) by indigenous launch vehicle PSLV-D2 (P series is named after PSLV) on October 15, 1994 with only LISS-II sensor. LISS-I and LISS-II sensors provided useful data for applications in the fields of land use land cover mapping, agriculture, forestry, hydrology, pedology, oceanography, geology, natural resource management, disaster monitoring, and cartography. To further improve the quality of data IRS-1C and 1D, identical satellites, were launched with three sensors – LISS-III, PAN (panchromatic) camera and a Wide Field Sensor (WiFS) with spatial resolutions of 23.5 m, 5.8 m and 188 m, respectively. In addition to fulfilling the general requirements, theme based IRS missions, for applications like natural resource management

(RESOURCESAT series and RISAT series), ocean and atmospheric studies (OCEANSAT series, Megha- Tropiques and SARAL) and large scale mapping i.e. detailed mapping applications (CARTOSAT series) have been introduced and well established (Table 1).

Table 1. History of Indian Remote Sensing (IRS) Satellites and Major Applications

Sl. No.	Name	Launch Date	Status	Applications
1	IRS-1A	17 March 1988	Mission completed in 1992	Land Use Land Cover Mapping, Agriculture, Forestry, Hydrology, Soil Classification, Coastal Wetland Mapping, Natural Resources (especially identification of potential groundwater locations), Disaster Monitoring, Cartography, etc.
2	IRS-1B	29 August 1991	Mission completed in 2001	
3	IRS-P1 (Also IE)	20 September 1993	Crashed, due to launch failure of PSLV	Mission failed
4	IRS-P2	15 October 1994	Mission completed in 1997	Land, Oceanographic and Atmospheric applications.
5	IRS-P3	21 March 1996	Mission completed in 2004	Technology Evaluation and Scientific Methodology Studies
6	IRS-1C	28 December 1995	Mission completed in 2007	Land and water resources management. Applications in forestry, agriculture, environment, soil characteristics, wasteland identification, flood and drought monitoring, ocean resource development, mineral exploration, land use and monitoring of underground and surface water resources.
7	IRS 1D	29 September 1997	Mission Completed in 2010	
8	IRS-P4 (Oceansat- 1)	27 May 1999	Mission Completed in 2010	Ocean- and atmosphere-related applications
9	Technology Experiment Satellite (TE S)	22 October 2001	Mission completed	Experimental satellite to demonstrate and validate the technologies
10	IRS P6 (Resourcesa t-1)	17 October 2003	In Service	Integrated land and water resources management

11	IRS P5 (Cartosat 1)	5 May 2005	In Service	First Indian Satellite (IRS P5) designed with capability to have stereo images;
12	IRS P7 (Cartosat 2)	10 January 2007	In Service	Digital Elevation Model (DEM); Geo-engineering (mapping) applications
13	Cartosat 2A	28 April 2008	In Service	Digital Elevation Model (DEM); Geo-engineering (mapping) applications
14	IMS1	28 April 2008	In Service	To provide remotely sensed data to students and scientists in developing counties,
15	Oceansat-2	23 September	In Service	Ocean- and atmosphere-related applications
16	Cartosat-2B	12 July 2010	In Service	Geo-engineering (mapping) applications
17	Resourcesat -2	20 April 2011	In Service	Integrated land and water resources management
18	Megha-Tropiques	12 October	In Service	To understand the tropical weather and climate and associated energy and moisture budget
19	RISAT-1	26 April 2012	In Service	In agriculture, especially paddy monitoring in Kharif season (sensor has cloud)
20	SARAL	25 February 2013	In Service	Marine meteorology and sea state forecasting seasonal forecasting climate
21	Resourcesat -2A	07 December 2016	In Service	Integrated land and water resources management
22	Cartosat-2D	15 February 2017	In Service	Cartographic applications, urban and rural applications, coastal land use and regulation, utility management like road network monitoring, water distribution and creation of land use maps. Change detection to bring out geographical and manmade features and various other Land Information System (LIS) as well as Geographical Information System (GIS) applications.
23	Cartosat-2E	23 June 2017	In Service	
24	Cartosat-2F	12 January 2018	In Service	
25	RISAT-2B	22 May 2019	In Service	

26	Cartosat-3	27 November 2019	In Service	
27	RISAT-2BR1	11 December 2019	In Service	

Characteristics of IRS Satellites:

The quality of data acquired by earth surface observation satellites depends on the sensors used in the satellites. The four major characteristic features of sensors are spatial resolution, spectral resolution, radiometric resolution and temporal resolution. Resolution is defined as the ability of the sensor system to render the information at the smallest discretely separable quantity in terms of distance (spatial), wavelength band of electromagnetic spectrum (spectral), radiation quantity (radiometric) and revisit frequency (temporal). In the identical satellites IRS-1A and 1B the Linear Imaging Self-Scanning Sensor (LISS-I and LISS-IIA/B) of two multispectral cameras were used. Each LISS camera consists of the collecting optics, imaging detectors, in-flight calibration system, the processing electronics and data formatting electronics. LISS uses linear array detectors (CCD – charged-couple-devices). These sensors operated in the visible and near-infrared (NIR) bands. In IRS-P2 satellite LISS-IIM (Linear Imaging Self-Scanning System-II Modified) sensor was used. It operated in push broom scanning mode as linear CCD line detector in four spectral bands in VNIR (Visible and near - infrared) bands.

IRS-1C/ID, the identical twin satellites, used LISS-III, PAN (Panchromatic camera) and WiFS (Wide Field Sensor) camera sensors operating in pushbroom scanning mode using solid state charge-coupled-device detectors. PAN (Panchromatic camera) is a push broom imager with a very high spatial resolution of 5.8 m. LISS-III sensor operates in VNIR and SWIR bands with a spatial resolution of 23.5 m and 70.5 m, respectively. WiFS camera provides two spectral bands in the VNIR range with spatial resolution of 188 m and temporal resolution of 5 days. The experimental earth observation satellite IRS-P3 used WiFS and MOS (Multispectral Optoelectronic Scanner) and IXAE (Indian X-ray Astronomy Experiment) experimental sensors. The payload in IRS-P4 or Oceansat-1 includes OCM (Ocean Color Monitor) and MSMR (Multi-frequency Scanning Microwave Radiometer). OCM is a solid- state radiometer with high radiometric sensitivity (12 bit quantization level), which provides multi-spectral imagery with narrow spectral widths in eight bands in VNIR range. MSMR is a dual-polarized four-frequency radiometer measuring microwave brightness temperature. Cartosat-1 or IRS-P5 has PAN-F (Panchromatic Forward-pointing camera) and PAN-A (Panchromatic After- pointing camera) cameras to obtain two-line stereo configuration for terrain modeling. Each camera operates in spectral band of 0.5 to 0.85 μm, a spatial or geometric resolution of 2.5 m, a swath width of 30 km for stereo imagery, and data quantization or radiometric resolution of 10 bits. The Cartosat-1 data products are to two types – standard product which is radiometrically corrected and georeferenced and precision product which is ortho rectified product. ResourceSat-1 or IRS-P6 carries three sensors – LISS-III, LISS-

IV and AWiFS (Advanced Wide Field Sensor) and all are push broom scanners using linear arrays of CCDs. LISS-III camera is identical to the one used in IRS-1C/1D. The LISS-IV is multispectral high-resolution three band push broom camera in VNIR bands with a spatial resolution of 5.8 m. It can be operated in multispectral mode i.e. data collected in 3 bands and mono mode i.e. data collected in single selected band corresponding to a swath of 70 km. AWiFS is a wide - angle medium resolution (56 m nadir and 70 m at swath edge) camera. The wide swath 804 km of this WiFS heritage sensor provides temporal resolution or revisit frequency of five-day.

Applications of IRS satellites:

In 1982 the Planning Commission of India had recognized necessity and significance of establishing a National Natural Resource Management System (NNRMS) to efficiently manage the natural resources by applying remote sensing techniques in conjunction with traditional techniques. Planning Committee of NNRMS (PC-NNRMS) sets guidelines for earth observation based systematic inventory of the country's natural resources and oversees the progress of remote sensing applications for natural resources management in the country. PC- NNRMS in 1984 constituted six Standing Committees on – (i) Agriculture and Soil; (ii) Bio-resources and Environment; (iii) Geology and Mineral Resources; (iv) Ocean Resources; (v) Remote Sensing Technology and Training and (vi) Water Resources ; and in 1997 three more were constituted on (vii) Rural Development; (viii) Urban and (ix) Cartography. The themes of these Standing Committees themselves represent the major fields of applications of information acquired from earth observation satellite IRS series. The main applications of IRS series satellites are listed in brief in the following section.

Applications in Agriculture and Soil

The agricultural applications of IRS satellite series are following: - (i) Cropping pattern mapping; (ii) Pre- harvest crop area, production and yield estimation; (iii) Condition assessment; (iii) Monitoring command areas; (iv) Compliance monitoring (farming practices) e.g. crop stubble burning; (v) Identification of suitable sites for different agricultural practices; (vi) Mapping of soil characteristics; (vii) Mapping of soil management practices; (viii) Mapping of saline soils and monitoring of land reclamation; (ix) Inventorying and categorization of wastelands; and (x) Identification of fishery prospects.

Applications in Bio-resources and Environment

The applications of IRS satellite series in forestry, b iodiversity and ecosystem sustainability are following: - (i) Mapping of forest cover, types, density and species inventory; (ii) Measurement of biophysical conditions of forest strands; (iii) Social forestry and agroforestry mapping; (iv) Biomass estimati on; (v) Afforestation and deforestation assessment; (vi) Forest fire surveillance; (vii) Forest health and vigor monitoring; (viii) Detailed survey and inventory of the existing bio-resources; (ix) Environmental impact assessment including pollution (land, water and air); (x) Mapping

and monitoring of tiger reserves, elephant corridors, biosphere reserves, mangroves and coral reefs; (xi) Assessment of fuel wood and timber resources; and (xii) Environmental hazard related studies like zonation and damage assessment (floods, drought, cyclone, landslide, volcano, earthquake etc.).

Applications in Geology and Mineral Resources

Geological applications of IRS series satellites include the following: - (i) mapping of surfacial deposits and bedrock; (ii) Lithological and structural mapping; (iii) Mineral prospecting and exploration; and (iv) Geo - hazard mapping, monitoring and zonation.

Applications in Oceanography

The applications of IRS series satellites, especially Oceansat-1 and Oceansat-2, include the following: - (i) Identification of potential fishery zones; (ii) Phytoplankton abundance and habitat assessment; (iii) Observation of marine pollution and sedimentation and its impact; and (iv) Assessment of sediment dynamics, tidal fluctuations, sea level changes and coastal circulations.

Applications in Water Resources

The applications of IRS series satellite data products in water resource include the following: - (i) Mapping of surface water bodies; (ii) Identification of potential ground water resources; (iii) Wetland mapping and monitoring; (iv) Snow pack and glacial monitoring; (v) Ice thickness measurements; (vi) Rivers, watersheds and ice lake monitoring and modelling; (vii) Flood mapping and monitoring; (viii) Monitoring reservoir extends over seasons and irrigation scheduling and flood management; and (ix) Snowmelt runoff forecasting.

Applications in Urban Sector

The applications of IRS satellites data products in urban sector are following: - (i) Mapping and Land Use Land Cover classification; (ii) Urban sprawl analysis; (iii) Identification of illegal encroachment, and constructions; (iv) Property tax assessment and estimations; (v) Transport and urban planning; (vi) Mapping of utilities and services; (vii) Population estimation; (viii) Slum detection and monitoring; and (ix) Site suitability analysis

Applications in Cartography

Mapping constitutes an integral component of the process of resource management and mapped information is the common product of analysis of remotely sensed data from IRS series satellites. The Cartosat series is especially oriented towards geo-engineering mapping and DTM (Digital Terrain Modelling) or DEM (Digital Elevation Modelling). Natural as well as manmade features such as transportation networks, settlements and administrative boundaries are represented spatially with respect to geo-referenced data and integrated with attribute information or non-spatial in GIS (Geographical Information System). Baseline, thematic and 2D and 3D topographical maps are essential for

planning, evaluation and monitoring, for civilian and military reconnaissance and land use planning.

Conclusion:

Since inception the IRS satellite series is oriented towards societal benefits and its ultimate objective is sustainable development of India. To address this goal it is applications driven and has greatly diversified in applications, that too in a limited time period. The information derived from remotely sensed data is an essential component of the National Natural Resources Management System (NNRMS). The Indian Remote Sensing (IRS) satellite program is to support national and sub national economies in the areas of agriculture, soils, water resources (surface and ground), forestry and ecology, geology and mineral resources, cartography, rural and urban development, marine fisheries, watersheds, coastal and disaster management.

MODULE-VII

GIS TECHNOLOGIES AND LAWS IN INDIA

GEOSPATIAL POLICIES IN INDIA AND THEIR IMPLEMENTATION IN GOOD GOVERNANCE

INTRODUCTION

During the First Five-Year Plan of the government, a S&T policy was announced in 1956 to give the boost of science, technology, application and development. Also, the government has opened various opportunities under various themes to promote multiple sectors towards the vision of inclusive growth in science. In the process, number of new institutions and academic institutions were set up to work exclusively in different areas. One of the important institutions, i.e. Survey of India was already in existence. The basic job of the Survey of India (SoI) was assigned to survey topographic maps on 1:50 K scale for the entire country. SoI has collected topographical details during 1965–1970 and finally printed the maps in 1980 for the use of different purposes by the government as well as by the general public. In order to distribute such maps, there was a policy under which topographical sheets were made available to the public with the written request.

With the advancement of satellite technology and also Indian capability in this area made possible to acquire large amount of topographical information by the satellite images and upscale the maps quickly. With this advancement, the availability of geospatial maps and data accessibility become easier and faster. In addition, there are number of other agencies in government like Geological Survey India (GSI), Forest Survey of India (FSI), National Informatics Centre (NIC), Directorate of Census and Ministry of Statistical and Programme Implementation have also collected huge data sets (spatial and non-spatial). In order to handle and use such voluminous data for various applications, the need was felt at different levels to draw the policies to address various issues related to the data quality, standards, usage, security and civil applications. In this series, the following policies were announced by various departments of the government.

