GI-02

KRISHNA KANTA HANDIQUI STATE OPEN UNIVERSITY

POST GRADUATE CERTIFICATE PROGRAMME IN GEOINFORMATICS

COURSE 2

BASICS OF REMOTE SENSING AND GLOBAL NAVIGATION SATELLITE SYSTEM

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UNIT-10: GPS Data and Applications

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Post Graduate Certificate Programme in Geoinformatics

Course 2

GI-02 BASICS OF REMOTE SENSING AND GLOBAL NAVIGATION SATELLITE SYSTEM

MARKS 100
DETAILED SYLLABUS

Credits - 4

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COURSE INTRODUCTION

"Basics of Remote Sensing and Global Navigation Satellite System" is the second course of this programme which is designed to provide the details of Remote Sensing and Geographic Positioning System.This course will help the learners to collect information over large spatial area.

This Course is divided into ten units.

The **first unit** covers the introduction to remote sensing, its concepts and definition, history and development, EMR spectrum, EMR interaction with earth's atmosphere and spectral signature and resolution.

The **second unit** includes the remote sensing platforms, remote sensing sensors, history of space imaging, types of satellites, and remote sensing in India.

The **third unit** introduces us to data products, data characteristics, overview of imageries from various satellites and procuring Remote Sensing Data.

The **fourth unit** covers the concept of thermal remote sensing, thermal inertia, thermal sensors and scanners, opto-mechanical CCD Arrays, application of thermal scannerand imagery and application of thermal data.

The **fifth unit** covers the basic concept of microwave remote sensing, microwave sensors, spectral and spatial resolution, microwave data sets, and application of microwave satellite data.

The **sixth unit** covers the overview of hyperspectral remote sensing, hyperspectral missions and sensors, data characteristics and processing, and applications of hyperspectral remote sensing.

The **seventh unit** includes the basic concepts of aerial photography, types of aerial photography and photogrammetry.

The **eighth unit** covers the basic idea of image enhancement techniques, elements of image interpretation, techniques of visual and digital interpretation.

The **ninth unit** consists of introduction to Global Positioning System, GPS satellites constellations, introduction to GLONASS, Galileo, GAGAN, IRNSS, GPS antennas, signals, and codes, GPS receivers and modes of measurements.

The **tenth unit** includes factors affecting accuracy of GPS data, post processing of GPS data, advantages and disadvantages of GPS and applications of GPS.

Each unit of this block has some questions as "Check Your Progress", to be answered by the learners while going through the units. The learners can tally their answers with the answers given at the end of each unit as "Answers to Check Your Progress". This will help them in judging their performance. The units of this block include some along-side boxes to help you know some of the difficult, unfamiliar terms. The learners will come across some "Activity" within the units which will help them in gaining practical experience in the related topics.

UNIT- 1 : INTRODUCTION TO REMOTE SENSING

UNIT STRUCTURE

1.1 Learning Objectives

1.2 Introduction

1.3 Introduction to Remote Sensing

1.4 Concepts and Definition

1.5 History and Development

1.6 EMR Spectrum

1.7 EMR Interaction with Earth's atmosphere

1.8 Spectral Signature and Resolution

1.9 Let us Sum up

1.10 Further Readings

1.11 Answers to Check Your Progress

1.12 Model Questions

1.1 LEARNING OBJECTIVES

After reading this unit, you will be able to-

- describe the basic concept of remote sensing
- explain the history and development in remote sensing
- illustrate the EMR spectrum
- discuss the EMR interaction with earth's atmosphere
- describe the spectral signature and interaction.

1.2 INTRODUCTION

This is the first unit of the second course. In this unit you are going to learn what is remote sensing. It includes meaning, concept and components of remote sensing. History and development of remote sensing are also to be discussed. This unit is also deals with the EMR

(Electromagnetic Radiation) Spectrum, EMR interaction with earth's atmosphere along with the spectral signature; interaction with soil, water and vegetation.

1.3 INTRODUCTION TO REMOTE SENSING

Remote sensing is comparatively a new branch of science. The term remote sensing is used by a number of scientific disciplines. The term remote sensing was first used in the early 1960s. It is currently used more commonly to denote identification of earth features by detecting the characteristic electromagnetic radiation that is reflected, emitted or scattered by the earth surface. To know about remote sensing one must know and understand the meaning and principles of remote sensing and its essential components of remote sensing. The components are- (1) The signal, which is the carrier of information from the object or phenomenon, (2) The sensor or detector, which transforms the energy of the incoming radiation into a form of recordable information, and (3) The sensing, i.e. the acquiring knowledge about the object analysing of the signals at the user's laboratory. The processes involves in collection of information in remote sensing are: (a) Source of energy (sun/ self-emission) (b) Transmission of energy from the source to the surface of the earth (c) Interaction of energy with the earth surface features (d) Propagation of reflected/emitted energy through atmosphere (e) Detection of the reflected/emitted energy by the sensor (f) Conversion of energy received into photographic/digital form of data, and (g) Conversion of information into Map/tabular forms.

Remote sensing makes it possible to collect data of remote or inaccessible areas. Remote sensing applications made it possible to monitor deforestation, forest fire in the midst of vast deep forests, glacial features and their changes with time in inaccessible Arctic and Antarctic regions, measurement of ocean depths and many more. It also replaces costly and slow data collection on the ground and changes of land use, land cover of the surface of the earth.



CHECK YOUR PROGRESS

Q.1: Since which decade the Remote Sensing in map making was started?

.....

.....

Q.2: What are the essential components of Remote Sensing?

.....

.....

Q.3: Write the processes involves in collection of information in Remote Sensing?

.....

.....

1.4 CONCEPTS AND DEFINITION

In the simplest form, the remote sensing could be defined as the sensing of an object or a phenomenon from distance. The principle of remote sensing is same with that of human eye vision, where the reflected sun rays are sensed by the eye sensor and send the information to brain for identification of the feature. In the same way, the science/technology of remote sensing is making inferences about material objects from measurements made at a distance without coming into physical contact with the objects under study. However the term 'remote' is considered as highly relative and depends on the characters of the signals and the sensors. In remote sensing though there is no physical contact between the sensor and the object, in all conditions the objects to be sensed and the sensors are always covered in an interacting fields like gravitational field, electromagnetic field etc.

As defined by Floyd F. Sabins "The term Remote Sensing refers to methods that employ electromagnetic energy, such as light, heat and radio waves, as the means for detecting and measuring target characteristics". An elaborate definition on remote sensing given by the National Academy of Sciences in which it "denotes the joint efforts of employing modern sensors,

data processing equipment, information theory and processing methodology, communication theory and devices, space and airborne vehicles and large system theory and practice for the process of carrying out aerial or space survey of the earth surface".



CHECK YOUR PROGRESS

Q. 4: State True or False:

a) Light, heat and radio waves are the electromagnetic energy.

b) In remote sensing there is a physical contact between the sensor and the object.

c) The principle of remote sensing is same with that of human eye vision.

1.5 HISTORY AND DEVELOPMENT

Though remote sensing has been accepted today in the scientific literature as a comparatively young branch of science, but the act of remote sensing is as old as the origin of life on our planet. Remote sensing is carried out with the help of sensors such as cameras, multispectral scanners etc. which are carried onboard airborne or space borne platforms like aircrafts or spacecrafts. The balloonist G. Tournachon made photographs of Paris from his balloon in 1858, which is considered as the first remote sensing aerial photograph of the earth surface. Messenger pigeons, kites, and unmanned balloons were also used for early images. But except the balloons, the images from other sources mentioned above were not found useful for map making or for scientific purposes.

Systematic aerial photography was developed for military purposes in the beginning of the World War I. Later on with the use of modified combat aircraft such as the P-51, P-38, RB-66 and the F-4C brought about revolutionary improvements in aerial photography. Specifically designed aerial platforms such as the U2/TR-1, SR-71, A-5 and the OV-1 series are the recent milestones in the development of aerial photography. In India also aerial photography is widely used for various purposes. Dakota, Avro,

Cessna, Canberra are the types of aircrafts generally used for aerial photography in India.

With the advent of artificial satellites, there has been a phenomenal increase in remote sensing mainly for higher capability and repetitive coverage. A real breakthrough in the field of remote sensing was achieved with the launching of Landsat series of satellites by NASA (USA) beginning with Landsat -1 in 1972. Other satellites of Landsat series have given lot of information of earth features. High resolution satellites like the French satellite SPOT (10 m resolution), American satellite IKONOS (1m resolution) brought about revolutionary changes in satellite remote sensing. The Nimbus and more recent missions such as RADARSAT and UARS also provided global measurements of various data for civil, research, and military purposes.

India also launched the first remote sensing satellite IRS- 1A in 1988. After that India has launched almost at regular interval the same series of satellites viz., IRS-1B in 1991, IRS-1C in 1995, IRS-1D in 1997.

Since 1st September 2008 NRSA (National Remote Sensing Agency), a centre under DOS (Department of Space)/ ISRO (Indian Space Research Organization) Carrying out the satellite remote sensing activities in India.

NRSA is closely associated with various programmes of the Department of Space (DOS)/Indian Space Research Organisation (ISRO), in particular, the Earth Observation Programme, Disaster Management Support and other programmes of national importance. In order to enable NRSA to carry out its responsibilities in a more effective manner, the Government has after careful consideration, decided to convert it into a Government entity, to be called a National Remote Sensing Centre (NRSC), a Centre under DOS/ISRO, effective 1 September 2008.



CHECK YOUR PROGRESS

Q.5: Write the principles of Remote Sensing.

.....

Q.6: What is NRSC?

.....

Q.7: What are the types of aircrafts generally used for aerial photography in India?

.....

1.6 EMR SPECTRUM

A sensor or a detector employed on earth observation platforms use electromagnetic radiation (EMR) to observe the land features. 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. The entire electromagnetic spectrum (EMS) is divided into different regions depending on the size of the waves and frequency, which are broadly known by different names viz. visible, near infrared (NIR), thermal infrared (TIR), microwave (MW) etc. Each one of these broad regions of spectrum is used in different applications. However, the visible, infrared and microwave regions of energy are used in remote sensing. The spectral regions, wavelength and characteristics of the electromagnetic spectrum are given in the following table.

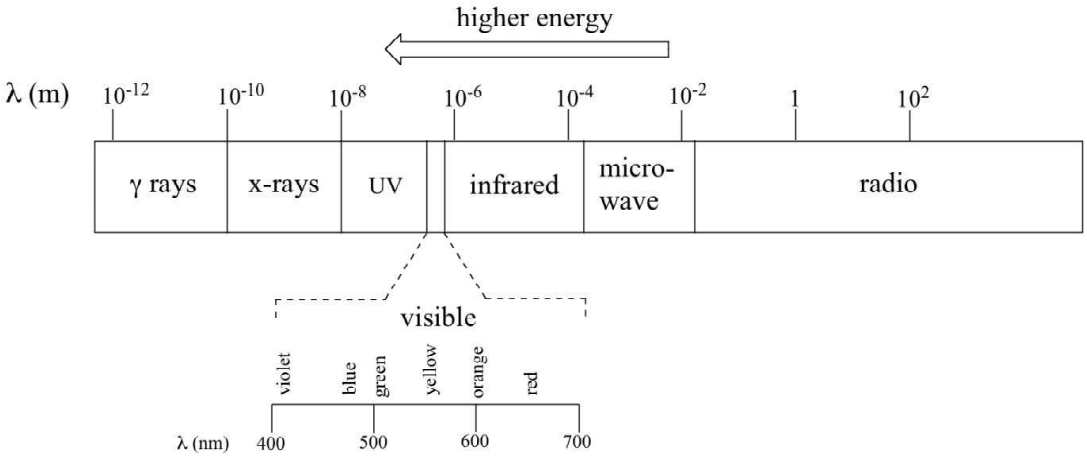


Figure 1.1: Electromagnetic Spectrum (Wavelength regions)

Table 1.1 Electromagnetic Spectrum: spectral region, wave length and characteristics

	Spectral region	**Wave length**	**Characteristics**
1	Gamma-Ray Regionas	<0.03 nm	It is not available for remote sensing the radiant energy is wholly absorbed in the upper atmospheric layer.
2	X-Ray Region	0.03-3.0 nm	It is also of no use for remote sensing as it is absorbed in the atmosphere
3	Ultraviolet Region (UV)	3 nm- 0.4 μm	The wavelengths less than 0.03 μm are absorbed in the ozone layer. The ultra violet region lies beyond the visible wave lengths. The earth materials like rocks and minerals emit ultraviolet radiation.
4	Photographic Ultraviolet Band	0.3-0.4 μm	It is suitable for film and photo detectors but atmospheric scattering is severe.
5	Visible Region	0.4-0.7 μm	It is visible to the eyes and is suitable for remote sensing by films and photo detectors. This region includes the earth reflectance peak i.e. about 0.5 μm.
6	Infrared Region (IR)	0.7- 300 μm	Variable interaction with matter in different wavelength. Includes both atmospheric windows and absorption bands.
7	Reflected IR Band	0.7-3.0 μm	It is reflected solar radiation with no information of thermal characteristics. 0.7-0.9 μm wavelength region is detectable with film and is known as photographic IR radiation.
8	Thermal IR Band or Mid	3.0-5.0 μm	Principal thermal atmospheric windows. Acquisition of thermal imagery is done byIR Band scanners but not by film
9	Microwave	0.3-300 cm	These can penetrate clouds and fog. Imagery can be acquired by both passive and active mode.
10	Radio Region	>30 cm	In the electromagnetic spectrum, it is the region of longest waves. It is suitable for collection of atmosphere conditions by remote sensing and also commercial broad casting.



CHECK YOUR PROGRESS

Q.8: What is the full form of EMR?

.....

.....

Q.9: What is electromagnetic spectrum?

.....

.....

Q.10: What is the wave length of X-ray region?

.....

.....

1.7 EMR INTERACTION WITH EARTH'S ATMOSPHERE

Electromagnetic radiation from the sun interacts with the atmospheric constituents and get absorbed or scattered. Scattering that takes place could be divided into two types. One is elastic scattering in which the energy of radiation is not changed due to scattering and the other is inelastic scattering in which the energy of the scattered radiation is changed.

Elastic scattering is again divided into three types depending on the size of the scatterers in relation to the wavelength of radiation. These are- (1) Rayleigh scattering, (2) Mie scattering and (3) Non-selective scattering. Rayleigh scattering causes the sky to appear blue. The red of the sunrise and sunset is also caused by Rayleigh scattering. The multispectral remote sensing data from the blue portion of the spectrum is of relatively limited usefulness due to Rayleigh scattering. In case of aerial photography, special filters are used to filter out the scattered blue radiation due to haze present in the atmosphere.

Mie scattering may or may not be strongly wavelength dependent. In remote sensing, Mie scattering usually manifests itself as a general deterioration of multispectral images across the optical spectrum under conditions of heavy atmospheric haze.

Non-selective scattering usually results when the atmosphere is heavily dust and moisture laden. However, the occurrence of this scattering mechanism is frequently a clue to the existence of large particulate matter

in the atmosphere above the scene of interest, and sometimes this itself becomes useful data.

As a whole the scattering of electromagnetic radiation by the atmospheric constituents degrades the quality of the directed signals.

Atmospheric constituents such as water vapour, carbon-dioxide and ozone primarily absorb certain specific wavelength region of the EMR spectrum. So, those wavelength regions are not available for remote sensing. These regions are called atmospheric absorption bands. However atmospheric bands in between separated by absorption bands referred to as atmospheric windows or atmospheric transmission bands which can penetrates the atmosphere without being absorbed are available for remote sensing.



CHECK YOUR PROGRESS

Q.11: What is elastic scattering?

.....

.....

Q.12: Why the sky appears blue in colour?

.....

.....

Q.13: What are the results of Non-selective scattering?

.....

.....

1.8 SPECTRAL SIGNATURE

Reflectance characteristics: The reflectance characteristics of an object depends on surface roughness, physical and chemical state of the material, angle of incidence, refractive index etc. The greater the ability of a substance to absorb, the higher is its reflectivity and lower is its transmission.

We all know that all objects on the earth vary in their appearance, composition, form and other visible and invisible properties. These characteristics allow us to differentiate them. These characteristics include size, shape, pattern, tone, association, and texture. Different features on the surface of the earth have different ***reflectance characteristics*** of electromagnetic waves. Electromagnetic radiation which is not absorbed or scattered in the atmosphere can reach and interact with the earth's surface, which leads to absorption, transmission, reflection or emission of

energy in various ways. In other words, the objects responses to the energy they receive are not uniform. The radiation reflected as a function of the wavelength is called spectral signature of the surface. Spectral signature is related to object's albedo characteristics. Albedo is the reflected portion of energy from the objects on earth's surface. The albedo of snow is higher than water bodies. Snows albedo is 95% whereas water's albedo is only 10%. Objects with high albedo are brighter and those with low albedo are darker. False colour images also provide a way to determine the spectral signature.

A particular object responds differently to the energy it receives in different regions of the spectrum. The spectral reflectance signatures of different earth features are different at different wavelength zones. For example, a fresh water body absorbs more energy in the red and infrared regions of the spectrum and appears dark or black in colour in a satellite image. On the other hand, turbid water body reflects more in blue and green regions of spectrum and appears in light tone.



CHECK YOUR PROGRESS

Q.14: What do you mean by Albedo?

.....

.....

Q.15: Write three fundamental energy interactions when EMR energy is incident on earth surface features.

.....

.....



1.9 LET US SUM UP

- Remote sensing is mainly used to identify the earth features by detecting the characteristic of electromagnetic radiation that reflected, emitted or scattered by the earth surface.
- The process of remote sensing involves source of energy, transmission of energy, interaction of energy with the earth surface

features, detection of the reflected or emitted energy by the sensor, conversion of energy received into photographic or digital form of data and conversion of information into map or tabular forms.

- The visual characteristics, which include size, shape, pattern, tone, association, and texture of the features of the earth surface are analysed in remote sensing technology.
- The entire Electromagnetic Spectrum (EMS) is divided into different regions depending on the size of the waves and frequency.
- Scattering of EMR is divided into two types namely, elastic and inelastic scattering.
- Elastic scattering is divided into Rayleigh scattering, Mie scattering and non-selective scattering.
- Rayleigh scattering causes the sky to appear blue.
- Mie scattering may or may not be strongly dependent on wavelength.
- Non-selective scattering usually results when the atmosphere is heavily dust and moisture laden.



1.10 FURTHER READINGS

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1.11 ANSWERS TO CHECK YOUR PROGRESS

Q. No.1: Since 1960s

Q. No.2: Signal, Sensor and Sensing

Q. No.3: The processes involves (a) Source of energy (sun/ self emission) (b) Transmission of energy (c) Interaction of energy with the earth surface features (d) Propagation of reflected/emitted energy through atmosphere (e) Detection of the reflected/emitted energy by the sensor (f) Conversion of energy received into photographic/digital form of data, and (g) Conversion of information into Map/tabular forms.

Q. No.4: a) True b) False c) True.

Q. No.5: The main principle of remote sensing is making inferences about material objects from measurements made at a distance without coming into physical contact with the objects under study.

Q. No.6: Since 1st September 2008 NRSC (National Remote Sensing Centre), a centre under DOS (Department of Space)/ ISRO (Indian Space Research Organization) Carrying out the satellite remote sensing activities in India

Q. No.7: Dakota, Avro, Cessna, Canberra are the types of aircrafts generally used for aerial photography in India.

Q. No.8: Electromagnetic Radiation

Q. No.9: The electromagnetic spectrum ranges from the shorter wavelengths including gamma and x-rays to the longer wave lengths including microwaves and broadcast radio waves.

Q. No.10: The wave length of X-ray region is 0.03-3.0 μm.

Q. No.11: In elastic scattering, the energy of radiation is not changed due to scattering.

Q. No.12: Rayleigh scattering causes the sky to appear blue.

Q. No.13: Non-selective scattering usually results when the atmosphere is heavily dust and moisture laden. The occurrence of this scattering gives clue to the existence of large particulate matter in the atmosphere above the scene of interest, and sometimes this itself becomes useful data.

Q. No.14: Albedo is the reflected portion of energy from the objects on earth's surface. Objects with high albedo are brighter and those with low albedo are darker.

Q. No.15: Electromagnetic radiation which reaches and interacts with the earth's surface leads to absorption, transmission, reflection or emission.



1.12 MODEL QUESTIONS

VERY SHORT ANSWER QUESTIONS

Q.1: What is RADAR?

Q.2: What is the full form of DOS?

Q.3: What is the full form of ISRO?

SHORT ANSWER QUESTIONS

Q.1: Give the definition of Remote Sensing

Q.2: What are the main advantages of Remote Sensing over conventional survey?

Q.3: What is the various types of Remote Sensing Sensors?

Q.4: What do you understand by EMR?

Q.5: What do you understand by the Visible Region of EMR?

Q.6: What do you understand by Spectral Signature?

Q.7: Which are the main visual characteristics of various objects of the earth?

LONG ANSWER QUESTIONS

Q.1: Write the historical development of Remote Sensing Technology

Q.2: Write a brief essay on the development of Remote Sensing in India

Q.3: Discuss the processes involve in collection of information in Remote Sensing.

Q.4: Write a brief essay on the characteristics of the Spectral Regions of electromagnetic spectrum.

*** *** ***

UNIT- 2: REMOTE SENSING PLATFORMS AND SENSORS

UNIT STRUCTURE

2.1 Learning Objectives

2.2 Introduction

2.3 Remote Sensing Platforms

2.4 Remote Sensing Sensors

2.5 History of Space Imaging

2.6 Types of Satellites

2.6.1 Meteorological Satellites

2.7 Remote Sensing in India

2.7.1 India's Remote Sensing Programme

2.7.2 Future Missions

2.8 Let us Sum up

2.9 Further readings

2.10 Answers to check your progress

2.11 Model Questions

2.1 LEARNING OBJECTIVES

After reading this unit, you will be able to-

- describe about remote sensing platform and sensor
- discuss the history of space imagery
- list out the types of satellite
- explain the development of remote sensing in India

2.2 INTRODUCTION

In the previous unit you were introduced to the basic concept of remote sensing. In remote sensing, the type of platform to be used is very important that depends on the purpose of acquiring data. In this unit we are

discussing the meaning and types of platforms and the types of data products generated from these platforms. Remote sensing sensors are also provided in this unit. Historical development of remote sensing in India and the future missions are also the important aspects to be covered in this unit. The types of satellites, their characteristics and their benefits are also to be discussed in this unit. It will also cover the overview of various satellites launched by India and their important features of data products.