Existing Policies Dealing Geospatial and Non-spatial Data

Open availability of satellite data and digital forms of maps, especially when seen in the global context, has necessitated policymaking in India, over the last two decades, such as:

- ***National Map Policy (NMP), 2005***: It basically defines the scope, distribution and liberalised access of digital survey of India topographic maps to user groups without jeopardising national security. As per this policy, SOI has prepared open series topographical maps for the use of the civil purposes which were made available as per the policy.
- ***The Civil Aviation Requirement (CAR), 2012***: This policy basically details procedures for issuance of flight clearances for agencies undertaking aerial photography, geophysical surveys and cloud seeding.

- ***The Remote Sensing Data Policy (RSDP), 2011***: It defines the distribution pro- cess of satellite images to different category of users and their availability for attending various applications.
- ***The National Data Sharing and Accessibility Policy (NDSAP), 2012***: This pol- icy basically deals with providing an enabling provision and platform for proactive and open access to data generated through public funds available with various departments and organisations of Government of India. The Policy at present has made considerable progress to enrol about 106 Government departments to proactively sharing the data on the national portal, i.e. data.gov.in. Further efforts are on to enrol State Government agencies to adopt this policy and share their data for public use.
- ***National Geospatial Policy (NGP):*** This policy is being coordinated by Department of Science and Technology and is at the drafting stage. Once, this policy is ready, it will empower people to access geospatial data for addressing their need using geospatial technologies without compromising national security. Also, it will play a vital interface between government and other agencies for doing ease of business.

Standards, Spatial Framework and Technologies

Open Geospatial Consortium (OGC) standards are immensely popular and adopted by government and industry and bring about a high level of focus on interoperability through open standards. OGC standards have been defined to systematise metadata, map services and Web services and host of applications services. The following key parameters are defined for standards development:

- Content standards
- Metadata standards
- Schema/data models
- Spatial framework
- Quality
- Image
- GIS services
- Portal standards.

In India, Department of Space has published NNRMS standards, 2005. Thereafter NSDI standards which were limited to metadata and SOI data exchange. Under Ministry of Urban Development, the national urban information system programme is initiated in 2004–06, adopted from NNMRS standards. As a part of this, 153 towns have been completed and verified.

Advancement in Technology for Data Acquisition

World over, satellite images have reached sub-meter accuracy levels operationally and with unprecedented coverage. As our capacity to handle massive spatial data sets grows, with higher bandwidth of networks, newer applications have evolved. Many more such applications that harness evolving technologies and standards need to be developed in various sectors like infrastructure development, agriculture and water resources, disaster management, land use and land management, developing state spatial data infrastructure for attending area specific problems using high resolution and accurate satellite images. This has made tremendous impact in the use of geospatial data and developing area specific problems. In the light of this, all the geospatial policies listed above have some component of supporting the technologies and applications and promoting and adopting to solve micro-level planning for good governance.

Other Advanced Technologies for Data Acquisition

In addition to the satellite images available in various resolutions and accuracy, the technologies unmanned vehicle, drone mapping and global positioning system (GPS)/ground penetrating radar (GPR) have made significant headway for data acquisition of high standard accuracy. For example, unmanned ariel vehicle (UAV) is of high potential and useful to support rapid mapping activities in terms of accuracy and flexibility. Its high resolution can be turned into proper higher accuracy by means of integration with existing geospatial data, i.e. airborne IFSAR data to map the disaster area immediately. In a similar light, unmanned surface vehicles (USVs) are useful in bathymetric surveys of reservoirs and other water bodies, towards creating data sets to help water resource planning or flood mitigation. Therefore, conventional data available with various departments are considered not so much important due to the availability of such data sets. Therefore, all the data sharing policies should be facilitating the use and accessibility of geospatial data to the common person and its benefit to the society.

Future Scope of Geospatial Data and Policies

At present, the advancement in the development of sensors and resolution of data capturing and accuracy has made significant progress. Considering this in view, the development of infrastructure to deal such data set and attend application needs high level of expertise and computational facility which needs to be developed at various levels including institutional as well as operational level. The only issue remaining is the operationalization of geospatial data and its usage at various hierarchical level, i.e. state, district and subdistrict level. The geospatial technology for good governance at the micro level needs to be promoted to accrue maximum benefit.

National Spatial Data Infrastructure India (NSDI-India)—Present Status and the Future Strategies

To facilitate data sharing over the Web in SDI framework, various agencies have been adopting international spatial data and process standards from Open Geospatial Consortium (OGC); and International Standardization Organization (ISO). Interoperable

spatial data services based on standards have been operationalized by the respective organizational data nodes/portals of various agencies for providing access to data services for automated access by applications/software utilities. Metadata (data about data) of the geospatial data sets to facilitate search and discovery of maps and data have been made accessible from the NSDI portal. At the state level, State Spatial Data Infrastructures (SSDIs) are being set up in collaborative mode between DST and the state governments for providing access to various geospatial data sets relevant to state's jurisdiction, e.g. cadastral plot boundaries, land ownership, groundwater, mining and geology.

Related Policies

With the launch of NSDI, efforts have been made to relax the restrictive policy regime. In 2005, the National Map Policy has been approved by the Union Cabinet providing for the preparation of Open Series Maps (OSM) for civilian use and Defence Series Maps (DSM) for exclusive use by the defence forces. NSDI initiative has been formally launched through a cabinet resolution in June 2006 with the objectives of improving access to organized collection of geospatial data, making those searchable and discoverable through their metadata and sensitizing end-users on the benefits of NSDI. A two-tier coordinating structure as indicated in later part of this section, with more details has been installed to facilitate standardization and interoperable sharing of geospatial data amongst the stakeholder agencies. A single window access mechanism of India geoportal has been made operational for providing access to metadata of various agencies.

In order to facilitate sharing of data sets and improving accessibility, a National Data Sharing and Accessibility Policy (NDSAP) has been notified by the government in February 2012. As per the provisions of the NDSAP, the National Open Government Data Portal (data.gov.in) has been implemented by the National Informatics Centre (NIC), New Delhi. A National Remote Sensing Data Policy has been framed in May 2011 to govern sharing of and access to satellite data sets and images in the country. The Information Technology (IT) Act, 2000 of Ministry of Electronics and Information Technology (MeitY); the Right to Information (RTI) Act, 2005 of Department of Personnel & Training (DoPT); and various state-level data sharing and Accessibility Policies have been framed by various states to improve sharing and accessibility. Despite availability of the above policy framework, it has not been possible to search/discover geospatial data sets in an easy and user-friendly way; quickly interpret analysed results and use them in decision-making process; and seamlessly link data sets from various sources/agencies. As a part of the implementation of the NDSAP, Open Government Data Portal has been operationalized for providing open access to government data sets.

Towards overcoming the above problems, it has been decided to frame a more comprehensive National Geospatial Policy (NGP) covering geospatial data, products, services and applications. Formulation of a National Topographic Frame and a National Image Frame covering the National Foundation Spatial Data Sets, formation of a National Geospatial Authority (NGA); and user-friendly sharing of geospatial data sets for easy accessibility by various stakeholders have been envisaged in the proposed Policy.

Databases, Metadata and Architecture

Over the past years, efforts have been made by NSDI to compile and serve metadata of different partnering agencies and reengineer the feature data sets for improving their use. The NSDI partnering agencies have large amounts of feature data sets/images and are presently managed in file-based systems largely through quadrangle sheets/scenes without appropriate strategies for fully automated search, querying and processing. This is evidenced in the present ways to store and manage metadata sets as per the indices of quadrangle sheets/scenes of data providing organizations. Identification and maintenance of feature data sets, in particular, thus pose a major challenge to the stakeholders, thereby inhibiting appropriate use of the geospatial data in real-life applications.

Data providing agencies partnering with NSDI at the national and state levels have thus developed and operationalized relational databases for effective search, discovery and sharing of processable data over the Web. Development and maintenance of the India geoportal have been the single window gateway to provide standardized Web-accessible services of the data providing agencies like Survey of India (SOI), National Remote Sensing Centre (NRSC), Geological Survey of India (GSI), Forest Survey of India (FSI), Central Water Commission (CWC), Central Ground Water Board (CGWB), and Ministry of Statistics and Programme Implementation (MoSPI) and several state governments.

Besides the geospatial metadata accessible from the India geoportal in BIS 16439/ISO 19115 standards, a National Data Registry (NDR) prototype containing additional metadata has been demonstrated with registry and catalogue services to facilitate automated search and discovery of map, feature and coverage data services. The NDR contains metadata relating to the feature data definitions, application schemas and classification codes for uniquely identifying geospatial data from various data nodes and correct interpretation of results of geospatial analyses carried out using services from the data nodes of multiple organizations.

A standard operating procedure (SOP) has been prepared for Survey of India's 1:50,000 scale topographic data reengineering towards development of processable GIS data and provision of Web Feature Service (WFS) in OGC Geography Markup Language (GML) format. Preprocessing and cleaning of the feature data sets have been carried out for the publication of the Web Map Services (WMS) with a countrywide coverage from the data node. Development of SOI's foundation data layers for Haryana State and publication of feature data sets for WFS/GML access from NSDI portal has been completed and demonstrated. SOI has been in the process of providing WFS/GML for all its 1:50,000 OSM data. Collaborative harmonization of administrative boundaries for the development of the National Foundation Spatial Data (NFSD) up to the revenue village level has been initiated with the involvement of the concerned State SDI set-up in one of the states as a demonstration for adoption of the procedure in other states.

Establishment of a formal linkage with Bureau of Indian Standards (BIS) has led to the development and publication of national standards. ISO standards critical to the

development of SDIs at the national and state levels like conceptual schema language (ISO 19103), rules for application schema (ISO 19109), Web Map Service (WMS—ISO 19128), Web Feature Service (WFS—ISO 19142), Geography Markup Language (GML—ISO 19136) are being co-branded as national standards by the BIS. Data content standards on surface geological mapping, forests and soils have been prepared for publication of national standards through stakeholder consultation.

In addition to the national agencies above, state government agencies in Karnataka, West Bengal, Uttarakhand, Odisha, Jharkhand and Haryana holding spatial data sets have collaborated with NSDI as partners for improving their data management procedures. Under the collaborative State Spatial Data Infrastructure (SSDI) initiative with the concerned state governments, state geoportals have been operationalized for provision of Web-based data services. To ensure regular flow of data sets in the state governments from the lower area (villages, block and district) levels to the state level for updating the state geoportals, a coordination mechanism with a GIS set-up has been established at each district.

More effective management and use of the data/images requires their registration, storage and sharing so that those could be put to appropriate processes of governance in line with the provisions of NSDI Resolution, 2006. Registering spatial data sets involves capturing definition/description of each data item, making each item persistently and uniquely identifiable by assigning them unique identifiers, organizing/maintaining the associated classification systems or the code lists for reference by all and a suitable governance system along with procedures for managing the related registers. Moreover, provision of geospatial resources like data, metadata and catalogue is governed by various standards that evolve or change over time. For consistent processing and interpretation of the data and services, it is essential that these changes are kept track of and properly managed. Establishment of registers in the form of a registry with a suitable management structure is thus essential. ISO 19135 prescribes standard specifications on procedures for registration of geographical information items and establishing a management structure.

In line with the end-user requirement stated above and the developments in geospatial technology-related data and process standards, a proof of concept (PoC) of an NDR for NSDI was implemented and demonstrated using data services from Survey of India, National Remote Sensing Centre and the Ministry of Railways 'IRCTC train running data over a week from the Northern Railway. The PoC success- fully demonstrated the utility of a sample registry, technical architecture and led to the development of an RFP for a real-life NDR implementation for engaging a system integrator. Potential system integrators have provided possible sample solutions around different open source and COTS-based products for the selection of a suitable partner for NSDI for the NDR development.

NSDI uses service-oriented architecture (SoA) in the management of the data and related services both at the national and state levels. A typical SoA (publish-find-bind model) widely used in the provision of geospatial information services is given in Fig. 1.

National- and state-level data nodes use both COTS (e.g. Oracle Spatial) and open source products (e.g. PostGreSQL/PostGIS) for the management of the data sets on the geoportal. Data services are published in the NDR using the registry service accessible at the India geoportal that is accessed by the end-users and application utilities for finding and discovering the data sets. Once identified, the end-user or application utility binds itself with the data provider for getting the data sets or for meeting any requirement of update of the provider's database, if necessary, as per the service-level agreements.

Geospatial Cloud

Efforts are currently being made by these nodal agencies to make interoperable Web Feature Services (WFS) accessible for download of feature data in standard encoding specifications (e.g. OGC's Geography Markup Language) for processing on a GIS platform. More national- and state-level geoportals are likely to be deployed in the near future for provision of feature and attribute data services over the Web. With Web-based data services gradually getting accessible from various agencies, emphasis in NSDI is shifting from enabling 'data 'services to 'product 'or 'application 'services to support provision of GIS products or applications over the Web. In the context of the above service-oriented framework and the GIS application requirement of the end-users and decision-makers, three of the cloud service modes of usage, i.e. Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS), are proposed to be used in the development and implementation of geospatial products and applications. Some of the service models of geospatial cloud as a part of the SaaS proposed to be used include GIS as a Service (GaaS), Application as a Service (AaaS) and ready-to-use Data sets/Imagery as Service (DaaS or Iaas). An experimental geospatial cloud has been developed and demonstrated around the State SDI data sets from West Bengal to the representatives of NSDI and State SDI partnering agencies.

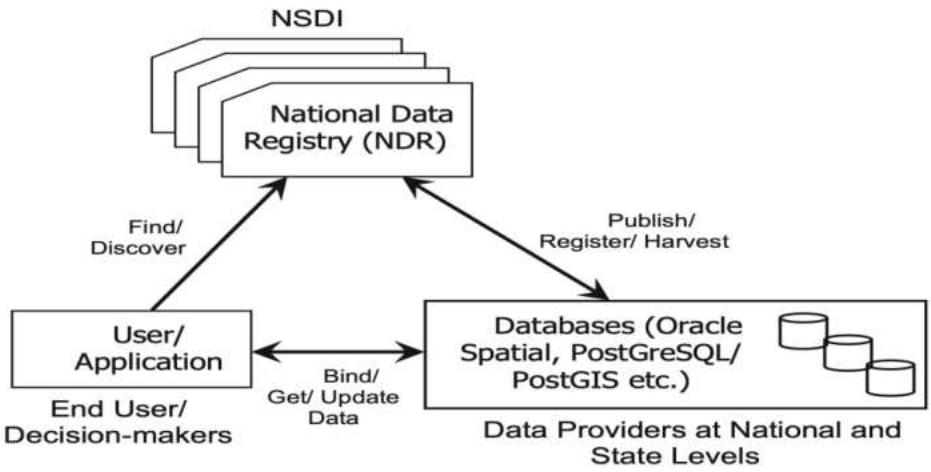


Fig. 1 Service-oriented architecture of NSDI-India—Publish-Find-Bind Model with National Data Registry

A proof of concept around the above cloud service models is thus under development to explore and demonstrate the utility of the cloud services using sample geospatial data sets prepared for the city of Varanasi (Uttar Pradesh) by Survey of India under the National Urban Information (NUIS) project of Ministry of Urban Development, Government of India. In addition to the imageries, photographs and topographic sheets of the area, existing data sets are proposed to be made avail- able/accessible for integration with the GIS-ready digital data is of 1:2000 scale on UTM projection and WGS 84 datum as per SOI NUIS data model. Additional 3D content up to LOD-3 (for selected areas only) with appropriate methods and techniques to meet specified quality and accuracy standards has been proposed to be used in the PoC of the geospatial cloud.

Some of the other proposed characteristics of the PoC include unilateral provisioning of services on the cloud by NSDI/SOI, use of appropriate communication bandwidth; providing for placing resources on a specific geographical zone as per the SOI/NSDI's requirement; near real-time service provisioning and deprovisioning, etc. The PoC is expected to throw light on the performance and sizing of an appropriate geospatial cloud facility for the automated processing and application/product development by the end-user.

R&D Activities

For effective utilization of the above Web-based data and application services by the stakeholders, efforts are being made to develop application prototypes and demonstrate applications with the involvement of user ministries/departments/state agencies and private enterprises. Assignment of unique IDs to plots/cadastres with inputs from the Department of Land Resources (DoLR), train running information and GIS enablement of

the Railways with the Ministry of Railways; developing 3D SDI for urban governance; setting up of a GIS Cell in National Disaster Management Authority (NDMA) for consuming WMS/WFS/GML for disaster mitigation; development of GIS applications in watershed development for Watershed Directorate of the Government of Karnataka have been some of the initiatives taken in this direction. The NSDI 2.0 Mission is proposed to be launched for the development of GIS applications for decision support at different levels of governance. Some of the important priority areas for the future include establishment of Geospatial Research Hubs and conducting R&D in areas like urban governance; village information systems, health GIS; watershed management; disaster management; coastal hazards and urban flood modelling; land resource management; agriculture; geodesy; sustainable development goals; assessment of regional hydrological systems using space-borne gravity observations; heat flux of urban cities; landslide forewarning systems with specific reference to the north-eastern region; interoperability and 3D SDI; large- scale mapping at the level of gram panchayats or wards. A gram panchayat or a ward is invariably a functional area or an electoral unit at the local level comprising of a few revenue villages or households for developmental administration as a part of government's effort towards decentralizing governance in the rural or urban areas for real-life geospatial application development.

Research & Development in Geo-Information and Communication Technologies (Geo-ICT) domains like ontologies and reasoning, high-performance computing and cyberGIS; geodesy; geospatial interoperability and analytics; cartographic generalization; 3D SDIs; and volunteered geographic information will be pursued with the involvement of a network of academic and research institutions.

Over the past years, training modules have been developed for large-scale building of technical capacity amongst staff and personnel of central and state government agencies and scientists/faculties from research and academic institutions. Development of additional training modules/kits in emerging areas of various relevant domains including Geo-ICT as mentioned above has been an important priority for NSDI.

Management Structure

At the national level, NSDI is managed through a two-tier coordinating arrangement as per the provisions of the NSDI Resolution, 2006, approved by the Union Cabinet as indicated earlier.

The apex body, called the National Spatial Data Committee (NSDC), is chaired by Minister of Science and Technology with the concerned secretaries to Government of India as the members. NSDC provides the overall policy direction to the activities of NSDI and advises, guides, authorizes and approves its overall implementation, reviews performance and authorizes/approves any mid-course corrections—including resource prioritization/reallocation. Surveyor General of India and the Director, National Remote Sensing Centre, act as member secretaries of the NSDC. A few professional experts in the domain of geospatial technologies also serve as members.

At the lower tier, the NSDI Executive Committee (EC) is co-chaired by the Surveyor General of India and the Director, National Remote Sensing Centre, with the heads of different data providing agencies of the central government as its members. EC is entrusted with the task of guiding NSDI in implementing the policies/decisions of the NSDC and NSDI's day-to-day operations. Working Groups/Technical Committees have been constituted in different thematic domains like 'Geospatial Metadata', 'Data Content Standards', 'Ínteroperability', 'National Data Registry', 'Geospatial Cloud'; 'Administrative Boundary Harmonization 'have been constituted with the participation of representatives from the partnering agencies from the national and state levels and leading experts from the IITs, universities and R&D institutions.

Invariably, two-tier coordination structures have also been in place for the State SDIs with the Steering Committee chaired by the chief secretaries with secretaries/principal secretaries of the concerned departments as members at the upper tier for policy-level guidance for the State SDI set-up. At the lower tier, the Executive Committee (EC) is chaired by the secretary/principal secretary, planning and coordination or science and technology with the directors of various state-level geospatial data handling agencies as its members for implementing the decisions of the Steering Committee.

Above coordinating structures are technically advised at the national level by a Steering Committee and several Technical Committees with members drawn from various leading R&D institutions, IITs, universities and laboratories. A Standing Finance Committee (SFC) under the chairmanship of Secretary, DST, with members from NSDI partnering agencies reviews allocation of funds to different activities.

Conclusions

Three major accomplishments of NSDI, so far, have been (i) the establishment of the NSDI mechanism with the enrolment of the stakeholders from national and state levels (ii) the institutionalization of geospatial data and process standards-making and adoption with the involvement of the Bureau of Indian Standards (BIS); and (iii) setting up the technical infrastructure. The technical infrastructure covers hard- ware, software; connectivity; data; metadata; manpower of NSDI and State SDI data nodes for provision of standards-based data and metadata services and applications [8]. Some of the other accomplishments of NSDI include formulation and adoption of a shared vision and goals by various partnering agencies for achieving the NSDI aspirations; framing and implementing relevant policies for a governance framework for data management; and training and capacity building of scientists, officials, staff and personnel of the partnering agencies. NSDI is now poised towards soon evolving into a national geospatial information infrastructure with its focus gradually shifting to building working linkages with the stakeholder; strengthening the development and sharing of standardized applications and solutions; framing supportive policies and acts for its more effective utilization. Setting up research hubs for pursuing R&D in the emerging areas of Geospatial Information Science and Technology for its continuous reorientation and upgradation; and nurturing international collaborative partnerships with Open Geospatial

Consortium (OGC), International Standardization Organization (ISO), and United Nations Global Geospatial Information Management (UNGGIM)'s committee of experts have been set as priorities for NSDI in the coming years. All these are expected to help NSDI achieve its vision of sustaining the economic growth in the short term that in turn will usher in the era of sustainable future.

National Data Registry (NDR) for the National Spatial Data Infrastructure (NSDI)

Introduction

Over the past years, efforts have been made by NSDI to compile and serve metadata of different partnering agencies and re-engineering the feature data sets for improving their use. The NSDI agencies have large amounts of feature data sets and are presently managed in file-based systems largely through quadrangle sheets without any sound strategies for their search and querying. This is evidenced in the present ways to store and manage metadata sets at the NSDI server as per the indices of the quadrangle sheets. Identification and maintenance of such feature data sets pose a major challenge to use of the data. More effective use of the data requires proper registration of the feature data sets so that the data could be put to appropriate processes of governance in line with the provisions of the NSDI Resolution, 2006. Registering spatial data sets involves capturing their definitions and descriptions, making them persistently and uniquely identifiable by assigning them identifiers and organizing/maintaining the associated code lists.

Data registries are in the process of development in different countries to facilitate governance of data sets. Infrastructure for Spatial Information in Europe (INSPIRE) has set up a registry to manage spatial data across various member states of the European Union. The member states have set up national registries to support implementation of the INSPIRE initiative. Open Geospatial Consortium (OGC) has developed specifications for registry services for enabling data providers to register their data sets and services at a common central place. The electronic business Registry Information Model (eb-RIM) specifications have been adopted in developing the OGC specifications for the registry services. ISO 19135 provides specifications for registering data items in a register and related governance processes.

Background

Taking into account the problems in the management of spatial data sets in different NSDI partnering organizations and the absence of a central register for keeping track of the data sets, it has been decided by NSDI, DST to evaluate the concept of NDR and its utility in possible application development to address specific end- user needs. The job consists of working out the specific roles that NDR seeks to play, its scope and structure; develop a few sample but related domain models and the application schemas for implementation of Web-based applications; evaluate the service orientation aspects of the prototype implementation; study some portals playing the role of registry; and recommend steps for actions at the data source level, at the registry (or NSDI) level, and for an early realization of the NDR.

This article has been divided into sections on role of NDR, its scope and structure, an approach for its realization covering the technical specifications, results of the prototype implementation, and the recommendations.

National Data Registry for NSDI

NSDI has been working with national- and state-level data providers to facilitate sharing of spatial data among the stakeholders. This is to be achieved by (i) compiling and providing metadata sets to facilitate discovery and access of spatial data; (ii) setting up of the spatial data nodes for the provision of interoperable spatial data services (e.g. WMS, WFS); and (iii) establishing a single-window access mechanism to the metadata and spatial data sets through installation of a clearing house and geoportals. Metadata sets in BIS standard format have been compiled from various Survey Agencies and State level Line Departments and made accessible from the geoportals (e.g. India Geo Portal at the National and State Geoportals at State Levels).

Problems with the Present Set-up

In the present set-up, metadata sets can be accessed by making queries/searches on the meta-database stored in NSDI or State SDI Data Nodes that are accessed through applications. The following are some of the limitations:

(i) Inadequate access to and maintenance of resources describing the data in order to allow for its correct processing and interpretation by applications for real-life decision support.

(ii) Non-availability of a mechanism to keep track of and manage changes in various rules and standards those govern the above resources for consistent processing and interpretation.

(iii) Even if feature metadata is to be provided by individual data nodes from the data providers, application schemas and code lists (domain value sets or enumerations with thesauri) should be made accessible from the geoportal for search and use. Presently, application schemas or code lists are not accessible.

(iv) Detailed specifications of coordinate reference systems used in data sets, units of measurement, identifier namespaces.

(v) Metadata sets are retrieved for each data unit of the provider (e.g. topographical or geological quadrangle sheets) instead of feature data-wise.

(vi) Inadequate updation of metadata corresponding to changes/updates in spatial data.

(vii) Spatial data sets are not appropriately organized on databases systems (but on file systems) causing major difficulties in accessing/searching data for decision support.

(viii) Although, there are services accessible from the geoportals, there is no meta- data about the services to facilitate their search and discovery.

(ix) Catalogue service as per OGC standard is not accessible.

(x) Machine access to metadata requires XML implementation, but presently no metadata from the portal is in the machine-accessible form.

While these problems are continuously encountered by end-users, concepts, technologies and standards have further evolved and are gradually getting available to address some of

the issues. Concepts like geospatial information infrastructure, service-oriented architecture, registry, technologies like geospatial cloud, geospatial platform, interoperability, geosemantics, and standards like catalogue service on web, procedure for registration of geographical information items (ISO 19135), geography markup language (ISO 19136) are thus required to be explored in this context, and prototypes demonstrated for possible adoption and improvement of the performance of Geospatial Decision Support Systems (Geo-DSS). The concept of "registry" in particular requires to be evaluated to overcome some of the above problems by studying a few existing portals acting as registries, available standards and tools, review of related literature, defining a role for the NDR, its scope and structure, and recommending a suitable approach for its development and realization for real-life applications.

The Concept of NDR

With several agencies geographically distributed and providing sharable geospatial data, there is a need for end-users—humans or machines—to search, discover, under- stand and access them over a distributed network for use in applications. Towards this, the data-providing agency must draw up and share a set of metadata consisting of the data type, meaning of the features and their associated attributes; underlying schema or structure; classification codes, used if any, in the attributes; location of the data or its bounding box; the coordinate reference system; time, accuracy or resolution of acquisition/survey; standards used in the data format; usage terms and conditions, etc. All these are required to be made accessible from a common catalogue, called a registry, in order to enable the end-user assess the fitness of the data sets in meeting his purpose or application requirements. On satisfactory assessment, the end-user gets access to the data sets from the provider with the help of Application Program Interfaces (APIs) to facilitate automated usage of the data in his/her software pack- ages/products. Such a common and appropriately managed registry at the national level—called a National Data Registry (NDR)—is vital to successful GIS application development by the end users by utilizing geospatial data from multiple sources of data. In effect, NDR links the data providers with the end-users in a service-oriented architecture by providing access to end-users to a common up-to-date system of catalogue.

Interoperability specifications or standards in the context of the above provider–user link assume significance considering the heterogeneity of data sets made accessible from multiple sources in terms of their meaning or semantics, their thematic content and the underlying data formats/structures. Such standards are avail- able from ISO, OGC, BIS or other standard bodies for use in the development of the NDR that are open, precise, unambiguous; comprehensive; extensible; widely acceptable; and consumable by both humans and machines.