2.3 REMOTE SENSING PLATFORMS

For collection of remotely sensed data, the first requirements are the platform and a sensor. Remote Sensing platform means the base where sensors are mounted, it may be moving or stationary. It may range from a simple tripod to balloons, rockets, helicopters, drones, aircrafts and spacecrafts. The choice of a particular platform is guided by the choice of sensor.

There are three main types of platforms used in remote sensing wherefrom information on earth's surface features are recorded or transmitted to the earth receiving stations for their analysis and interpretation. These platforms are-

(1) Ground borne
(2) Air borne and
(3) Space borne

(1) Ground borne platform:

Ground borne platforms are necessary to develop the scientific understanding on the single object and signal-sensor interactions. Important ground observation platforms include- handheld platform, cherry picker, towers and portable masts. Portable handheld photographic cameras and spectro-radiometers are used for laboratory and field experiments to collect the ground truth. In cherry pickers, automatic recording sensors can be placed at a height of about 15 m from the ground. Towers can be raised from placing

sensors at a great height for observation. Portable masts mounted on vehicles can be used to support cameras and other sensors.

(2) Airborne platform:

When observation platforms are placed on balloons, aircrafts or high altitude sounding rockets, such platforms are called airborne platform. Drone is also used as airborne platform which is a remotely piloted vehicle looks like a miniature aircraft. Balloons and aircrafts used for remote sensing purpose are of different types. Different aircrafts have different ceiling height, speed and area coverage. High altitude sounding rocket can provide synoptic imageries for areas of some 500,000 sq km per frame. Such high altitude sounding rocket is fired from a mobile launcher. During the flight its sensors are held in a stable altitude by an automatic control system. The Skylark Earth Resource Rocket is an example of this type of platform.

(3) Space borne platform:

It is the platform where sensor is placed on artificial satellite. Platforms in space are not affected by atmosphere and hence the orbits can be defined. It provides synoptic view i.e. observation of large area in a single image, and systematic and repetitive coverage. The ceiling heights of the space borne platforms of different series of satellites are between 220 km in case of shuttle to 30,000 km for geostationary. There are two types of satellite platforms namely (i) Manned satellite platform and (ii) Unmanned satellite platform. In the manned satellites, crew operates the sensors as per the programme schedules. Some manned satellite programmes of NASA are Mercury, Gemini, Apollo, Skylab, International Space Station etc.

On the other hand, unmanned satellite includes LANDSAT series, SPOT series, IRS series, NOAA series, INSAT series and entire constellation of the GPS satellites.



CHECK YOUR PROGRESS

Q.1: What are the types of Remote Sensing Platforms?

.....

.....

Q.2: What is the use of Drone in remote sensing?

.....

.....

2.4 REMOTE SENSING SENSORS

Remote sensing sensors employed on earth observation platforms and designed to record radiations in one or more parts of the electromagnetic spectrum. Sensors are electronic instruments that receive electromagnetic radiation and generate an electric signal that correspond to the energy variation of different earth surface features. The signal can be recorded and displayed as numerical data or an image.

There are basically two kinds of sensors- (i) image forming and (ii) non-image forming. Within the image forming sensors there are two types- active sensor and passive sensor. Passive sensors gather radiation that is emitted or reflected by the object or surrounding areas. Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, infrared, charge-coupled devices and radiometers. Active sensors create their own radiation to illuminate the target whereas passive sensors rely on naturally occurring radiation. When remote sensing is done using sensors that have their own source of electromagnetic radiation of specific wavelengths to illuminate the terrain, it is called active remote sensing sensors. Examples of such sensors are RADAR (Radio Detecting and Ranging) or LiDAR (Light Detection and Ranging).

The sensors mounted on a platform receive spectral signatures from the earth's surface features, pixel wise, in a number of spectral bands. These data are stored as latent image on photographic films or stored on

magnetic tape in digitized form. After completion of the mission these data are physically brought to the laboratory where images are processed. This method of data transmission is not possible from an unmanned space-borne platform i.e. from the satellites, which are continuously remaining in space for many years. In such case radio/microwave communication provides a link between the sensors on satellites and the data receiving stations on ground.

However the radio or microwave transmission of data may be made in real time or it may be delayed until the ground receiving station come within the data transmission and reception range of the revolving satellites. For such delay in transmission of data, an onboard data storage facility is required. Before transmitting, in the satellite platform itself the imagery is scanned by various processes to organize the information in a series of similarity or its equivalent digital form.

When the remote sensing data are conveyed by radio link to the ground receiving station, the reception begins with a large high-gain antenna, thereby maximizing the signal power level from the remote satellite.

At present, there is limited number of ground receiving stations. These are found to be inadequate to handle the high volume of image data transmitted from a large number of satellites launched by the countries like USA, Russia, France, India, Canada, China, Japan and many other countries. To avoid large volume of on-board data storage facilities, the USA has launched the Tracking and Data Relay Satellites (TDRS). These satellites are placed in geo-stationary orbits to receive data directly from remote sensing satellites and transmit them to the TDRS ground receiving stations. These TDRS relay the image data via a Domestic Communication Satellite (DOMSAT) to different centres where satellite data convert into master film negatives, computer compatible tapes or other data products for distribution to users. Although at present requisite number of TDRS platforms are not there, efforts have been made to increase the number of TDRS so that all remote sensing satellite data could be acquired on a worldwide basis.



CHECK YOUR PROGRESS

Q.3: Define a sensor.

.....

.....

Q.4: What are the two types of remote sensing sensors?

.....

.....

2.5 HISTORY OF SPACE IMAGING

In the year 1891, a patent was granted for an apparatus to Ludwig Rahrmann of Germany for a "New or Improved Apparatus for Obtaining Bird's Eye Photographic Views". The apparatus was a rocket–propelled camera system that was recovered by parachute. In 1907, another German, Alfred Maul added the concept of gyro stabilisation to rocket-camera systems and in 1912 he successfully boosted a 200x250 mm format camera to a height of 790 m. During the period 1946 to 1950 small cameras were carried aboard captured V-2 rockets that were fired from the White Sands Proving Ground in New Mexico. In the succeeding years numerous flights involving photography were made by rockets, ballistic missiles, satellites, and manned spacecrafts. The photographic procedure during the early space flights was of inferior quality. However the US military space imaging reconnaissance programme, called Corona started in 1960, which went through many development phases.

A real breakthrough in the field of satellite remote sensing was achieved with the launching of a series of resource satellites called Landsat by NASA (National Aeronautical and Space Administration), USA. It was began with the satellites Landsat-1 in 1972 followed by Landsat-2 (1975), Landsat-3 (1978), Landsat-4 (1982), Landsat-5 (1984), Landsat-6 (1993, aborted) and Landsat-7 (1999). Later, a number of high resolution satellites like French satellite SPOT of 10m resolution or the American satellite IKONOS of 1m resolution are now available for remote sensing activities.

The New Millennium Programme (NMP), managed by NASA's Goddard Space Centre is aimed at developing and demonstrating new technologies to ensure the continuity of data collection to compare Landsat data.

An earth observation satellite programme SPOT (System Pour l'Observation de la Terre) was initiated by the French government, in which, later Sweden and Belgium joined hands in the year 1978. The first satellite in the programme, SPOT-1 was launched in 1986, followed by SPOT-2 in1990, SPOT-3 in 1993, SPOT-4 in 1998 and so on.

Russia launched a series of satellites with the first one RESURS-01 satellite in 1985. This was followed by the second one launched in 1988. This system remains operational for seven years. The third satellite in this series became operational since 1994. The ADEOS (Advanced Earth Observing Satellite) launched by Japan in1996 carried two primary sensing systems: the Advanced Visible and Near Infrared Radiometer (AVNIR) and the Ocean Color and Temperature Sensor (OCTS).

Indian space programme was started with launching of Aryabhatta in the year 1975 which was an experimental satellite. It was followed by several other satellites like Rohini (1976), STEP, BHASKARA (1979) and APPLE (1981). The first Indian remote sensing satellite IRS-1A was launched on March 17, 1988. This was followed by IRS-1B, IRS-1C, IRS-1D, IRS-P6, Cartosat etc. and many are in pipeline.



CHECK YOUR PROGRESS

Q.5: In which year NASA launched remote sensing satellite in the orbit for the first time?

.....

.....

Q.6: Which country launched the SPOT series of satellites?

.....

.....

Q.7: What are the two primary sensing systems carried by Advanced Earth Observing Satellite?

.....

.....

.....

.....

Q.8: In which year the first Indian remote sensing satellite IRS-1A was launched?

.....

.....

.....

.....

2.6 TYPES OF SATELLITES

The types of satellites used for remote sensing could be divided into two—

(i) Geo-stationary or communication satellite: This type of satellite is stationary with respect to a given position of the earth. As such its velocity is very high to keep its position over a fixed point of the rotating earth. In other words, its velocity is equal to the velocity with which earth rotates about its axis. Its orbit is fixed with reference to particular latitude on earth. Generally, this type of satellite is placed at very high altitude (approx. 36,000 km) from the earth surface e.g. INSAT. This type of satellite is used for communication and meteorological purposes.

(ii) Sun synchronous or polar orbiting or remote sensing satellite: The sun synchronous means that the satellite's orbital plane always remains at the same angle relative to the sun-earth line during all seasons. In other words its orbit defined by its fixed inclination angle from the earth's north- south axis. This enables the satellite to cross the given latitude at the same local time. Generally, these satellites are placed at low altitude between 700km to 1500km. Such satellite covers the entire earth at the same equator crossing time.

2.6.1 Meteorological Satellites

The Meteorological satellite is a type of satellite that is primarily used to monitor the weather and climate of the earth. Satellites can be polar orbiting, covering the entire Earth asynchronously, or geostationary, covering over the same spot on the equator.

Meteorological satellites see more than clouds and cloud systems. City lights, fires, effects of pollution, auroras, sand and dust storms, snow cover, ice mapping, ocean currents, energy flows, etc., and other types of environmental information are collected using such satellites. Weather satellite images helped in monitoring the volcanic ash, smoke from fires etc.

It is to be mentioned that some other environmental satellites can detect changes in the earth's vegetation, ocean color, and ice fields. For example, the 2002 Prestige oil spill off the northwest coast of Spain was watched carefully by the European ENVISAT, which, though not a weather satellite, flies an instrument (ASAR) which can see changes in the sea surface.

The first weather satellite, Vanguard 2, was launched on February 17, 1959. It was designed to measure cloud cover and resistance, but a poor axis of rotation and its elliptical orbit kept it from collecting a notable amount of useful data. The Explorer VI and VII satellites also contained weather-related experiments.

The first weather satellite to be considered a success was TIROS-1, launched by NASA on April 1, 1960. TIROS operated for 78 days and proved to be much more successful than Vanguard 2.

Geostationary weather satellites orbit the earth above the equator at altitudes of 35,880 km (22,300 miles). Because of this orbit, they remain stationary with respect to the rotating earth and thus can record or transmit images of the entire hemisphere below continuously with their visible-light and infrared sensors. The news media use the geostationary photos in their daily weather presentation as single images or made into movie loops.