NSDI's present metadata contains information regarding spatial data from various data-providing agencies as per Bureau of Indian Standards (BIS) 'IS 16439:2016 Metadata Standards for Geospatial Information. IS 16439 standards are founded on the ISO 19115 specifications and have evolved out of NSDI Metadata Standards 2.0. These

specifications provide for citation, quality, features, lineage, temporality, reference systems, extent, etc., and are expected to be served to users or their applications as catalogue services that offer the functionalities to store and serve metadata about the data sets. However, the current catalogue specifications do not define formal procedures for the modification of the stored information. The user does not have the ways and means to ascertain, for example, by whom and when some data sets or services have been modified, added or removed from the database or catalogue.

Since data, metadata and standards undergo changes due to data life cycle management in data-providing agencies and development/adoption of new standards or evolution of existing ones, there is a need to keep track of the changes. Keeping track of the changes facilitates end-user's sustained access to data and metadata and support correct interpretation of their analyses. NDR provides the framework for tracking such changes. Defining the roles for the NDR and its stakeholders or associated actors in this context assumes importance.

Moreover, provision of these resources like data, metadata and catalogue is governed by various standards that evolve or change over time. For consistent processing and interpretation of the data and services, it is essential that these changes are kept track of and properly managed with the support of an appropriate management structure. Establishment of registers and registries with a management structure is thus essential. These are required over and above the establishment and maintenance of data and service catalogues providing standardized catalogue services capable of getting consumed by end-users or applications.

ISO 19135 prescribes standard specifications on procedures for registration of geographical information items and establishing a management structure. As per the standard document, a "register" is defined as a set of files containing identifiers assigned to items with descriptions of the associated items. An identifier is a linguistically independent sequence of characters capable of uniquely and permanently identifying that with which it is associated. A "registry" is defined as an information system on which a register is maintained.

It is therefore essential to maintain registers of different geographical data items and keep track of the data item status for the benefit of the end-user. The registers should be managed through proper governance procedures. ISO 19135 prescribes a common structure for the registers like identifier, name, definition, item class and status. Some of the attributes like description, date of acceptance are treated as optional items.

Roles of the NDR and Its Stakeholders

The data item identifier is a positive integer that uniquely identifies the item in the containing register. The item class identifies a class of geographic information items specified in a technical standard. In the implementation described hereafter it also defines any additional attribute required for describing the items of that class. The item status

clearly identifies whether the item is valid at the time it is queried: “valid” means that it can be used in the production of new data sets.

The content of a register can change over time since there might be the need to introduce new items, retire existing items, replace (supersede) existing items with other items, clarify an existing item to correct the phrasing without changing its semantics, etc.

Item status of an item is an indication at any moment in its life the status of the item like not valid, valid, superseded or retired. An item starts in the “Not Valid” status at the time of a data-providing organisation creating a proposal for a new item.

The standards defined in the ISO 19135 could be used to assign various roles to the NSDI that proposes to remain the nodal organization for managing the NDR, while the data-providing organizations could be defining and maintaining their metadata

details, application schema, services, coordinate reference systems, code lists, etc., in their respective databases for access. At the minimum, they are expected to provide the WFS, WMS and the CSW. NDR should also consider allowing the private agencies to put up their data and metadata services in the registers.

ISO 19135 specifies the following roles involved in the management and use of a registry and the registers it contains. The definitions are mainly taken from ISO 19135.

Registry Manager
The registry manager is the entity that maintains the registry service operational.

Register Owner
The register owner is an organization that establishes a register and is responsible for the content of the register in terms of intellectual property and management. The register owner can delegate the management of the register to a register manager.

Register Manager
The register manager is responsible for maintaining the register. The register owner, if unable to play this role, can appoint a different organization.

Submitting Organization
An organization authorized by the register owner to propose changes to the content of a register.

Control Body
The control body of a register is a group of technical experts who make decisions regarding the content of the register.

Register User
A register user accesses a registry in order to use one or more of the registers held in that register.

Scope and Structure

NSDI uses service-oriented architecture (SoA) in the management of the data assets and related services. A typical SoA (publish–find–bind model) widely used in the provision of geospatial information services is given in Fig. 2.

Based on the above service-oriented model, a detailed architecture is proposed for the implementation of registry and other associated components:

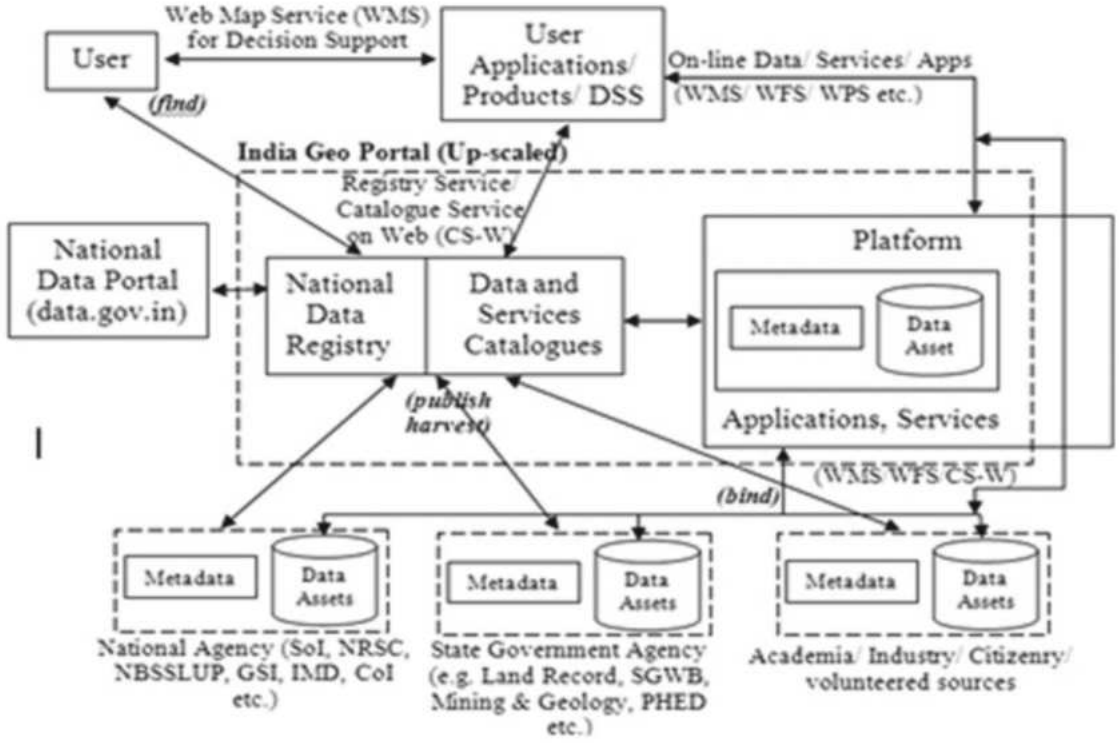


Fig.2 Overview of NSDI technical architecture shown with National Data Registry and data/service catalogues

It is important to note that this architecture primarily separates any content in one of two categories—spatial objects representing phenomena in the real-world (the "data") and the other items of spatial information, i.e. data description, referenced by or related to the spatial objects, i.e. "metadata", but in a wider sense than geographic information metadata as understood in ISO 19115.

Data Assets

Data Assets form the core component of the NSDI. These are GIS-processable data sets and could be accessed by Web Feature Services (WFS) by applications and services in the NSDI platform. The Data Assets belong to different national, state agencies or stakeholder groups in the academia, industry or non-governmental sec- tors. The Data Assets are maintained by the concerned agencies and made accessible as services.

Metadata

Agencies publishing their Data Assets 'information in the data catalogue of the India Geo

Portal must make their metadata accessible from their website or portal or the local registers. Setting up the local registers may be considered as an additional job to be completed by the agencies participating in the NDR initiative. Over the past years, various agencies have been establishing their NSDI node with a view to compiling and making accessible their metadata by compiling and uploading those to the India Geo Portal. Considering this additional component to the metadata, it is essential that metadata in respect of each of the Data Assets are maintained by the agencies themselves at their local registers of the data nodes for harvesting and automated updation at the NDR node.

Services

Web Map Services (WMS) provide access to ready-made Data Assets and products for use in applications. Web Feature Service (WFS) helps access to Data Assets for download in different formats including geography markup language (GML). The agencies may consider providing data or service catalogues to the end-users and applications to facilitate discovery and access.

India Geo Portal

Presently, India Geo Portal provides product metadata available for each quadrangle sheet for visualization. In addition, it provides WMS for a select group of survey agencies like SoI, NRSC and FSI or state government (e.g. Government of Karnataka) who have made their data sets accessible from their data nodes. WMS could be viewed concurrently from multiple sources at the India Geo Portal. The India Geo Portal is proposed to be upgraded with additional features like National Data Registry comprising of data/service catalogue and the Geospatial platform for provision of application services (i.e. processed products) for decision support.

National Data Registry is expected to consist of a set of register with items like data specifications indicating the semantics and the characteristics of the types of spatial objects in a data set. The spatial object types provide a classification of the spatial objects and determine among other information the properties that any spatial object may have (be they thematic, spatial, temporal, a coverage function, etc.) as well as known constraints (e.g. the coordinate reference systems that may be used in spatial data sets). This information is, in principle, captured in an application schema using a conceptual schema language standard, which is a part of the data specification. As a result, a data specification provides the necessary information to enable and facilitate the interpretation of spatial data by an application. However, presently, existing spatial data sets are not adequately documented. Thus, in the current proposal, it is proposed that the survey agencies participating in the NDR prototype experiment make concerted effort to document their data assets for building the registers.

With the present emphasis on the transition of NSDI from the development (enabling) phase to the implementation (performing) phase, the ability to consistently reference these resources in the registry through unique identifiers is a vital requirement. There is thus a need to collaborate in a long term on defining common specifications for metadata, data, network services as well as data and service sharing, monitoring and reporting. These are

useful in consistently establishing interoperability at the organizational, semantic and technical levels in the NSDI infrastructure. Technical guidelines, data models and code lists are required to be hosted in document and UML repositories, and should be accessible through and maintained. In the long term, a separate dedicated agency may be assigned the task of maintaining these resources on behalf of NSDI.

Approach

There are several key characteristics associated with a register. Every item in the register is associated with a unique, unambiguous and permanent identifier. A register keeps track of changes so that data created in the past can still be interpreted completely and correctly. Superseded or retired register items are also maintained in the registry for future reference.

Worldwide, experiences suggest that the number of registers that eventually are required in an infrastructure is significant. A clear and sustainable operational model forms a key part of the set-up of the infrastructure. However, initially the following kinds of spatial information items could form registers that could be implemented:

- Feature concept dictionary,
- Feature catalogue,
- Application schema,
- Code list,
- Coordinate reference systems and operations,
- Units of measurements,
- Spatial object identifier namespaces,
- Glossary, etc.

The feature concept dictionary establishes a set of feature-related concepts that may be used to describe geographic information. A common feature concept dictionary is proposed to be maintained for all NSDI application schemas and feature catalogues. Conflicts in definitions and meanings of geographical features (e.g. water bodies versus lakes versus ponds) could be overcome by this register. Naming of features at the national and state levels differs significantly and needs to be addressed by setting up a common dictionary accessible to all.

A feature catalogue assumes significance at the time of data acquisition, process- ing and use. A catalogue containing definitions and descriptions of the spatial object types, their attributes and associated components occurring in one or more data sets, together with any operations that may be applied is essential for access by end-users for correct data processing and interpretation.

As per the ISO documentation, an application schema is a conceptual schema for data required by one or more applications. It is a part of data specification and specified in

UML. Each data-providing agency at the national and state levels should publish their application schemas in UML/XSD formats for access by human and software users.

A code list is a dictionary describing the attribute value domains for selected property types in a feature catalogue/application schema. The value domain is not fixed in the feature catalogue/application schema, but is managed separately.

Coordinate reference systems and operations are managed in a dictionary of coordinate reference systems, datums, coordinate systems and coordinate operations which are used in data sets.

A dictionary of units of measurement, which are used in data sets, should be maintained as a register. For example, coordinates are presented as geographical latitude/longitude values or in metres.

Spatial object identifier namespaces bear significance considering the fact that similar spatial objects are maintained by different agencies or content providers for varying purposes. A mechanism is required to guarantee uniqueness of object identifiers across various content providers. Identifier namespaces are thus required to be managed.

A register of general terms and definitions used in NSDI data specifications should be prepared and maintained for access by all.

Prototype Implementation

A prototype of the complete system depicted in the above architecture has been implemented for a comprehensive demo of the utility of the registry. The sub- systems of the architecture proposed to be implemented (Fig. 2) include

(i) Database consisting of data assets and the metadata at individual nodes of data providers;

(ii) The registry;

(iii) The platform for developing GI applications/products and services;

(iv) The Geo Portal as a single-window access to data/services/applications;

(v) Decision Support Systems based on end-user workflows capable of consuming various data sets/services/applications to support decision-making by end- users.

(i) Database

The database of a data provider consists of feature data (Data Assets) along with its metadata. The data and metadata from the data provider's node should be accessible or shareable as WMS, WFS/GML, CS-W. Both feature metadata and service metadata should be stored as per ISO 19115 and ISO 19119 specifications. Data updation is an important component and may be implemented either through database protocols in a local area network from a GIS or using WFS-T from a remote surveyor in the field. Each node should implement a relational database of sample feature data sets on open source or commercial tools for demonstration of services like WMS, WFS/GML, WCS and CS-W.

(ii) The Registry

The registry should contain the description of the data in the form of feature concept dictionary, object catalogue, application schema and a set of procedures for registration of various items maintained in the registry. ISO 19135 standard specifications should be followed in the implementation of the registry.

(iii) The Geospatial Platform

The Geospatial Platform prototype should be developed and implemented to test the utility of the services from various data nodes, processing of the data sets and provision of application/products services to the end-users for decision support. The platform should be accessible as a portal for use by end-users for processing of the data sets for delivery of products/applications or access to readymade applications from the web or mobile devices.