CHECK YOUR PROGRESS

Q.9: When NASA launched the first weather satellite TIROS- 1?

.....

.....

Q.10: What do you understand by Geo-stationery satellite?

.....

.....

Q. 11: What is meteorological satellite?

.....

.....

2.7 REMOTE SENSING IN INDIA

2.7.1 India's Remote Sensing Programme

India launched two satellites namely Bhaskara 1 and Bhaskara 2 in 1979 and 1981 respectively to support the national economy in the areas of agriculture, water resources, forestry and ecology, geology, watersheds, marine fisheries and coastal management. A moderate resolution satellite system, the IRS (Indian Remote Sensing) programme began with the launch of IRS-1A in the year 1988. It was followed by IRS-1B in 1991, IRS-1C in 1995 and IRS-1D in 1997. The Indian Remote Sensing Satellites are the main-stay of National Natural Resources Management System (NNRMS), for which Department of Space (DOS) is the nodal agency. Data from IRS satellites is received and distributed to several countries all over the world.

Remote sensing applications in the country, under the umbrella of NNRMS, now cover diverse fields such as crop acreage and yield estimation, draught warning and assessment, water resource management, under-ground water exploration, prediction of snow-melt run-off, management of watersheds and command areas,

fisheries development, under development, mineral prospective, and forest resource survey. Besides, IRS-P1 in 1993, IRS-P2 in 1994, IRS-P3 in 1996, IRS-P4 (Oceansat) in 1999, IRS - P6 (Resourcesat) in 2003 were launched by India. At present the Indian Remote Sensing satellite system becomes one of the largest constellations of remote sensing satellites in operation in the world. Resourcesat - 2, Cartosat - 2B, Oceansat - 2, Risat - 2, Cartosat - 2A, IMS - 1, Cartosat - 2, Cartosat - 1,Resourcesat-1 and TES satellites of India are currently in operation state in addition to the IRS satellites. INSAT-3A and SARAL, are some of the recent additions of successful satellite missions of the country. With these it is expected that the thematic series of satellites in the coming years, such as Cartosat-3, Megha Tropiques, and Insat-3D will continue to provide enormous data in several areas spanning from cartography to climate related issues. India's Remote Sensing Satellites-

Satellites of the past are–

- Aryabhata, 1975
- Bhaskara I, 1979
- Bhaskara II, 1981
- Rohini Series, 1980-83
- SROSS Series, 1985-92
- IRS-1A, 1988
- IRS-P1, 1993

Presently working Satellites–

- IRS-1B, 1991
- IRS-P2, 1994
- IRS-1C, 1995
- IRS-P3, 1996
- IRS-1D, 1997
- IRS-P4, 1999 (Oceansat)
- IRS-P6, 2003 (Resourcesat-1)
- IRS-P5, 2005 (Cartosat-1)

- IRS-P7, 2007 (Cartosat-2)
- IRS-P6, 2011 (Resourcesat-2)
- RISAT-1, 2012 (RISAT-1)

2.7.2 Future Missions

Future Missions of India, ISRO is now getting ready to launch Indian Regional Navigation Satellite System or IRNSS for our mobile phones to replace GPS. All the seven satellites of Indian Regional Navigation Satellite System (IRNSS) are expected to be in orbit by March 2016. India has launched 81 Indian satellites (as of 20 January 2016) of many types since its first in 1975. Following are the remote sensing satellites planned by ISRO to be launched next strengthening the fleet of IRS satellites and widening their applications:

- **RESOURCESAT-3**: A follow on to Resourcesat-2, it will carry more advanced LISS-III-WS (Wide Swath) Sensor having similar swath and revisit capability as Advanced Wide Field Sensor (AWiFS), thus overcoming any spatial resolution limitation of AWiFS. Satellite would also carry Atmospheric Correction Sensor (ACS) for quantitative interpretation and geophysical parameter retrieval. It slated to be launched during 2021.
- **CARTOSAT-3**: A continuation of Cartosat series, it will have a resolution 30 cm and 6 km swath suitable for cadastre and infrastructure mapping and analysis. It would also enhance disaster monitoring and damage assessment. It is slated to be launched during 2018.



CHECK YOUR PROGRESS

Q.12: What is the full form of NNRMS?

.....

Q.13: What is the full form of IRNSS?

.....



2.8 LET US SUM UP

- The three main types of platforms used in remote sensing are Ground borne, Air borne and Space borne.
- Two types of satellite platforms are manned satellite platform and unmanned satellite platform.
- All sensors employed on earth observation platforms use electromagnetic radiation (EMR) to observe the land features.
- Though the real breakthrough in satellite remote sensing data generation is the Landsat series of satellites launched by the USA, the contribution of the satellites like SPOT, IRS, MODIS, TERRA, IKONOS, QuickBird, ERS series etc. launched by different countries is tremendous for difference in data quality.
- There are basically two types of sensors namely image forming and non-image forming.
- Image forming sensors are of two types- active sensor and passive sensor.
- Examples of passive remote sensors include film photography, infrared, charge-coupled devices and radiometers.
- Examples of active remote sensors are RADAR (Radio Detecting and Ranging) or LiDAR (Light Detection and Ranging).
- Two types of remote sensing satellite are Geo-stationary or communication satellite. And Sun synchronous or polar orbiting or remote sensing satellite.
- The Meteorological satellite is a type of satellite that is primarily used to monitor the weather and climate of the earth.
- Since 1975 India has launched as many as 81 Indian satellites up to January 20, 2016 through which huge amount of data have been generated so far.



2.9 FURTHER READINGS

1) Bansal, V. K. 2013, Encyclopedia of Remote Sensing; Principles and Techniques, Vol-1 & 2, ALP Books, Daryaganj, New Delhi

2) Campbell, J. B., 2006 Introduction to Remote Sensing, Taylor & Francis Group, London

3) Joseph G, 2003, Fundamentals of Remote Sensing, Universities Press, Hyderabad, India

4) Konecny, G. 2003, Geoinformation- Remote Sensing, Photogrammetry and GIS, Taylor and Francis, London

5) Lillesand M. Thomas & Kiefer W. Ralph 2000, Remote Sensing and Image Interpretation, John Wiley & Sons, Inc. New York

6) Sabins, F. F. 2000, Remote Sensing Principles and Interpretations, W. H. Freeman and Company, New York



2.10 ANSWERS TO CHECK YOUR PROGRESS

Q. No.1:

(1) Ground borne

(2) Air borne and

(3) Space borne

Q. No.2: Drone is airborne platform used for remote sensing purpose. It is a remotely piloted vehicle looks like a miniature aircraft.

Q. No.3: A sensor is a device comprising of optical component or system and a detector with electronic circuitry.

Q. No.4: Two types of remote sensing sensors are image forming sensor and non-image forming sensor

Q. No.5: Landsat-1 in 1972

Q. No.6: France

Q. No.7: Two primary sensing systems are the Advanced Visible and Near Infrared Radiometer (AVNIR) and the Ocean Color and Temperature Sensor (OCTS).

Q. No.8: March 17, 1988

Q. No.9: On April 1, 1960.

Q. No.10: Geo-stationary satellite is the type of satellite remains stationary with respect to a given position of the earth. In other words, its velocity is equal to the velocity with which earth rotates about its axis. Its orbit is fixed with reference to particular latitude on earth. Generally, this type of satellite is placed at very high altitude (approx. 36,000 km) from the earth surface e.g. INSAT.

Q. No.11: The Meteorological satellite is a type of satellite that is primarily used to monitor the weather and climate of the earth.

Q. No.12: National Natural Resources Management System.

Q. No.13: Indian Regional Navigation Satellite System.



2.11 MODEL QUESTIONS

VERY SHORT ANSWER QUESTIONS

Q1 What is TDRS?

Q2 What role plays by DOMSAT?

Q3 In which year the India's space programme was started by launching Aryabhatta?

SHORT ANSWER QUESTIONS

Q1 Write briefly on the difference between Airborne and Space borne platforms

Q2 Write briefly on the difference between image forming and no-image forming sensors

Q3 Give a brief note on Spectral Signature

Q4 Write briefly on the difference between the Geo-stationery and Sun-synchronous satellites

Q5 Write a brief note on India's future missions on satellite remote sensing

Q6 Give a brief note on the United States Landsat programme

Q7 Give an explanatory note on QuickBird

LONG ANSWER QUESTIONS

Q1 Discuss the characteristics of different platforms used in collecting the remotely sensed data

Q2 Write the difference between the manned and unmanned satellite platforms with suitable examples

Q3 Write a historical note on the development of Satellite Remote Sensing

Q4 Discuss how the satellite remote sensing was developed in India

Q5 Write an essay on the important characteristics of satellite data generated by different countries.

*** *** ***

UNIT- 3: REMOTE SENSING DATA PRODUCTS

UNIT STRUCTURE

3.1 Learning Objectives

3.2 Introduction

3.3 Data Products

3.4 Data characteristics

3.5 Overview of imageries from various satellites

3.6 Procuring Remote Sensing Data

3.7 Let us Sum up

3.8 Further Readings

3.9 Answers to check your progress

3.10 Model Questions

3.1 LEARNING OBJECTIVES

After reading this unit, you will be able to-

- explain various data products used in geoinformatics
- describe the different characteristics of remote sensing data in terms of different types of resolutions.
- illustrate about different satellite systems operational at present.
- discuss how these data can be procured or collected.

3.2 INTRODUCTION

In the previous unit you have gone through remote sensing platforms and sensors. This unit focuses on different types of resolutions of remote sensing data. In this unit you are going to learn about different satellite systems and their sensors which are available at present. You will also learn about different online and offline platforms from where different types of remote sensing data products can be procured for different applications.

3.3 DATA PRODUCTS

The first step for starting any geoinformatics related project is to procure remote sensing data. There are two types of data used in geoinformatics. One is raster data and the other is vector data. In its simplest form, a raster data means data consisting of a matrix of cells or pixels organized into rows and columns (or in grids) where each cell contains a value representing information, such as reflected electromagnetic radiation (EMR), temperature, or height values. Raster data products include digital aerial photographs, imagery from satellites, digital pictures, or even scanned maps. These data can procured either by purchasing from the respective agencies by placing an order in their prescribed format (indent) when these are to be purchased, or some of the data can downloaded free of cost from the web portal of data providers.

The data from various sensors are presented in a form and format with specified radiometric and geometric accuracy which can be readily used by various application scientists for specific themes of their interest. Remote sensing data can be procured by a number of users for various applications and information extraction, in the form of a ***'data product'***. Data Products are data from various sensors in a suitable and standard form and format, which can be readily used by user. This may be in the form of photographic output for visual processing or in a digital format amenable for further computer processing. There are varieties of remote sensing data which are acquired by different sensors and satellites. Before reaching to users, the data undergo some processing steps. Requirements of users may vary depending upon their interests and the targeted project objectives. Hence, there are various remote sensing data providers which prepare variety of data products in different formats.

The user should be aware of the types of data products available with the data agencies before ordering it. Once the data are received by the users, these need to be prepared into a form required to perform image analysis task. To convert the data into required form, the users should have basic understanding of the characteristics of different data formats. There

are some standards which are followed by data centers with regard to the data products and formats for sharing with a variety of users.

Remote sensing data products are generated in certain **'data formats'** for various practical reasons. Pre-processed remote sensing data are generated into a number of products such as hardcopy print and digital print on various storage devices. If the data product is in hard copy print then it is impossible to carry out any further processing or conversion before use. But if the product is in digital form, it may be possible to convert the data into required digital format. It may be further required to carry out certain tasks like radiometric and geometric corrections, image enhancements before any image analysis operation is performed. Types of data products may vary from country to country and from one data provider to another.

INDEX NUMBERS FOR DATA PRODUCTS

All remote sensing data products carry a specific index number. This index number is generated using the satellite path which runs from North Pole to South Pole of Earth. This pole to pole coverage on the Earth for each pass of the satellite is given a specific number, called **path number** or **track number**. In case of coverage of India, path numbers range from 88 to 116 from west to east for LISS sensor of IRS (Indian Remote Sensing) satellites. These paths are nothing but orbital tracks of a satellite which at a small angle from geographical north-south, and are somewhat parallel to each other. East-West lines (called row) cut across these lines giving a grid like structure. This is how a series of rectangular blocks of images are created, which may be termed as image tiles / scenes by assigning each column a specific number and each row another specific number. India is covered by rows 45 to 70 from north to south. In a similar way, the entire world is covered by paths and rows, and each grid (a scene) is identified by a specific path and row number. As the path-row for different satellites are different, the Index Number of image for an area is also different for all the satellites.



CHECK YOUR PROGRESS

Q.1: What is a data product?

.....

.....

Q.2: What is an Index Number?

.....

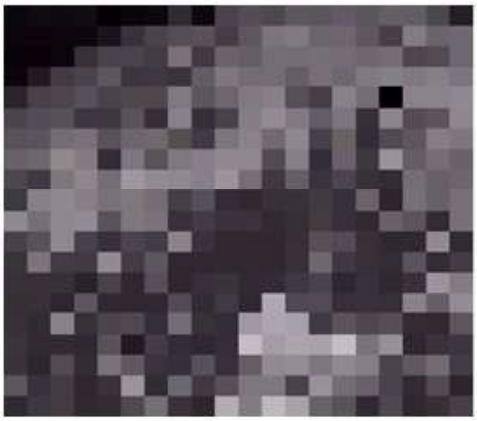
.....

3.4 DATA CHARACTERISTICS

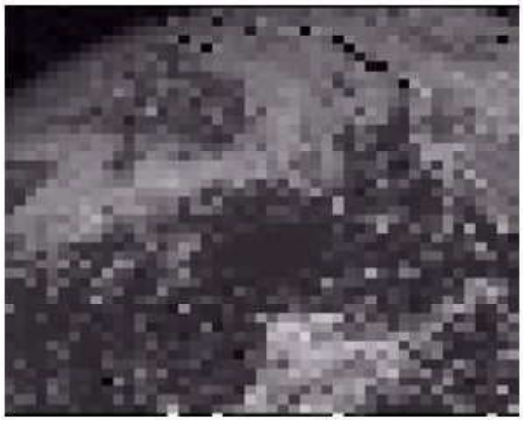
Remote-sensing data has several concrete and special characteristics. These data are multi-source, multi-scale, high-dimensional, dynamic and non-linear. The quality of remote sensing data consists of its spatial, spectral, radiometric and temporal resolutions.

Spatial Resolution

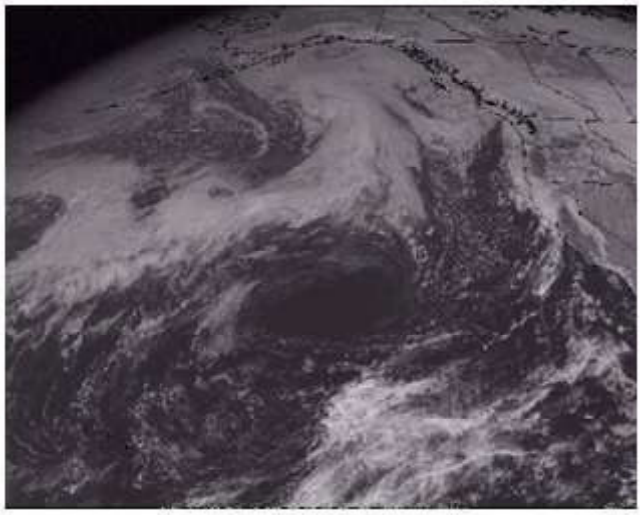
Spatial Resolution refers to the size of the smallest feature that can be detected by a satellite sensor or displayed in a satellite image. It is usually presented as a single value representing the length of one side of a square. For example, a spatial resolution of 250 m means that one pixel represents an area 250 m by 250 m on the ground.



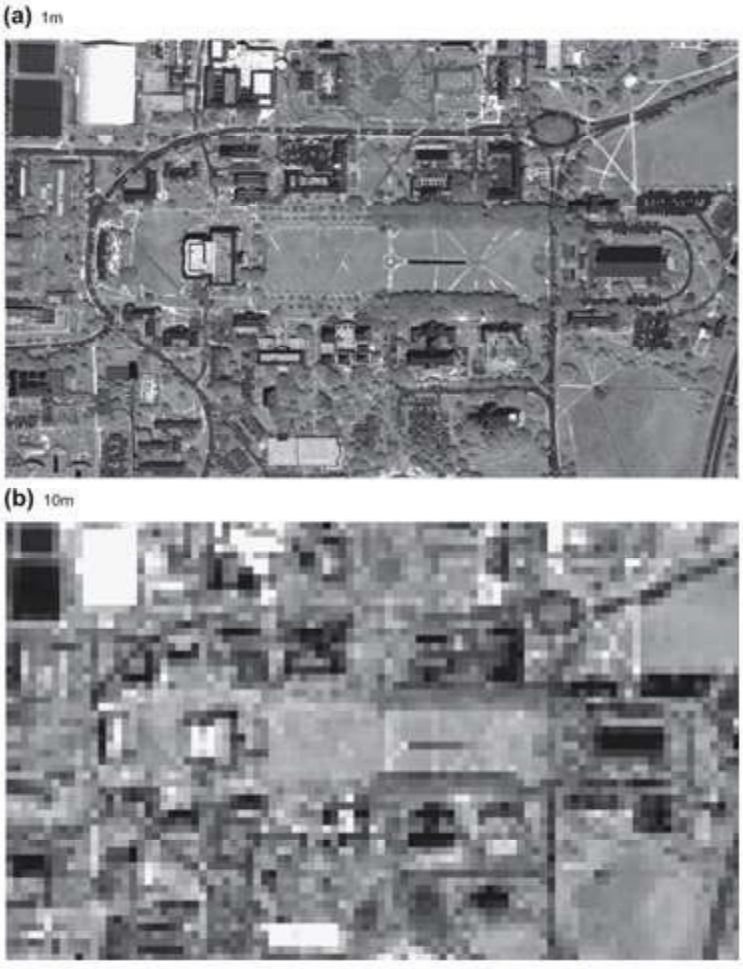
GOES visible image (400 pixels)



GOES visible image (2209 pixels)



GOES visible image (360000 pixels



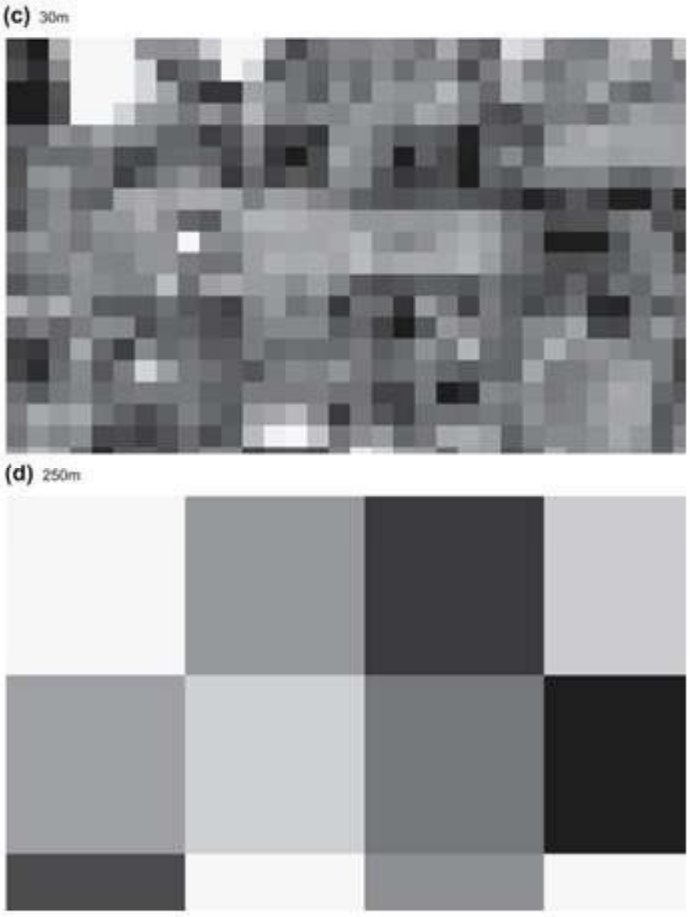


Fig 3.1 a: Spatial Resolution of 1m, b: Spatial Resolution of 10m, c: Spatial Resolution of 30m, d: Spatial Resolution of 250m

Source: Kenji Ose, Thomas Corpetti, Laurent Demagistri, "*Optical Remote Sensing of Land Surface: Techniques and Methods*", ISTE Press Ltd. 2016, Published by Elsevier Ltd, Pg. 57-124.

Spectral Resolution

Spectral Resolution denotes to the ability of a satellite sensor to measure specific wave lengths of the electromagnetic spectrum. The finer the spectral resolution, the narrower the wave length range for a particular channel or band. The spectral resolution describes the number and width of spectral bands in a sensor system. Many sensor systems have a panchromatic band, which is one single wide band in the visible spectrum, and multispectral

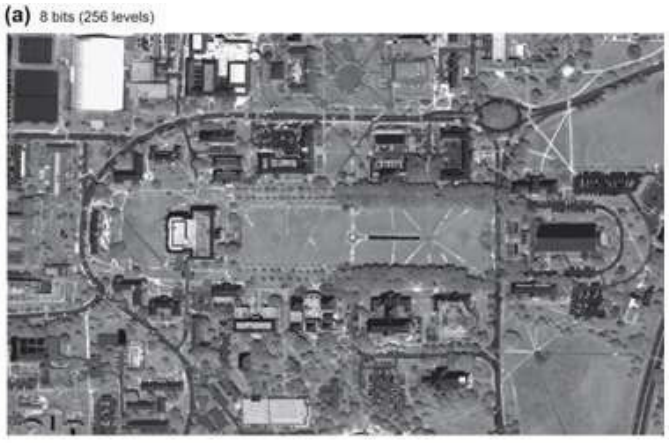
bands in the visible-near-IR or thermal-IR spectrum. Hyperspectral systems have hundreds of spectral narrow bands.

Spatial and spectral resolution are also discussed in unit 5 of this course.