(iv) The India Geo Portal

The India Geo Portal should be upscaled to provide a single-window access to the data and product services from multiple data providers along with the Catalogue Service on Web (CS-W). A comprehensive catalogue of all the data sets, services, applications and products should be made accessible from the India Geo Portal.

(v) Decision Support Systems

Decision Support Systems based on end-user workflows capable of consuming var- ious data sets/services/applications from either India Geo Portal or Geospatial Platform Portal should be established to support decision-making by end-users.

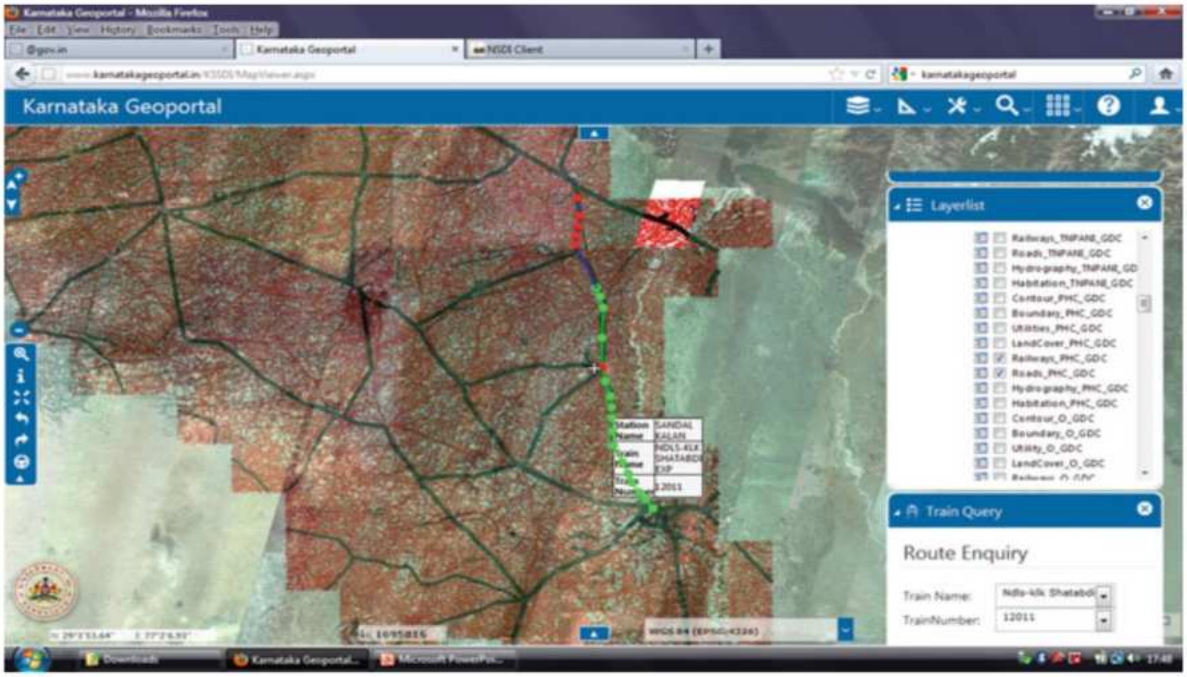


Fig. 3 Sample screenshot showing the train route and location on the SOI topographic sheet and NRSC's Bhuvan imagery coming from different sources

Implementation Result

In the context of the above framework, different components of the sub-systems have been developed. Experiences of a prototype implementation of the catalogue service along with features like metadata insertion/deletion/modification/harvest available at selected NSDI nodes have been made use of in the implementation of a use case relating to the Railways.

The use case involves locating a moving train between various stations of the Northern Railway on a topographic sheet of Survey of India or/and with Bhuvan imagery of National Remote Sensing Centre (NRSC) of Indian Space Research Organisation (ISRO) along with departure and arrival information at each station. Relevant data sets on departure and arrival of trains have been taken from the Northern Railway and the Indian Railway Catering and Tourism Corporation (IRCTC) of the Indian Railway. Existing data services from NSDI, Surveykshan and Bhuvan Portals have been made use of by a user on the platform of Karnataka Geo Portal. The GeoNetwork tool has been used in the implementation of the sample data registry along with metadata management and catalogue service for demonstration. IIT Bombay implemented the proof-of-concept registers on the GeoNetwork for demonstration. Application schema for SoI is available in UML/GML implementation and developed using Enterprise Architect tool for developing the schema register. Feature concept dictionaries (samples) on topography, surface geological mapping, soils, forests have been developed along with the feature catalogues and code lists for demonstration of registers. A sample screenshot of the prototype implementation of the application has been shown in Fig. 3. As per the use case of train running information and route enquiry, the application shows the actual location of the selected train on the combined WMS display of topographic sheet of Survey of India and the satellite imagery of the National Remote Sensing Centre.

Implementation of the NDR prototype containing sample registers from SOI, GSI, FSI, the Indian Railways and demonstration of its utility in automated processing of spatial data for a selected use case have thus been successful. NDR has the potential to help overcome the issues relating to sound governance and utilisation of the spatial data sets by NSDI in India.

Recommendations

NDR is a useful concept and has the potential to overcome the problems of search and access and automated processing of spatial data sets from the NSDI agencies. NDR platform should be operationalised by initially linking it up with a few (say 2–3) agencies to share their metadata and services and then gradually covering more agency nodes in an incremental manner in order that the implementation could be iteratively improved through the process of verification and validation. Considering that the ingredients of NDR and their utilities have been understood through demonstration of a proof-of-concept in the Indian context, professional agencies should be involved to operationally develop and implement the NDR. Harvesting should be a part of the NDR utility for

automatic and periodic updation of metadata. In particular, focus of the implementation should be on development of domain-specific application schemas using ISO/OGC/BIS standards, existing data sets re-engineered and new data sets appropriately engineered using the standards-based feature model for ensuring interoperability; setting up spatial databases and application systems to provide WFS and WMS services; identifying use cases for provision of web processing services based on WPS and RESTful Service standards; setting up necessary system platform, hardware and software for operationalising registers and required processing services; demonstrating search on the NSDI partnering agency sources; and preparing a few case studies for demonstrating discovery and use of data and services from the NDR data nodes for training on integrating the web-based services with the end user's business workflows.

Development of State Spatial Data Infrastructure (SSDI): Indian Experience

Introduction

In its journey of planned development, the current emphasis in India is on local-level planning. The concept of spatial planning has been brought in to strengthen it. The constitutional support has come in the form of 73rd and 74th amendments, while Geo-graphical Information and Communication Technology (Geo-ICT) has been adopted as the main tool for achieving it. The Government of India initiated a number of Geo-ICT-based programmes to support the local-level planning in 1980s, viz. Natural Resources Data Management System (NRDMS) of the Department of Science and Technology, National Natural Resources Management System (NNRMS) of the Department of Space (DOS) and Geographical Information System (GISNIC) and District Information System (DISNIC) of the National Informatics Centre (Ministry of Communication and Information Technology). These programmes had demonstrated the utility of spatial data in generating information required for efficient decision-making, as a result since early 90s there has been considerable awareness among local administrators about Geo-ICTs. In order to facilitate and coordinate the availability and access of spatial data between stakeholders at all levels of government, National Spatial Data Infrastructure was established in 2006.

However, non-availability of and inaccessibility to spatial data of the desired resolution and currency, incompatible data sets and inadequate capacity among the officials of the local government departments (LGDs) remained the major bottle- necks to the utilization of National Spatial Data Infrastructure (NSDI) for local-level planning. In order to obviate the same and create synergy between spatial infrastructure at national level and state level, decision was taken during the Chief Secretaries 'Conference held on 4–5 February 2011 for the establishment of State Spatial Data Infrastructure (SSDI) by the Department of Science and Technology, Government of India. In October 2011, National Spatial Data Committee (NSDC), chaired by the Honourable Minister of Science & Technology—apex body for the formulation of Spatial Data Policy had approved the creation of SSDI.

Globally, the experience of development and operationalization of SSDI is very limited, especially in the developing world. In the developed world, there are some experiences in Australia, USA, Europe and Canada. In Australia, state governments play a significant role in policy development and the building and managing of spatial data infrastructures. Each of the Australian states and territories has established a coordination agency or group to reflect each of their mandates and state goals with respect to spatial data infrastructures. The state government agencies are active in pursuing SDI development with most activity generally focussed on delivering product outcomes. Each state has an overarching policy to facilitate SDI development which usually includes encouraging the active participation of the private sector in their SDI vision. In the USA, individual state coordination bodies have generally shouldered the majority of the SDI coordination responsibilities, e.g. Maryland, Illinois, California. In addition, the Federal Geographic Data Committee (FGDC) has encouraged the development of SDIs at sub-national levels through partnerships and collaboration. Müller and Würriehausen has reported a case study of local SDI implementation in the South Western German State of Rheinland-Pfalz it in the context of the evolution at higher SDI levels represented by the INSPIRE initiative at the European level and by the GDI-DE initiative at the German national level.

The Canadian Geospatial Data Infrastructure (CGDI) is developed by the Natural Resources Canada to provide open, secure and continually available access to comprehensive location-based information about Canada through the community-sustained CGDI in support of prosperity and well-being for all Canadians. In British Columbia, the provincial Spatial Data Infrastructure (SDI) is utilized by legislated and mandated lines of business such as resource development, water management, land tenure, transportation, public safety and emergency response.

The main objectives of SSDI in India are:

- To develop and operationalize a standard framework in states for the purpose of sharing and exchange of spatial data sets from various state-level line departments/agencies
- To utilize the spatial data sets from the above framework in GIS operations required for decision support by various stakeholder communities
- To create awareness and build the capacity of various stakeholders for carrying out various activities of SDIs.

Development of SSDI:

In order to realize the potential of spatial data to be made available for planning processes at various levels, the Department of Science and Technology (DST) through its NSDI (National Spatial Data Infrastructure) initiatives has supported the establishment of State|Spatial Data Infrastructure in some states on competitive selection basis. However, this would require a synergizing effort between various entities/stakeholders involved towards creating a network of state data nodes for operationalization of State SDIs.

Key Components of SSDI

The key components required for successful operation of a SSDI are:

- People: Implementing agency, data and ICT infrastructure providers, policy- makers and users.
- Processes: Data acquisition, data management, data availability and sharing.
- Technology: Hardware, software, geoportal services, and applications.
- Policy.

Resource Requirement

IT Infrastructure and Processes

The system architecture shown in Fig. 4 represents the hardware and software required in the development of a geoportal for SSDI. The geoportal has to be designed using Web-enabled GIS Software Supporting RDBMS (open source/proprietary) for delivering dynamic maps and related data and services via the Web. It should operate in a distributed environment that consists of both client-side and server-side components. Typically, the client will request information from an Internet server holding the data repository. Then, the server will process the request and send the information back to the client viewer. The server components, i.e., the Web server/application server and the data server, will form a part of the server architecture. Only authorized clients will have access to the server application and database. For a better performance, this architecture should also include two backup servers.

Open source/commercial off-the-shelf SDI software package interoperable to various OS platforms will be required to provide various Web services, viz. Catalogue Service on Web (CSW), Web Map Service (WMS), Web Feature Service (WFS/GML), Web Registry Service (WRS) and Web Coverage Service (WCS).

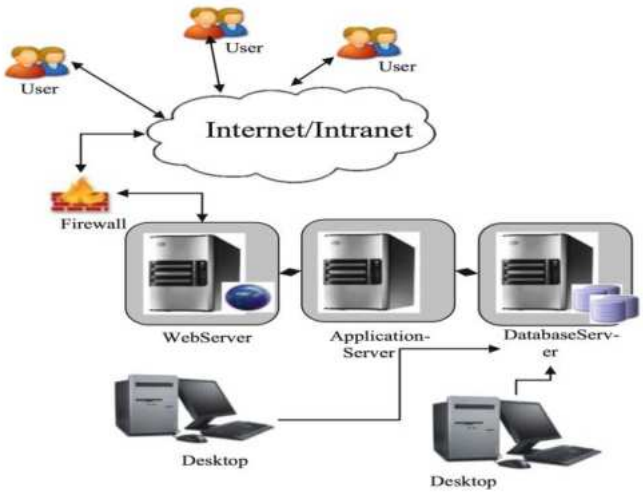


Fig. 4 Systematic representation of a common state's spatial database infrastructure (system architecture)

Skill Required:

The indicative technical skill sets required for the development of a SSDI are GIS expertise; thematic expertise; IT expertise (website developers and managers, data/system administration software developers and programmers, security related, etc.); information risk management expertise; other expertise on need basis, etc.

Methodology

The following generic steps would be required to ensure the successful implementation of SSDIs (Fig. 5):

• ***Selection of nodal agency:*** The nodal agency for the implementation of SSDI is selected based upon their technical/organizational capacity in geospatial information management (GIM).

• ***Selection of system integrator:*** RFP document should be prepared by the nodal agency for the selection of the vendor for setting up the state geoportal/data clearing house as well as developing state, district and block data nodes.

• ***Identification of stakeholders and need assessment:*** Identifying the users/user groups already associated or to be potentially associated with the use of geospatial data in the context of developmental planning is an essential step. This could be done through a state-level workshop/meeting, etc. Interviews should be conducted with various line departments/agencies of the state government to assess their information needs.