Radiometric Resolution

Radiometric resolution is the ability of the sensor to detect the differences in energy. It also refers the ability of the sensor to distinguish the intensities of the grey scale values in each band. It denotes the number of different outputs in each band of data and is determined by the number of bits into which the recorded radiation is divided. In 8-bit data, the digital numbers (DN) can range from 0 to 255 for each pixel (2^8 = 256 total possible numbers). Obviously more bits results in higher radiometric accuracy of the sensor. Every time an image is acquired by a sensor, its sensitivity to the magnitude of the electromagnetic energy determines the radiometric resolution. Imagery data are represented by positive digital numbers which vary from 0 to a selected power of 2. This range corresponds to the number of bits used for coding numbers in binary format. Each bit records an exponent of power 2. The maximum number of brightness levels available depends on the number of bits used in representing the energy recorded. Thus, if a sensor used 8 bits to record the data, there would be 2^8= 256 digital values available, ranging from 0 to 255.

1	2	3	4	5	6	7	8	9	10	**Number of bits**
2	4	8	16	32	64	128	256	512	1024	**Maximum values**



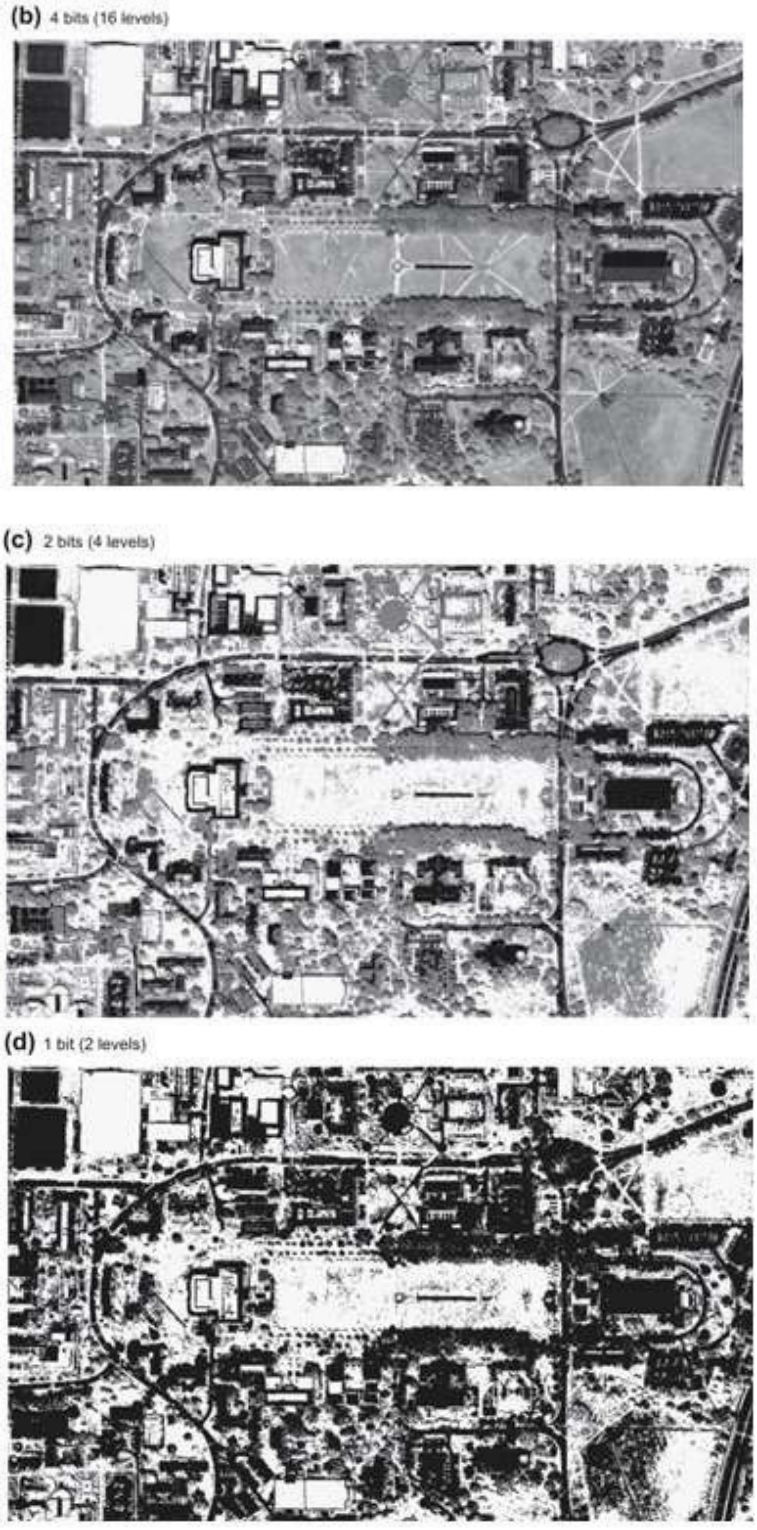


Fig 3.2 a: 8 Bits Radiometric Resolution, b: 4 Bits Radiometric Resolution, c: 2 Bits Radiometric Resolution, d: 1 Bit Radiometric Resolution
Source: Kenji Ose, Thomas Corpetti, Laurent Demagistri, "*Optical Remote Sensing of Land Surface: Techniques and Methods*", ISTE Press Ltd. 2016, Published by Elsevier Ltd, Pg. 57-124.

Temporal Resolution

Temporal resolution refers to the time between images. The capability for satellites to provide images of the same geographical area more frequently has increased dramatically since the dawn of the space age. Temporal resolution is a measure of the repeat cycle or frequency with which a sensor revisits the same part of the Earth's surface. The frequency characteristics are determined by the design of the satellite sensor and its orbit pattern.



CHECK YOUR PROGRESS

Q.3 Fill in the blanks:

a. The spectral resolution describes ____ and ____ of spectral bands in a sensor system.

b. Hyperspectral systems have _____.

3.5 OVERVIEW OF IMAGERIES FROM VARIOUS SATELLITES

Remote-sensing data are multi-source, multi-scale and dynamic. Satellite imageries and other related data are available from different sources and platforms. These platforms are acquiring and storing remotely sensed data in their archives and making it available for the entire world. Some of the most sought-after platforms are discussed in the following sections.

IRS Satellites

Indian Remote Sensing (IRS) satellite program was started to support the national economy in the areas of agriculture, water resources, forestry and ecology, geology, watersheds, marine fisheries and coastal management. The National Natural Resources Management System (NNRMS) was established for providing operational remote sensing data services. The IRS system is the largest constellation of remote sensing satellites used in operation with 11 operational satellites. All these are placed in polar Sun-synchronous orbit and provide data in a variety of spatial, spectral and temporal resolutions. Indian Remote Sensing Programme completed its 25 years of successful operations on March 17, 2013.

Table 3.1: Satellite Chronology

Serial No.	Satellite	Date of Launch	Status
1	IRS-1A	17 March 1988	Mission Completed
2	IRS-1B	29 August 1991	Mission Completed
3	IRS-P1 (also IE)	20 September 1993	Crashed, due to launch failure of PSLV
4	IRS-P2	15 October 1994	Mission Completed
5	IRS-1C	28 December 1995	Mission Completed
6	IRS-P3	21 March 1996	Mission Completed
7	IRS 1D	29 September 1997	Mission Completed
8	IRS-P4 (Oceansat-1)	27 May 1999	Mission Completed
9	Technology Experiment Satellite (TES)	22 October 2001	Mission Completed
10	IRS P6 (Resourcesat-1)	17 October 2003	In Service
11	IRS P5 (Cartosat 1)	5 May 2005	In Service
12	IRS P7 (Cartosat 2)	10 January 2007	In Service
13	Cartosat 2A	28 April 2008	In Service
14	IMS 1	28 April 2008	In Service
15	RISAT-2	20 April 2009	In Service
16	Oceansat-2	23 September 2009	In Service
17	Cartosat-2B	12 July 2010	In Service
18	Resourcesat-2	20 April 2011	In Service
19	Megha-Tropiques	12 October 2011	In Service
20	RISAT-1	26 April 2012	In Service
21	SARAL	25 Feb 2013	In Service
22	Cartosat-2C	22 June 2016	In Service
23	ScatSat-1	26 September 2016	In Service
24	RESOURCESAT-2A	07 Dec 2016	In Service
25	Cartosat-2D	15 Feb 2017	In Service
26	Cartosat-2E	23 June 2017	In Service
27	Cartosat-2F	12 Jan 2018	In Service
28	RISAT-2B	22 May 2019	In Service
29	Cartosat-3	27 Nov 2019	In Service
30	RISAT-2BR1	11 Dec 2019	In Service

Data from IRS is available to its users through NRSC Data Centre and also through Bhuvan Geoportal of ISRO. NRSC data center provides data through its purchase process while Bhuvan Geoportal provides data in free and open domain. The capacity building programme of ISRO for IRS and other remote sensing applications is through Indian Institute of Remote Sensing (IIRS) Dehradun and UN affiliated Center of Space Science and Technology Education in Asia and the Pacific (CSSTEAP) Center located at Dehradun of Uttrakhand State in India.

Following are the remote sensing satellites planned by ISRO to be launched next strengthening the fleet of IRS satellites and widening their applications.

- **RESOURCESAT-3**: A follow on to Resourcesat-2, it will carry more advanced LISS-III-WS (Wide Swath) Sensor having similar swath and revisit capability as Advanced Wide Field Sensor (AWiFS), thus overcoming any spatial resolution limitation of AWiFS. Satellite would also carry Atmospheric Correction Sensor (ACS) for quantitative interpretation and geophysical parameter retrieval. It is scheduled to be launched during 2021.
- **OCEANSAT-3**: Oceansat-3 would carry Thermal IR Sensor, 12 channel Ocean Color Monitor, Scatterometer and Passive Microwave Radiometer. IR Sensor and Ocean Color Monitor would be used in the analysis for operational Potential Fishing Zones. Satellite is mainly for Ocean biology and sea state applications. It is slated to the launched aboard PSLV in January 2020.
- **GISATs**: GISAT-1 is planned for launch in January 2020 and GISAT-2 is planned for launch in July 2020. They are expected to provide images from geostationary orbit during disasters.

LANDSAT

The Landsat program is the longest-running initiative for acquirement of satellite imagery of Earth. On July 23, 1972 the Earth Resources Technology Satellite was launched which renamed to Landsat-1. The most recent, Landsat 8, was launched on February 11, 2013. The instruments

on the Landsat satellites have acquired millions of images. These images are a unique resource for research and applications in areas like agriculture, cartography, geology, forestry, regional planning etc. These images can be viewed through the U.S. Geological Survey (USGS) 'EarthExplorer' website.

Table 3.2: Satellite Chronology

Instrument	Launched	Status
Landsat 1	July 23, 1972	Terminated in January 6, 1978
Landsat 2	January 22, 1975	Terminated in February 25, 1982
Landsat 3	March 5, 1978	Terminated in March 31, 1983
Landsat 4	July 16, 1982	Terminated in December 14, 1993
Landsat 5	March 1, 1984	Terminated in June 5, 2013]
Landsat 6	October 5, 1993	Terminated in October 5, 1993
Landsat 7	April 15, 1999	Still active
Landsat 8	February 11, 2013	Still active
Landsat 9	January 14, 2021 (expected)	

Landsat 1 through 5 carried the Landsat Multispectral Scanner (MSS). Landsat 4 and 5 carried both the MSS and Thematic Mapper (TM) instruments. Landsat 7 uses the Enhanced Thematic Mapper Plus (ETM+) scanner. Landsat 8 uses two instruments, the Operational Land Imager (OLI) for optical bands and the Thermal Infrared Sensor (TIRS) for thermal bands.

Quick Bird

QuickBird was a high-resolution commercial Earth observation satellite, owned by DigitalGlobe, launched in 2001 and decayed in 2015. QuickBird used Ball Aerospace's Global Imaging System 2000 (BGIS 2000). The satellite collected panchromatic (black and white) imagery at 61 centimeter resolution and multispectral imagery at 2.44 m - (at 450 km elevation) to 1.63-meter (at 300 km elevation) resolution, as orbit altitude is lowered during the end of mission life.

GeoEye

GeoEye was an American commercial satellite imagery company based in Herndon, Virginia. GeoEye was merged into the Digital Globe Corporation January 29, 2013.

GeoEye-1 was launched on September 6, 2008. It provides 41-centimeter (16 in) panchromatic and 1.65-meter multispectral imagery in 15.2 km swaths. GeoEye-1 can image up to 60 degrees off nadir. It is operated out of Herndon, Virginia and was built in Arizona by General Dynamics Advanced Information Systems.

The **GeoEye-2** satellite is designed to provide panchromatic images at a highest resolution of 0.31 meters per pixel (12.2 in/px), and multispectral images at 1.24 meters per pixel (48.8 in/px).

Sentinel

Sentinel-1 is the first of the Copernicus Programme satellite constellation conducted by the European Space Agency. This mission is composed of a constellation of two satellites, Sentinel-1A and Sentinel-1B, which share the same orbital plane. They carry a C-band synthetic-aperture radar instrument which provides a collection of data in all-weather, day or night. This instrument has a spatial resolution of down to 5m and a swath of up to 400 km. The constellation is on a sun synchronous, near-polar (98.18°) orbit. The orbit has a 12-day repeat cycle and completes 175 orbits per cycle.

SPOT

SPOT is a commercial high-resolution optical imaging Earth observation satellite system operating from space. It is run by Spot Image, based in Toulouse, France. It was initiated by the French space agency in 1970 and was developed in association with the SSTC (Belgian scientific, technical and cultural services) and the Swedish National Space Board (SNSB). The SPOT system includes a series of satellites and ground control resources for satellite control and programming, image production, and distribution.

SPOT Satellites:

Since 1986 the SPOT family of satellites has been orbiting the Earth and has already taken more than 10 million high quality images.

SPOT 1 was launched with the last Ariane 1 rocket on February 22, 1986. SPOT 2 joined SPOT 1 in orbit on January 22, 1990, on the Ariane 4 maiden flight and SPOT 3 followed on September 26, 1993, also on an Ariane 4. These satellites are no longer functioning since 2009.

SPOT 4 launched March 24, 1998 and stopped functioning July, 2013.

SPOT 5 was launched on May 4, 2002. It has two high resolution geometrical (HRG) instruments.They offer a higher resolution of 2.5 to 5 meters in panchromatic mode and 10 meters in multispectral mode (20 metre on short wave infrared 1.58 – 1.75 μm).

SPOT 6 was launched by India's Polar Satellite Launch Vehicle on flight C21 at 04:23 UTC on 9 September 2012, while SPOT 7 was launched on PSLV flight C23 at 04:42 UTC on 30 June 2014. In December 2014, SPOT 7 was sold to Azerbaijan's space agency Azercosmos, who renamed it *Azersky*.

SPOT 6 and SPOT 7 are phased in the same orbit at an altitude of 694 km, forming a constellation of 2-by-2 satellites - 90° apart from one another.

Features of imageries:

- Image product resolution:
  - ▶ Panchromatic: 1.5 m
  - ▶ Colour merge: 1.5 m
  - ▶ Multi-spectral: 6 m
- Spectral bands:
  - ▶ Panchromatic (450 – 745 nm)
  - ▶ Blue (450 – 525 nm)
  - ▶ Green (530 – 590 nm)
  - ▶ Red (625 – 695 nm)
  - ▶ Near-infrared (760 – 890 nm)
- Footprint: 60 km × 60 km
- Responsive satellite tasking, with six tasking plans per day, per satellite
- Capacity to acquire up to 3 million km^2 daily



CHECK YOUR PROGRESS

Q.4: What is the purpose of the IRS satellite programme?

.....

.....

Q.5: Give five examples of IRS satellites.

.....

.....

Q.6: What are the sensors carried by Landsat 8? Mention its spatial resolution.

.....

.....

Q.7: What are the satellites in the SPOT series of satellites?

.....

.....

3.6 PROCURING REMOTE SENSING DATA

There are two ways to procure remote sensing data in India:

- by ordering online to various data providing agencies e.g. NRSC Data Centre in India, and
- by sending indents (in specified format - available on website) through post to NRSC Data Centre on the address given below:

NRSC Data Centre
National Remote Sensing Centre (ISRO)
Dept. of Space, Govt. of India
Balanagar, Hyderabad - 500 625
Andhra Pradesh, India

There are also some organizations/agencies which provide specified remote sensing data for free. To procure data from these agencies, one has to register oneself online. These registrations are completely free. Once a

person gets registered to these agencies' websites, it is easy to download after giving the required specifications. Following are such websites:

- https://earthexplorer.usgs.gov
- http://glovis.usgs.gov
- http://glcf.umiacs.umd.edu/data
- https://bhuvan.nrsc.gov.in



3.7 LET US SUM UP

- There are two types of data used in geoinformatics. One is raster data and the other is vector data
- The data from various sensors are presented in a form and format.
- Products are data from various sensors in a suitable and standard form and format.
- Remote sensing data products are generated in certain ***'data formats'*** for various practical reasons.
- All remote sensing data products carry a specific index number. This index number is generated using the satellite path which runs from North Pole to South Pole of Earth.
- Remote sensing data comprises of four important characteristics: Spatial Resolution, Spectral Resolution, Radiometric Resolution and Temporal Resolution.
- Indian Remote Sensing (IRS) satellite program was set to support the national economy in the areas of agriculture, water resources, forestry and ecology, geology, watersheds, marine fisheries and coastal management.
- The Landsat program is the longest-running initiative for acquirement of satellite imagery of Earth.
- QuickBird was a high-resolution commercial Earth observation satellite, owned by DigitalGlobe, launched in 2001 and decayed in 2015.
- GeoEye was an American commercial satellite imagery company based in Herndon, Virginia. GeoEye was merged into the Digital Globe Corporation January 29, 2013.

- Sentinel-1, the first of the Copernicus Programme satellite constellation, is composed of a constellation of two satellites, Sentinel-1A and Sentinel-1B.
- SPOT is a commercial high-resolution optical imaging Earth observation satellite system operating from space.



3.8 FURTHER READING

1) Basudeb Bhatta, *Remote Sensing and GIS*, published by Oxford University press, 2008.
2) Paul A. Longley, Michael F. Goodchild, David J. Maguire, David W. Rhind, *Geographic Information Systems and Science*, Published by Wiley, 2010.
3) Kang-Tsung Chang, *Introduction to Geographic Information System,* Published by McGraw-Hill, 2002



3.9 ANSWERS TO CHECK YOUR PROGRESS

Q. No. 1:

Data Products are data from various sensors in a suitable and standard form and format, which can be readily used by user. This may be in the form of photographic output for visual processing or in a digital format amenable for further computer processing.

Q. No. 2:

All remote sensing data products carry a specific index number. This index number is generated using the satellite path which runs from North Pole to South Pole of Earth. As the path-row for different satellites are different, the Index Number of image for an area will not be the same for all the satellites.

Q. No. 3:

a. the number and width
b. Hundreds of spectral narrow bands.

Q. No. 4:

India developed the indigenous Indian Remote Sensing (IRS) satellite program to support the national economy in the areas of agriculture, water resources, forestry and ecology, geology, water sheds, marine fisheries and coastal management

Q. No. 5:

5 examples of IRS satellites are:
IRS-1B, IRS-1C, IRS 1D, IRS P6 (Resourcesat-1) and IRS P5 (Cartosat 1).

Q. No. 6:

Landsat 8 uses two instruments: the Operational Land Imager (OLI) for optical bands and the Thermal Infrared Sensor (TIRS) for thermal bands. The spatial resolution is 30m.

Q. No. 7:
The satellites in the SPOT series are SPOT 1, SPOT 2, SPOT 3, SPOT 4, SPOT SPOT 5, SPOT 6, SPOT 7 and SPOT 8.



3.10 MODEL QUESTIONS

Q.1: How is the Index Number of a satellite image determined?
Q.2: Give a brief explanation of data product and data format.
Q.3: Explain the radiometric resolution of a sensor.
Q.4: Give a brief history of Indian Remote Sensing satellites.
Q.5: Explain the characteristics of the sensors in Landsat satellites.
Q.6: What are the satellites in the GeoEye series?

* * *

UNIT- 4: FUNDAMENTALS OF THERMAL REMOTE SENSING

UNIT STRUCTURE

4.1 Learning Objectives

4.2 Introduction

4.3 Concept of Thermal Remote Sensing

4.4 Thermal Inertia: Temperature from Radiance Value

4.5 Thermal Sensors and Scanners

4.6 Opto-mechanical CCD Arrays

4.6.1 Uncooled Infrared Detectors

4.6.2 Cooled Infrared Detectors

4.7 Application of Thermal Scanner Imagery

4.8 Application of Thermal Data

4.9 Let us Sum up

4.10 Further Reading

4.11 Answers to check your progress

4.12 Model Questions

4.1 LEARNING OBJECTIVES

After reading this unit, you will be able to:

- explain thermal remote sensing
- describe the concept of thermal inertia
- outline about the thermal sensors and scanners
- discuss about opto-mechanical CCD arrays
- get an idea on the application of thermal scanner imagery
- discuss the applications of thermal data in various fields.

4.2 INTRODUCTION

In the previous unit, we have discussed the remote sensing data products. In this unit you are going to discuss the fundamentals of thermal remote sensing. In this unit, we will also study the basic concepts of thermal remote sensing, thermal inertia and how data is acquired in these processes. This unit will also help you to learn about some common instruments or use of devices in thermal remote sensing such as thermal sensors and scanners as well as the opto-mechanical CCD arrays. Apart from the introduction, this unit will familiarize you with the applications as well the as use of thermal data in different fields.

4.3 CONCEPT OF THERMAL REMOTE SENSING

Remote sensing is the acquisition of information about an object or phenomenon of earth surface without making physical contact with the object and thus in contrast to on site observation. In the last few decades remote sensing has reached from an experimental to an operational level. Thermal remote sensing is the branch of remote sensing that deals with the acquisition, processing and interpretation of data acquired primarily in the thermal infrared (TIR) region of the electromagnetic (EM) spectrum. It is a well-known fact that all natural targets reflect as well as emit radiations. All bodies having temperature more than 0°K or -273°C (absolute zero) emit heat. In thermal remote sensing, we measure the EMR 'emitted' from the surface of the target (shown on the Figure 3.1), as opposed to optical remote sensing where we measure the radiations 'reflected' by the target under consideration.