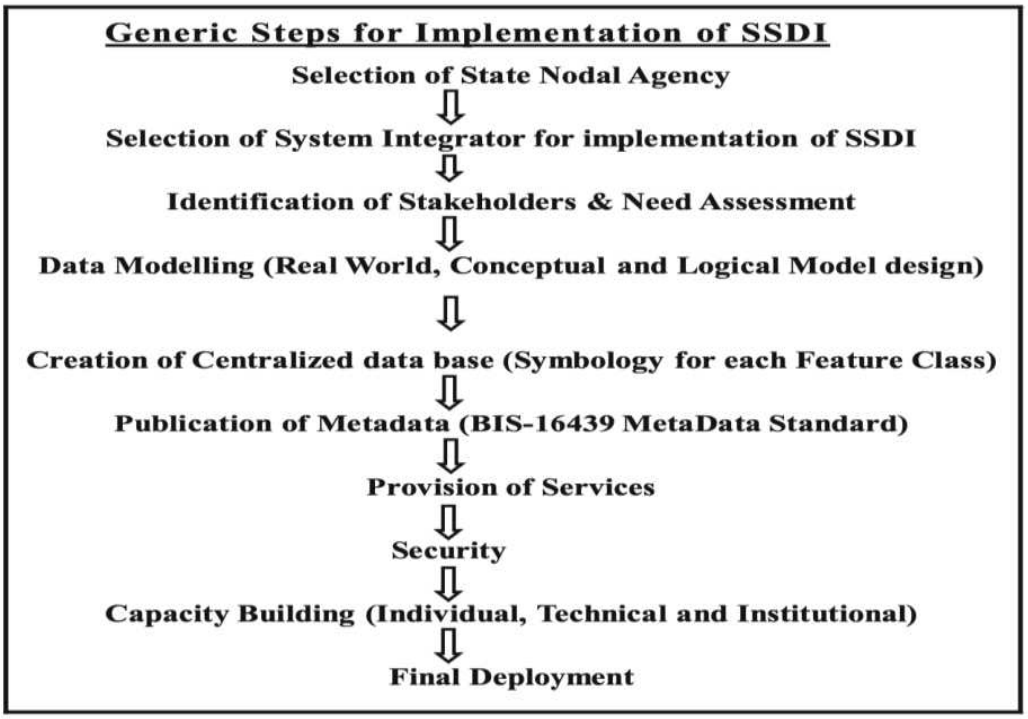


Fig. 5 Common steps for development of state geoportal/data clearing house

• ***Data Modelling***

– *Creation of real-world object catalogue:* Based on the need assessment, a detailed catalogue of underlying real-world objects clearly defining each object should be drawn up. A real-world object catalogue is useful in developing the data models (conceptual/physical) for the implementation.

Conceptual Data Model: A conceptual data model bringing out the objects and the associations is required to be developed and appropriately documented. The conceptual model should address software recommendations, refinement of physical system configuration (servers, network, storage requirements, etc.).

- ***Creation of a centralized database:*** Initially, a Web-enabled centralized database of various existing spatial, attribute or statistical data should be developed at the state node to store spatial, attribute or statistical data sets already available with the nodal agency and line departments. Proper indexing mechanism of data sets should be adopted to facilitate efficient query/access. Mechanism for updating the existing data sets on the database using OGC standards-based Web Feature Service (WFS) should be provided to facilitate upgradation/maintenance of the database from remote clients located in the individual line departments/agencies of the state government, GIS data centres/cells, viz. district NRDMS centres.

- ***Publication of metadata***: In order to support easy discovery and access, various geospatial data providers in the state should publish their metadata sets into the geoportal/centralized database following metadata standards prescribed in BIS 16439.

- ***Provision of services:*** After following the specifications of OGC's geospatial portal reference architecture, a geoportal (a website for SSDI) should be developed, demonstrated and installed to provide portal services/portrayal services/data services, and catalogue services.

- ***Security system to handle data, user identity and network:*** In order to secure the geoportal/clearing house from unauthorized access, an appropriate security software module having provisions to safeguard data sets, manage user identity and transaction security, detect unauthorized intrusion, permit authorization/authentication, and non-repudiation-based access controls on resources is required.

- ***Capacity building of stakeholders:*** In order to build up individual, technical and organizational capacity, training workshops at the state and organizational levels should be organized.

- ***Final deployment:*** Based on the user feedback, the complete system should be integrated and operationalized for use. The complete system and its use should be presented in a series of workshops in different parts of the state having participants from groups like elected representatives, officials from different tiers of the

governmental hierarchy from the state, district, tehsil, and village, other employees of different concerned organizations, and selected citizens.

State/district data layers	State/district data layers
Agroclimatic zones	Drainage
Taluk/district boundary	Basin boundary
District headquarters	Catchment boundary
Division boundary	Subcatchment boundary
Division headquarters	Subdivision boundary
Geology	Subwatershed boundary
Meteorological station	Tanks
Parliamentary constituencies	National highway
Legislative assembly constituencies	State highway
Rail network	Major district road
Reservoir	Other district road
Rail gauge station	Village road
River	Airport

Table 2 List of data layers required to make foundation of a SSDI

Data Layers

The data layers displayed in Table 2 should make the foundation of the SSDI. Additional thematic layers could be added depending on the availability of data on additional themes and future user needs.

Management Structure for Governance of SSDIs

The management arrangements may comprise of a three-tier organization structure consisting of the following committees:

- ***State Spatial Data Committee (apex body):*** A State Spatial Data Committee (apex body) should be constituted under the chairmanship of a senior official of the level of Chief/additional Chief Secretary or Secretary Planning with membership drawn from Secretaries of line departments concerned with spatial data in the state.
- ***SSDI Executive Committee:*** Committees similar to the Executive Committee may be constituted at the district level, headed by the district collectors with heads of various line departments in the districts to coordinate spatial data management.

- ***GIS cell:*** In order to coordinate among different line departments and office of the district collector/magistrate, a district GIS cell should be established at headquar- ters of each district. The cell should update its GIS data on daily, monthly and annual basis. Nodal officers should be identified in the line departments at state and district levels for coordinating with the GIS cell.

Enabling Policies

Geospatial policies governing spatial data sets and processes constitute an important component of Spatial Data Infrastructures (SDIs). Various policies in vogue regarding different aspects of data/information are as follows:

National Map Policy (2005) defines the scope, distribution and liberalized access of digital Survey of India (SOI) topographic maps to user groups without jeopar- dizing national security.

Civil Aviation Requirement (CAR) was issued in 2012 detailing the procedure for the issuance of flight clearances for agencies undertaking aerial photography, geophysical surveys, cloud seeding, etc.

Remote Sensing Data Policy (RSDP, 2001 & 2012) defines the distribution pro- cess of satellite images to users.

National Data Sharing and Accessibility Policy (2012) ensures proactive and open access to the data generated through public funds available with various departments/organizations of Government of India.

There are also the Information Technology (IT) Act (2000); the Right to Information (RTI) Act (2005); and various State-Level Data Sharing & Accessibility Policies getting framed by various states to improve sharing and accessibility.
Despite the availability of the above policy framework, it has not been possible to discover and access geospatial data sets easily. Towards overcoming the above problems, a comprehensive National Geospatial Policy (NGP) is under formulations covering geospatial data, products, services and applications.

Best Practices in the Implementation of SSDI

Various state government agencies in states like Karnataka, West Bengal, Uttarakhand, Odisha, Jharkhand, J&K, Nagaland, Punjab and Haryana holding spatial data sets have collaborated with NSDI as partners for improving their data management procedures by developing GIS data assets (Table 3). Under various State Spatial Data Infrastructure (SSDI) collaborative projects implemented in cost-sharing mode between the DST Government of India and the concerned state governments, the agencies have either operationalized or demonstrated state geoportals/or their prototypes, worked on contract management for engaging system integrators, standardizing spatial data sets for the provision of Web-based data services in the framework of service-oriented architectures (SOA), and set up coordination mechanisms in the state governments. The best practices of various states in technological implementation, development of institutional

mechanism and capacity building along with applications in governance are shared below.

S. No.	States	Funding status	Geoportal status	Data sharing policy	Long-term sustenance mechanism	Institutional mechanism
1.	Karnataka	Rs. 253 lakh (Rs. 192 lakh/Rs. 61 lakhs)	Operational	Draft ready	Yes	Coordination structure
2.	West Bengal	Rs. 1178.98 lakhs (Rs. 477.38 lakhs/Rs. 701.60 lakhs)	Prototype	Draft ready	Yes	Coordination structure
3.	Jammu and Kashmir	Rs. 377.72 lakh (Rs. 264.40 lakh/Rs. 113.32 lakh)	Prototype	Yet to initiate	Initiated	Initiated
4.	Uttarakhand	Rs. 375.63 lakhs (Rs. 251.68 lakhs/Rs. 123.9 lakhs)	Operational	Draft ready for finalization	In the process	Well-established coordination structure
5.	Haryana	Rs. 203 lakhs (Rs. 125 lakh/Rs. 78 lakh)	Operational	Yet to initiate	Initiated	Process initiated
6.	Odisha	Rs. 650.02 lakh (Rs. 383.3 lakh/Rs. 266.72 lakh)	Operational	Odisha Spatial Data Policy in 2015	Yes	Coordination structure
7.	Jharkhand	Rs. 195.49 lakh (Rs. 181.35 lakh/Rs. 14.14 lakh	Operational	Draft ready	Yes	Coordination structure
8.	Nagaland	Rs. 184.95 lakh (Rs. 123.76 lakh/Rs. 61.19 lakh)	Data layers identified for upload	Initiated the process	Not yet	Not yet

Table. 3: Representing status of spatial data infrastructure readiness in the various SSDI implementing states in the country.

Operationalization of the Geoportal: Karnataka Experience

The Karnataka State Council of Science and Technology (KSCST) with the support of state and central government have developed a geoportal (Fig. 6) and data clearing house to discover/access spatial data sets useful in the local-level planning. Karnataka Geoportal is a centralized single window access mechanism for all the spatial data acquired by various agencies. The council has institutionalized the geospatial technologies for informed decision-making by establishing district NRDMS centres in all the thirty districts of Karnataka with the support of Government of Karnataka. The available data is catalogued, and the search for the availability of any data set is made available through metadata.

The complete Karnataka Geoportal is developed using an OGC-compliant proprietary software with facilities to share the vector and raster data sets through WMS, WFS and WCS Web services. The geoportal has been kept operational and maintained by the council through funding support by the state.

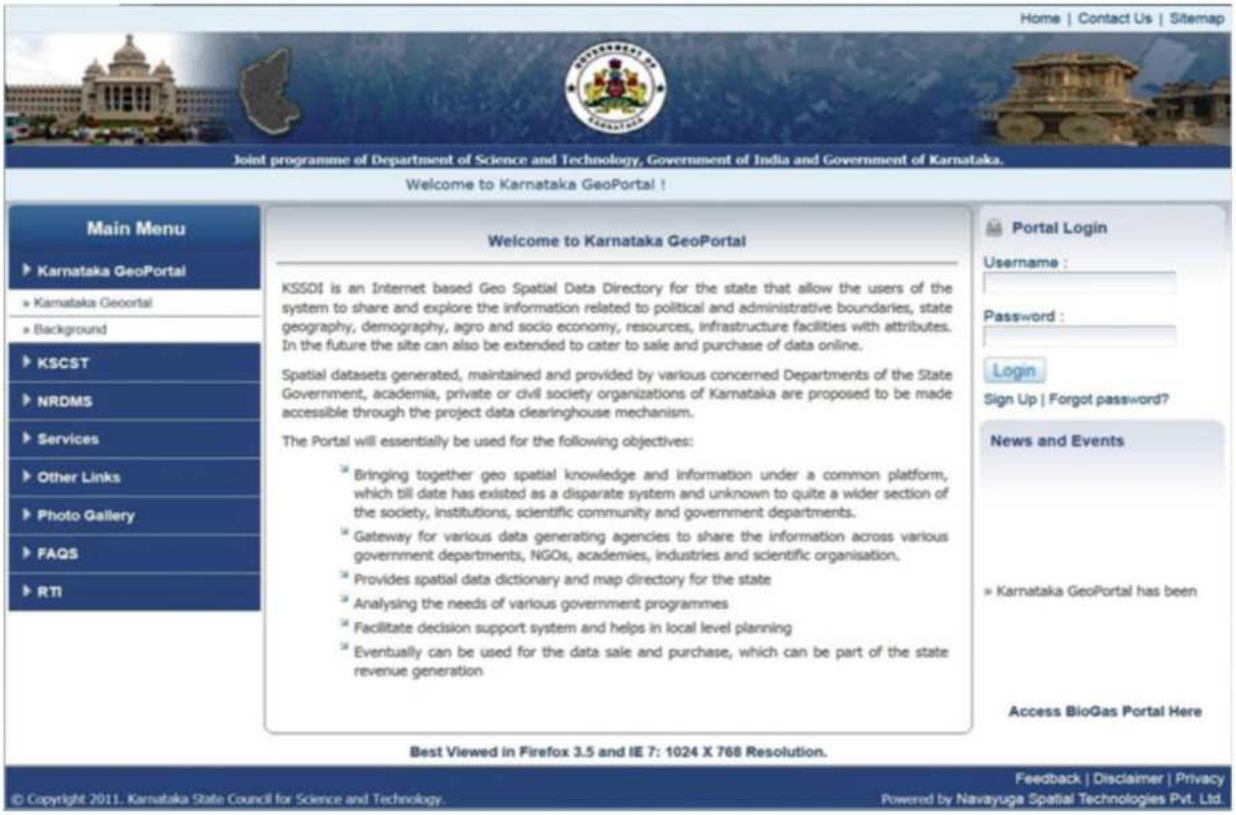


Fig.6: Screenshot of the Karnataka Geoportal (http://www.karnatakageoportal.in)

Institutional Framework and Capacity Building

Apart from technologies, appropriate institutional framework and capacity building are essential for long-term sustainability of SSDIs.

Keeping this in view, many SDI implementing states such as Karnataka, Odisha, Madhya Pradesh Uttarakhand and Jharkhand have already published in the process of publishing State Spatial Data Policy to promote sharing and enable access to the government-owned data. For example, Government of Odisha has published Odisha Spatial Data Policy through its Gazette No. 1270, Dt. 29-08-2015, to facilitate easy access and sharing of government-owned data in open format for supporting sustainable and inclusive governance and effective planning, implementation and monitoring of developmental programmes, managing and mitigating disasters and scientific research aiding informed decisions, for public good.

Among SDI implementing states, Uttarakhand (UK) has shown a best example of capacity building and coordination mechanism. The Uttarakhand State has a coordinating structure in the state government with nodal officers identified at the state/district levels. For capacity building of the state government personnel and staff, various district-wise sensitization and training workshops have been organized where the primary focus has been on exposing them to application of Web-based geospatial technologies; providing

hands-on training on GIS development and data capturing through GPS; information need assessment; and drawing up a road map for SDI development as per their own needs. The state government has also established a GIS cell at the headquarters of each district for coordinating the SSDI activities. The GIS cells at districts are integral to State SDIs to support geospatial data upgradation, publishing and sharing up-to-date data as WMS/WFS/GML, and utilization of GIS in various applications.

Applications in Governance

The utilization of geospatial data and services for a wide range of uses has seen steady growth in the requests for both data and services by planners and administrators. The NRDMS-NSDI programme of DST is continuously updating its data sets in diverse fields with an increasing set of application requirements. One of the successful examples is in watershed management.

Use of Geospatial Technologies for Watershed Management: The KSCST has showcased the utilization of geospatial technologies by developing geospatial applications on Karnataka Geoportal to evaluate watersheds in Belagavi Division of Karnataka. The council has integrated the KWDD's MIS with the Web-based SDI approach to provide standards-based online geospatial information services to end users in KWDD by utilizing the Karnataka State Geoportal already operational in the state. Earlier, KWDD does not have an easy and timely access to geospatial data of right resolution and currency for use in planning, implementation, monitoring, and evaluation processes. The geospatial services like multi-spatial-attribute queries; mobile compatibility; crowdsourcing; online editing of data and integration of MIS are the highlights of this development. Other portlets such as monitoring of biogas programme, health GIS, location of train services have also been demonstrated to the end users to support planning.

Future Directions

Rajabifard et al. proposed that the future of SDI lies in addressing the balance between the competing foci in SDI development to encourage process-based facilitation for participant initiatives for spatial data sharing. While ongoing content development, a product-based approach, is essential to complement process-based facilitation, with the main aim to link existing and potential databases of the respective political/administrative levels of the community.

In order to maintain this balanced approach of Indian SSDI development, some of the considerations for the technological requirement are as follows:

New Techniques to handle Geospatial Data Streams

With the development of geo-sensor networks in various geo-domains (e.g. smart cities, agriculture, hydrology), human sensing, etc., geospatial streams are going to be one of the new modes of data. There are need to upgrade SDI to handle geostreams, interfaces to process and analyse these streams, development of domain-specific techniques/algorithms

for events detection and monitoring and geospatial complex event processing (CEP) approaches.

Developing Approaches for Knowledge Representation of Geospatial Information

Geoinformation is highly diverse and needs approaches for reconciliation and integration at various syntactic, semantic levels. Geoinformation generated by various application projects needs to be converted to knowledge and represented formally. Thus, new ways of querying and reasoning on knowledge to obtain actionable intelligence are required. National-level geo-knowledge platform should be developed to provide various tools for knowledge representation, reasoning and visualization. There is need to develop controlled vocabularies, emergence of interdisciplinary programme on geo-ontology engineering.

Linked Geospatial Data

With the growth of multimedia, social networks, news, Twitter, user comments, etc., there is a need to develop approaches to link geospatial data with other forms of data available online to create various views of geospatial data in conjunction with other data. Thus, approaches need to be developed so that geospatial data conforms to the linked data concepts. For example, enabling RDF data available on the Web, and interconnect it with other data with the aim of increasing its value for user, enabling the development of geospatial linked data graphs, etc.

Spatial Data Fusion

New research directions in data fusion approaches should be explored to develop fusion models of multi-sensor, multi-source, multi-temporal geospatial data, which are also scale- and rotation-invariant. India specific fusion products should be identified, and standardized work flows for geospatial data fusion for various applications including near real-time applications should be published. This should be based on the type of product required for that application.

Big Data Analytics and Geo-Computational Systems

With the emergence of geospatial big data processing approaches, there is a need of development of geo-computational platforms integrated with SDI big data analytics techniques that are domain-specific.

Geospatial Approaches for Critical Infrastructures Protection (CIP)

Critical infrastructures are under constant threat from various man-made and natural disasters and other subversive activities. Understanding how resilient these infrastructures are after an event is critical. Also, there is a need to understand the interdependencies between the critical infrastructures. Thus, research is needed on deterministic and stochastic approaches for interdependency modelling, development of simulation environments, situational awareness, visualization.

3D Visualization

There will be an increase in the ways we visualize geospatial data, moving from a mapping environment view to a view that demonstrates how the user would experience a location as if their feet were on the ground, e.g. street views in Google Earth. Three-dimensional building models will continue to grow and help to create realistic views of our landscape. Geospatial data is critical in helping to supplement 3D views of other geo-coded information to provide 3D business intelligence. Three-dimensional visualization will be fed by new semi-structured data from mobile devices, geo-tagging of existing enterprise structured data, and tapping into new streams of location-aware unstructured data.

Location-based Business Intelligence

Solving business problems with geospatial data and cloud computing will become increasingly important in future. More and more geospatial solutions and 3D business intelligence services that provide customers with "answers" rather than "data" need to be developed. Increasing complexity of geospatial solutions, and the continued growth in the geospatial technology industry, will lead to both business consolidation as well as increasing partnerships.

Crowdsourcing

In an increasingly connected world, volunteered information will become more and more important. Information created in this way will be increasingly important for government and business and may radically challenge traditional approaches to geospatial data generation and maintenance.

The Puzzle of The Geospatial Technology Legal Framework

BACKGROUND

Geospatial technology is a multidisciplinary field that covers various forms of technology that are implemented in fields such as archaeology, geology, geography, statistics, etc. At present, there are a multitude of laws in India with respect to geospatial technologies and the regulation of geospatial data. This article attempts to enumerate the various legislations currently in force and the draft stage.

The different types of geospatial technologies include the following:

1. Remote Sensing: this includes images and data collected by instruments from space – or through aerial cameras and sensor-based platforms.

2. Geographic Information Systems (GIS): This includes software-based tools for mapping and examining data collected and the georeferencing of data. These systems are put to use to detect geographic patterns, such as disease clusters stemming from toxins, sub-optimal water access, etc.

3. Global Positioning System (GPS): a network of satellites which can give precise coordinate locations to civilian and military users.

INDIAN FRAMEWORK

The usage of such geospatial technology results in the creation of geospatial information. In the Indian context, geospatial information has been defined under the draft Geospatial Technology Bill, 2016 ("draft Bill") as "geospatial imagery or data acquired through space or aerial platforms such as satellite, aircrafts, airships, balloons, unmanned aerial vehicles including value addition; or graphical or digital data depicting natural or man-made physical features, phenomenon or boundaries of the earth or any information related thereto including surveys, charts, maps, terrestrial photos referenced to a co-ordinate system and having attributes."

The definition of geospatial information has been kept very open-ended and can potentially incorporate everything from satellite imagery, to books, navigation systems, newspapers, magazines, town plans, survey data, to every smartphone that bears a GPS chip.

GEOGRAPHIC INFORMATION SYSTEMS

Traditionally, mapping has been an activity solely reserved for the Survey of India, which was formed in the year 1767. However, the National Map Policy of 2005 was released on May 19, 2005 due to the recognition of the importance of high quality spatial data in various facets such as conservation of natural resources, socio-economic development, infrastructure development etc. The intent of this policy was to "liberalize access" to spatial data without compromising security concerns.

With the aim of realizing the security concerns, a dual-classification was designed with respect to the maps, namely – i) Defence Series Maps ("DSM") and ii) Open Series Maps ("OSM"). While the DSM constitutes of topographical maps that mainly cater to defence and security requirements of the country, the OSM supports developmental activities.

Henceforth DSMs, irrespective of whether they are in analogue or digital form, shall be classified under this category and the power to issue guidelines with respect to their usage lies mainly for developmental purposes. They are not openly accessible ipso facto and need to gain the 'unrestricted 'tag after clearance from the Ministry of Defence.

While the DSMs are completely classified, restrictive provisions regarding usage and dissemination of OSMs have also been incorporated in the policy. OSMs are not allowed to show any civil and military Vulnerable Areas and Vulnerable Points (VA's/VP's). OSMs on a scale larger than 1:1 needs to be disseminated either by sale or an agreement, which will allow the entity engaged in the activity of mapping to add its own value to the maps obtained, and to share these maps with others.

REMOTE SENSING

In 2011, the confusion pertaining to applicability of the National Map Policy of 2005 to both territorial and satellite mapping was resolved with the release of the Remote Sensing Data Policy of 2011. The policy recognized the importance of remote sensing data and

noted that it was largely used by government and non-government users from Indian and foreign remote sensing satellites.

However, again banking upon the need for security considerations, the policy was released with the purpose of "…managing and/ or permitting the acquisition/dissemination of remote sensing data in support of developmental activities". The Department of Science ("DOS") was made the nodal government agency for all actions pertaining to remote sensing data under the policy.

A perusal of the policy indicates a parallelism between the Remote Sensing Policy of 2011 and the National Map Policy of 2005. Thus, similar to National Map Policy of 2005, Remote Sensing Policy of 2011 assures of a government managed Indian Remote Sensing Satellites (IRS) Programme, the data produced by which will be owned solely by government, and any users other than the government would be provided with licences on a case to case basis, only if such need arises. It further provides that any attempt at acquiring and/or dissemination of remote sensing data within India shall require permission through the nodal government agency.

National Remote Sensing Centre ("NRSC") of the Indian Space Research Organisation (ISRO)/ DOS is vested with the authority to acquire and disseminate all satellite remote sensing data in India, both from Indian and foreign satellites. NRSC is also supposed to maintain a systematic National Remote Sensing Data Archive, and a log of all acquisitions/ sales of data for all satellites. Therefore, nodal government agencies were established for both terrestrial mapping and satellite imagery, former being Survey of India and latter NRSC.

CIVIL AVIATION – OPERATION OF DRONES

Drones, as we know them today, represents a significant development in robotic technology. Unmanned aerial vehicles, or Remote Piloted Aircraft Systems ("RPAS"), as termed by the International Civil Aviation Organisation have been defined as "a set of configurable elements consisting of a remotely-piloted aircraft, its associated remote pilot station(s), the required command and control links and any other system elements as may be required, at any point during flight operation."

In December 2018, the Director General of Civil Aviation issued the Civil Aviation Requirements 1.0 ("CAR") under Rule 15A and 133A of The Aircraft Rules, 1937. The CAR classifies RPAS based on their weight (including payload), as under:

1. Nano – under 250 grams.
2. Micro – between 250 grams and 2kg.
3. Small – between 2kg and 25kg.
4. Medium – between 25kg and 150kg.
5. Large – greater than 150kg.

Eligibility for operators of RPAS:

1. Citizen of India; or

2. Central Government or any State Government or any company or corporation owned or controlled by either of the said Governments; or a company or a body corporate provided that:

3. it is registered and has its principal place of business within India;

4. its chairman and at least two-thirds of its directors are citizens of India; and,

5. its substantial ownership and effective control is vested in Indian nationals; or

6. Company or corporation registered elsewhere than in India, provided that such company or corporation has leased the RPAs to any organization mentioned as above.

For all RPAS other than those falling under the nano category, the mandatory equipment required for operation are:

1. Global Navigation Satellite System (GPS);

2. Return-to-home;

3. Anti-collision light;

4. ID plate;

5. Flight controller with flight data logging capability; and

6. Radio Frequency Identification (RFID) and SIM/ No Permission No Takeoff.

Additionally, RPAS would be required to operate within visual line of sight, during the day and only upto a maximum altitude of 400 feet. The CAR also demarcate the permissible zones for operation of drones into three categories:

1. Red Zone: operation of drones not permitted

2. Yellow Zone: this is a controlled zone and operation of drones would be subject to prior approval. For operation of drones in this zone, filing of flight plans and obtaining Air Defence Clearance/ Flight Information Centre number would be necessary.

3. Green Zone: this would form the uncontrolled airspace with an automatic permission for operation of drones.

The Regulations also define No Drone Zones which would cover the following areas:

1. Radius areas of 5 kms from airports;

2. Within a radius of 50 km from the international borders;

3. Within a radius of 5 km from Vijay Chowk; and

4. Buildings such as State Secretarial Complex in State Capitals, strategic and military installations.

The enforcement actions provided for include:

1. Suspension or cancellation of registration or permit;

2. Penalties under the Aircraft Act, 1934 or Aircraft Rules; and

3. Penalties under Indian Penal Code such as:

4. Section 287 – negligent conduct with respect to machinery; or

5. Section 336 – act endangering life or personal safety of others; or

6. Section 337 – causing hurt by endangering life or personal safety of others; and

7. Section 338 – causing grievous hurt by act endangering life or personal safety of others.

The Drone Policy 2.0 was released on January 15, 2019, which sought to address issues of Beyond Visual Line of Sight ("BVLOS") and regulate autonomous operations. The key changes proposed were:

1. Privacy by Design – Manufacturers to adhere to a privacy by design standard, eliminating risks of future privacy harms by operators.

2. Drone Corridors – To segregate air routes of commercial airliners and RPAS, limit human presence, enable autonomous takeoff and landing at designated drone-ports.

3. BVLOS and night-time operations – as opposed to the current visual line of sight of 400ft, and day-time operations only.

4. Droneports – To facilitate takeoff and landing, operate as distribution centers/ cargo holds and battery charging stations. They must be integrated with Digital Sky Platform and listed on the National Droneport Registry.

5. Unmanned Aircraft System Traffic Management ("UTM") – Hyper-local and real-time tracking and management of UAS induced traffic in Drone Corridors and detect obstacles and avoid collisions. UTM will give Digital Sky the ability to electronically disrupt operations of a rogue UAS.

6. Artificial Intelligence ("AI") – Enable re-routing and de-confliction by integrating AI into the UTM system.

7. Airworthiness Certifications – Pursuant to BVLOS and night-time operations, it provides a broad criterion of airworthiness for manufacturers.

8. Commercial Operations of UAS – Enables transportation of bodily organs for emergencies, surveying of landscapes and active monitoring of rail/road traffic.

9. Foreign Direct Investment ("FDI") – 100% FDI under the automatic route in RPAS-based commercial civil aviation services, subject to the financial threshold applicable to non-scheduled air transport operators.

10. Insurance – Cover the liability towards the cargo, hull loss and third-party risks that may be possessed due to commercial and/or BVLOS operations of the UAS in compliance with the Carriage by Air Act, 1972 or any other applicable law.

11. Autonomous Operations – Pursuant to BVLOS, operators need not maintain control of the UAS, provided it is used for ethical purposes and subject to protection of security and privacy of human beings.

GLOBAL POSITIONING SYSTEMS

Global positioning systems play a key role in identification, location and navigation. These systems are reliant solely on the operation of satellites and transmission/ collection of data using such satellites.

The legislative framework surrounding the operation of satellites in India is currently lacking. India has ratified the 1967 Outer Space Treaty, 1968 Rescue Agreement, 1972 Liability Convention, and 1975 Registration Convention that govern the operation of satellites in outer space.

Despite such ratifications, no specified legislation has yet been enacted by the Indian legislation in this regard. The only legislations that are considered to constitute India's policy framework with respect to the operation of satellites and handling of data generated in this regard are the SATCOM policy of 2000 and the Remote Sensing Policy of 2011. However, neither are applicable to satellite navigation.

The SATCOM policy of 2000 addresses policy implementation for nationwide satellite communications whereas the Remote Sensing Policy of 2011 establishes the modalities for permitting and/or managing remote sensing data acquisition to support development activities.

The data collected with respect to global positioning systems would be deemed as geospatial information under the draft Bill and any person or entity generating such geospatial information would be required to obtain a license to own or use such data.

WAY FORWARD

As is evident, there is a lack of a specific and concise legislation with respect to regulating the domain of geospatial information. The draft Bill was introduced in the right direction in 2016 but has not been worked upon further. At present, the regulation of geospatial technology is spread across various policy documents that often leads to a lot of confusion with respect to compliance for businesses operating in this business domain.

The regulation of geospatial technology and geospatial information is a multi-faceted domain which spills into many sectors including information technology, space technology, remote sensing, defence, and even aviation if we include drones. Therefore, any policy related to geospatial must be framed by an interdisciplinary group which has a clear understanding of what the technology means and entails.

Draft Geospatial Information Regulation Bill, 2016:

In the light of gross misrepresentation of India's international boundaries not only by some of our immediate neighbouring countries but also by a few powerful media houses, intelligence agencies of other countries, as well as by some world organisations, the Government of India felt the need to have a geospatial data and information regulation bill. The draft of the Geospatial Information Regulation Bill, 2016 circulated by the Ministry of Home Affairs, Government of India, to regulate the acquisition, dissemination, publication and distribution of geospatial information of India, contains many provisions which will adversely affect academic activities and economic interests. The immediate provocation for the bill is the misrepresentation of our international borders, especially with Pakistan and China. Though the intention of the bill is in the interest of the protection of the sovereignty and integrity of the country, the fact that the whole gamut of geospatial information is set to get into the Indian bureaucratic realm, reputed for "redtapism," is what is worrisome.

We are over-secretive with our maps; not making them accessible in the internet for the use of students, researchers, scientists, academics and the like. Earth scientists mostly use

maps produced by the Survey of India and the National Atlas and Thematic Mapping Organisation (NATMO). Maps produced by these organisations are used to derive other thematic maps. Thus, most of the maps that are generated by the earth scientists are redrawn maps. The most commonly used redrawn map is perhaps the India map to show location of a certain study area within India.

Control or Deter?

Today maps have gone digital and global. People use the internet freely to borrow a map of India. As a result, maps of India with misrepresented international boundaries abound in various internet sources. This is where people are caught unawares. It has come to light that a couple of our neighbouring countries and a few international publishing and media houses insist on "their version" of the map of India to be used, if a scientific or academic paper is to be published in their journal and/or site. That is the level of campaign some of India's neighbours and a few international agencies have directed to bring misrepresented maps of India into circulation. No one doubts the need of the hour for this bill. However, the bill will serve to control only Indian citizens, instead of serving as a deterrent to others.

The crux of the proposed bill is the sweeping definition of "geospatial information"—to include

geospatial imagery or data acquired through space or aerial platforms such as satellite, aircrafts, airships, balloons, unmanned aerial vehicles including value addition; or graphical or digital data depicting natural or man-made physical features, phenomenon or boundaries of the earth or any information related thereto including surveys, charts, maps, terrestrial photos referenced to a coordinate system and having attributes; ...

The definition is so thorough that it leaves nothing in the hands of map and remote-sensing data-users to go with, without the approval of the Security Vetting Authority (SVA). Fortunately, Indian governmental bodies have been left as exceptions to this regulation bill.

However, the draft bill in its present form will badly affect all academics teaching and researching in earth sciences. As it is, restrictions on topographic maps at scales 1:50,000, 1:25,000 produced by the Survey of India, which are utilised as "base" maps not only for bringing remote-sensing data to a coordinate/ referencing system but also employed for an umpteen number of purposes, already exist. Restrictions on access to aerial photographs, other important tools in the kit of earth scientists are so tight, the less said the better. Accuracy and precision in geospatial data and information is scale-dependent. While tracing, redrawing or digitising smaller scales (smaller maps showing large areas), certain inaccuracies or omissions may take place. For instance, a crenulated boundary in a large-scale map (large maps showing small areas) can turn into a rounded, smooth line in a small-scale map.

Remote-sensing data came as a respite and the earth science community did a wonderful job using this data for a variety of purposes and the country benefit- ted. But the axe fell

on remote-sensing data. High resolution remote-sensing data had been restricted leaving low- and medium-resolution data free for users. If this bill comes into play all types of data come within the ambit of "restriction" and "vetting."

The bill may be good in spirit, but in letter (if one looks at the definition of geospatial information), it does not augur well for the earth scientists and the country.

Contours of a Bill

Maps, aerial photographs and satellite- based, remote-sensing data are the tools of earth scientists and this bill takes away the most important tools left in the kit of earth scientists to go about their job. How do we know what to do with our most precious asset—our land—if we do not know how our land looks like? This bill in its present form will restrict earth scientists in our country from making updated, competent maps, thus bringing about economic ramifications for the country. It is not just government organisations that generate geospatial information. Substantial and significant contributions come from academic institutions at less than half the actual cost the government organisations spend. We are poor producers and users of maps and atlases. With the result we have a scarcity of maps, especially of India in the country. This would discourage and deter small- to medium-sized business- es from producing maps which are used everywhere, from schools to universities. Moreover, the cost of map production would increase because of fee levies and charges to obtain permissions from SVA.

The bill talks about misrepresentation of topography. Topography in glacial areas (our boundary passes through many glaciers), large riverine plains and deltas (Ganga–Brahmaputra–Meghna), large tidal and salt flats (along coastal Indo–Bangladesh and Indo–Pakistan borders) is highly dynamic and it is a challenge to obtain the updated, competent maps. In such cases of changing topography, misrepresentation of topography cannot be ruled out.

Keeping the spirit aside, if one has a look at the letters of the bill, two aspects of geospatial information stand apart— one, the data, which means the maps made by various organisations; the other being remote-sensing data acquired by our country. From these maps and remote-sensing data, "information" is extracted through various methods. This information extraction is both a technical and intellectual activity and mistakes can occur here; but, who will judge this information? Would a joint secretary be competent enough or would it be a technical or a national security expert? In difficult situations the judgment will move to the SVA now and in most of the cases of geospatial information, it would be a "no" from SVA because there is a fear factor playing in. It would then be excruciating for producers of information to follow through such situations, which are more likely to be common than exceptions. After all, the question is one of political boundaries, and rigour must be applied so that misrepresentations do not enter the public digital domain.

From the security point of view, coordinates of locations and the remote- sensing data that facilitate the making of three dimensional models of topography are important.

Remote-sensing technology is available with many countries. Fortunately, the political boundaries do not extend into space. Space, from where one can peep into other countries, is free for all. Remote-sensing data are available for a price—and for no price also—in several countries and organisations. When data is available so freely from several other sources, restrictions on acquiring data for our own scientists and the academic institutions are meaningless. Withholding of data and information dissemination are two totally different aspects. Dissemination of wrong information must not be allowed; it must be punished. However, withholding data of certain kind should be freed from this bill.

Connecting the Dots

From the mid-1970s an enormous amount of remote-sensing data had been acquired by academic institutions, teachers and researchers and an equally enormous amount of information had been generated. What the bill will end up doing will amount to asking every person who has already acquired any remote-sensing data to process an application in order to retain it. Other than the obvious implications this will have to many people as well as institutions, this will also mean that the SVA itself would drown under the deluge of sifting through this task alone.

A geospatial data and information regulation bill is a necessity; but not with all the provisions as proposed in the draft of the Geospatial Information Regulation Bill, 2016. There are already restrictions on maps and aerial photos and high resolution 2D and stereo remote-sensing data along international boundaries and around strategic areas and installations. The data recorded by satellite/aerial sensors/cameras do not lie, nor do they misrepresent. Instead, it is suggested that the data be left free, while restrictions be imposed on the information extracted. If at all there have to be restrictions, they ought to be limited to very high resolution 2D and 3D remote-sensing data of 1m and sub-metre pixels, and not on medium and high resolution 2D and 3D remote-sensing data.

To avoid the problem of misrepresentation of our international boundaries, the simplest solution lies in uploading authenticated (authenticated, perhaps, by Survey of India with a watermark seal certification) maps of India at various scales and in various software formats. The punishments proposed in the bill for wrong depiction of boundaries of India are welcome, but, we believe, too harsh.

Finally, the intention of the map-maker/ user should be factored into the question of legality and illegality. Though the provision of punishments may make the citizens of India a little more conscious now about representation of international boundaries, there is no mechanism to stop intentional misrepresentation by non-Indians. Having said this, it must also be added here to the powers that be that a healthy academia does not flourish under the shackles of draconian restrictions but on freedom.

How it will affect industry & growth:

Geospatial Information today is not limited to Survey of India or Google Maps. Modern innovative technologies like Building information Modelling, Internet of Things, Cloud

computing, Big Data analytics, mobile commerce, autonomous vehicles, and social media are all location-dependent.

Going by this Bill, use of any of these business processes not only has to seek clearance for generating geospatial information but also seek licenses for every value addition. And in case a license is rejected, the unique intellectual property of the innovator has to be destroyed.

Mathur points out geospatial technologies would power several mega projects of the government like Smart Cities, Digital India, Clean Ganga Mission, Swachh Bharat Abhiyan, roads and highways, among others. Hence, it is imperative that geospatial information products like maps, imageries, aerial photographs, etc. are made available to all those who can benefit from them. Aiyar feels if access to data is compromised, even initiatives like Skill India and Start-Up India will fail. The Bill in its current form is sure to discourage start-ups who would require licence and clearances for each and every update or value addition made, as also investments into location-based services critical for national growth.

The larger losses would be map users in navigation space like in automobiles and services related to them.

Interestingly, ISRO's successful completion of the IRNSS constellation was being touted as a huge opportunity for India to come up as a low-cost, high-skill manufacturing hub for GNSS sensors and other related hardware and software. The Bill is sure to severely impact any such plans.

How it affects research & innovation

Under open data policy, coarse and moderate resolution data is available for carrying out research and societal application. Many datasets like MODIS and NOAA are not even available from ISRO. Since the Bill restricts acquisition of any kind of spatial data by anyone, a researcher cannot download any satellite images of any resolution, thematic maps or other spatial content of India which are available free of cost on the Internet. More than 99% students use open source data — usually with resolution between 20 m to 1 km available globally — for their practical and project works.

Besides, many satellite data provide information like soil moisture, land/sea surface temperature, greenhouse gases, polar ice and many such parameters. Non-availability of these datasets will practically kill any innovation in this space. A researcher in geospatial information, environmental and climate science will now need a license with a requisite fee (not known) for the acquired satellite images and thematic maps for their degrees. Thus, in essence they are being denied the IPR for the value addition that they have done on openly available spatial data. Also, if the license application is rejected, researchers need to destroy that information which is otherwise their IPR.

Researchers in geospatial science cannot publish their papers in any international journal or make presentations at international conferences/seminars/workshops outside India

without license and clearance. An individual carrying out innovative research will have to wait for clearance which can take months to years. By that time his research will be irrelevant.

The way forward

Geospatial is a multidisciplinary activity which spills into or borrows from many areas including IT, space technologies, remote sensing, defense, and even aviation if we include drones etc. Therefore, any policy related to geospatial must be framed by an interdisciplinary group which has a clear understanding of what the technology means and entails. In this case, the very wordings of the Bill makes it obvious that MHA committee that drafted it did not have a sufficiently interdisciplinary group with clear understanding about how geospatial data is created and used.

Forget about involving in drafting, the immediate controversy the Bill generated even from within the government departments — though no one will go on record on this — is clear enough to indicate that the draft was not even circulated among the members of the Committee of Secretaries (CoS). The CoS includes the Secretary DST and the reaction from DST was knee-jerk to say the least.

While Dr Swarna Subba Rao, Surveyor General of India, responded by saying his office was currently examining the draft law (thus exposing how collaborative the MHA efforts have in if the Surveyor General of the country has to read a draft law on maps after its release in public domain!) a DST spokesperson had gone on record saying the Bill will be drastically modified, the penalties reduced and mainly target specific companies that "wrongly depict borders."

There is no doubt that the existing version of the Bill will be "significantly changed" as it "goes against the spirit" of the National Geospatial Policy, 2016, spearheaded by the DST. The official also said that DST forwarded its inputs to MHA who acknowledge the same but are silent about its future actions. It will be at least two years before it could become law, the spokesperson said, thus indicating inter-departmental opposition to this Bill.

A clear cut law on geospatial information and sharing is welcome. India does need a law in this field spelling out clarity. And the numerous policies in this field that the successive governments keep flaunting are not enough. A policy is not mandatory, a law is. But any law must have an understanding of ground realities, must be open and encouraging for industry and users.