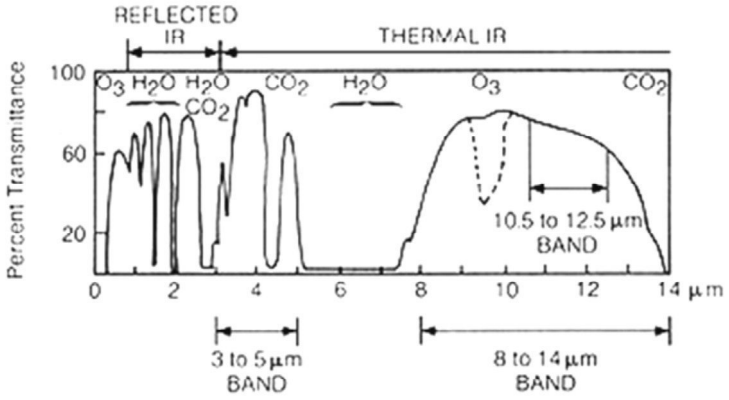


Figure 4.1: Visible and Thermal Infrared Region

CHECK YOUR PROGRESS

Q. 1: State True or False:

I. Thermal means "pertaining to heat".

II. In remote sensing we collect data by making physical contact with the object.

III. Thermal Remote Sensing is a part of remote sensing.

IV. Absolute Zero means 273°C.

Q. 2: Fill in the blanks:

I. In thermal remote sensing we measure the _____ EMR.

II. Ratio of radiant energy emitted from a real body to radiant energy emitted from a reference black body is called _____.

III. The rate at which heat is transferred within a substance through diffusion is _____.

4.4 THERMAL INERTIA: TEMPERATURE FROM RADIANCE VALUES

The primary objective of temperature measurements and related thermal response is to infer something about the nature, composition and other physical attributes of materials at the earth's surface and in its atmosphere. However, the basic thermal properties of materials are:

Black Body:
Black body is a theoretical object that absorbs and then emits all incident energy at all wavelengths.

Emissivity (ε): It is the ratio of radiant energy emitted from a real body to radiant energy emitted from a reference ***black body***.

Heat capacity (C): The amount of heat required to raise the temperature of a unit mass of substance by 1°C. It is the ability of a substance to store heat, which is highest for water (1.01).

Thermal Conductivity (K): It is the rate at which heat is transferred within a substance through conduction.

Thermal Diffusivity (Γ): It is the rate at which heat is transferred within a substance through diffusion.

Thermal Inertia (P): It is the measure of resistance offered by a substance in undergoing temperature changes. In other words, thermal inertia is the resistance of a material to temperature change, indicated by the time dependent variations in temperature during a full heating/cooling cycle (a

24-hour day for Earth); P is a measure of the heat transfer rate across a boundary between two materials. For example: air or soil. Because materials with high P possess a strong inertial resistance to temperature fluctuations at a surface boundary, they show less temperature variation per heating/ cooling cycle than those with lower thermal inertia**.** In simple words, Thermal Inertia is a measure of the responsiveness of a material to variations in temperature. In remote sensing it is measured by diurnal changes in temperature. Materials with a high heat capacity display high thermal inertia, consequently such materials will show small changes in temperature through the diurnal cycle.

The thermal inertia is the product of three factors: the energy needed to raise the temperature of a material by 1^0 C (heat capacity c) per mass unit of the substance, the density of a material p, and the thermal conductivity k, of the object.

$$I = \sqrt{c \times p \times k}$$

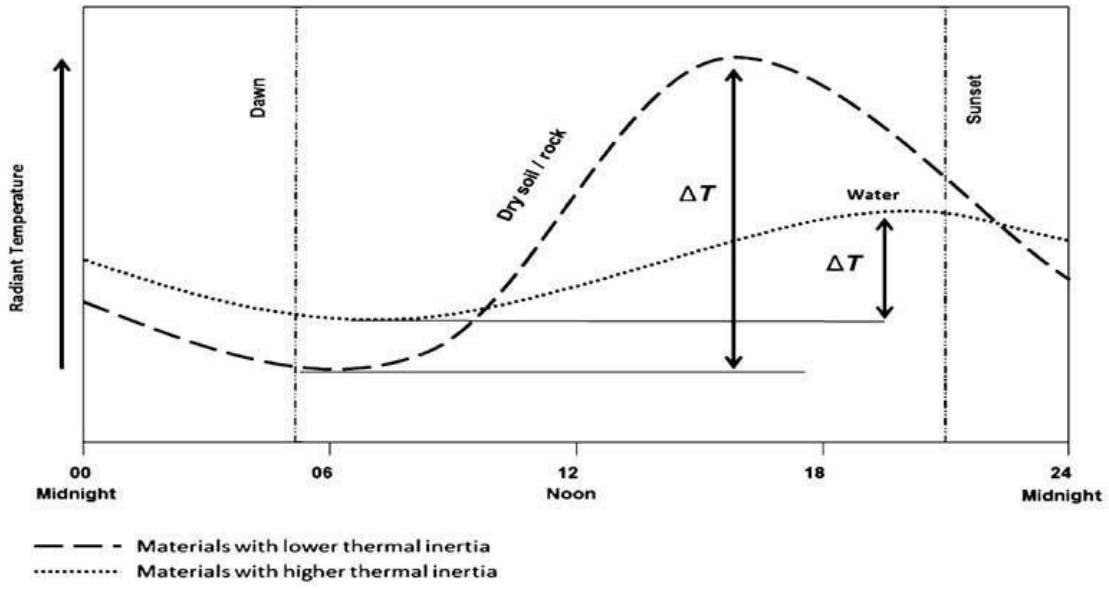


Fig. 4.2: Diurnal temperature variation of water and dry soil/rock. Each object shows a distinct diurnal temperature cycle determined by the thermal Inertia of the object and the history of the solar radiation (Modified from Lillesand et al. 2008)

In thermal remote sensing, radiations emitted by ground objects are measured for temperature estimation. Thermal remote sensing exploits the fact that everything above absolute zero (0 K or -273.15 °C or –459 °F) emits radiation in the infrared range of the electromagnetic spectrum. How much energy is radiated, and at which wavelengths, depends on the emissivity of the surface and on its kinetic temperature. Emissivity is the emitting ability of a real material compared to that of a black body, and is a spectral property that varies with composition of material and geometric configuration of the surface. Emissivity denoted by epsilon is a ratio and varies between 0 and 1. For most natural materials, it ranges between 0.7 and 0.95. Kinetic temperature is the surface temperature of a body/ground and is a measure of the amount of heat energy contained in it. It is measured in different units, such as in Kelvin (K); degrees Centigrade (°C); degrees Fahrenheit (°F).

Table 4.1: Thermal properties of various materials

Material	K $Wm^{-1}K^{-1}$	C $10^3 J kg^{-1}K^{-1}$	ρ $10^3 kg m^{-3}$	Γ $10^{-6} m^2s^{-1}$	P $1000 Js^{-1/2}m^{-2}K^{-1}$
Basalt	2.1	0.9	2.6	0.9	2.2
Clay(moist)	1.3	1.5	1.7	0.5	1.8
Concrete	0.1	3.4	2.4	0.01	0.9
Copper	400.0	0.39	8.9	120.0	37.0
Dolomite	2.0	0.75	2.6	1.0	2.0
Glass	0.8	0.6	2.3	0.6	1.1
Granite	3.0	0.8	2.7	1.4	2.5
Gravel	1.3	0.8	2.0	0.8	1.4
Gravel(sandy)	2.5	0.8	2.1	1.5	2.0
Ice	2.3	2.1	0.9	1.2	2.1
Iron	84.0	0.44	7.9	24.0	17.0
Lead	36.0	0.16	11	20.0	8.0
Limestone	0.9	0.7	2.5	0.5	1.3
Marble	2.5	0.9	2.7	1.0	2.5
Pumice (loose)	0.3	0.7	1.0	0.4	0.5
Quartz	9.0	0.7	2.6	4.9	4.0
Sand (dry)	0.4	0.8	1.6	0.3	0.7
Shale	1.9	0.7	2.3	1.2	1.7
Soil (sandy)	0.6	1.0	1.8	0.3	1.0
Steel	25.0	0.5	7.7	6.5	9.8
Water	0.56	4.2	1.0	0.13	1.5
Wood	0.15	1.2	0.7	0.2	0.4

Black body is a theoretical object that absorbs and then emits all incident energy at all wavelengths. This means that the emissivity of such an object is by definition. Needless to say, such an object is only imaginary and no natural substance is an ideal black body.

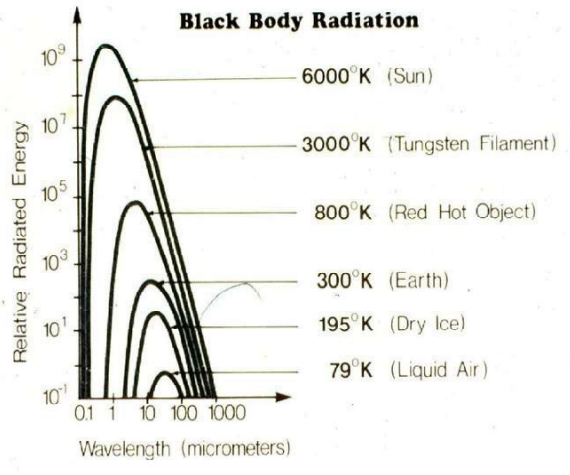


Fig. 4.3: Black body radiation of features

Factors affecting the Kinetic Temperature can be categorised in two broad groups - heat energy budget and thermal properties of the materials. Heat energy budget includes factors such as solar heating, long wave upwelling and down welling radiations, heat transfer at the earth-atmosphere interface and active thermal sources such as fires, volcanoes etc. Thermal properties of material include factors such as thermal conductivity, specific heat, density, heat capacity, thermal diffusivity and thermal inertia of the material. An excellent explanation of these factors is given by Kahle (1980).

Radiant Temperature (TR) is the actual temperature obtained in a remote sensing measurement and as mentioned earlier, depends on actual or kinetic temperature (TK) of the body and its emissivity.

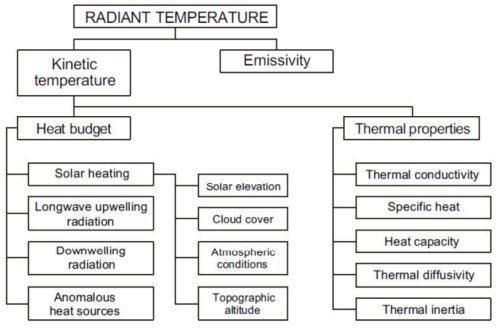


Figure 4.4: Classification of Radiant



CHECK YOUR PROGRESS

Q.No.3: What is emissitivity?

.....

.....

Q. No.4: What are the three factors whose product is equal to the thermal inertia?

.....

.....

Q. No. 5: What is radiant temperature?

.....

.....

4.5 THERMAL SENSORS AND SCANNERS

There is a large fleet of international sensors available which allow for the acquisition of data in the thermal infrared. Thermal sensors use photo detectors sensitive to the direct contact of photons on their surface, to detect emitted thermal radiation. Thermal sensors essentially measure the surface temperature and thermal properties of targets. A detailed overview of typical sensors and their characteristics (spatial resolution, revisit time, swath width, platform, agency operating the sensor and launch year) employed for the analysis of land and sea surface temperatures and related applications is given in the form of table above.

Table 4.2: List of sensors and their characteristics

Sensor	Spatial res.	Revisit	Swath width	Platform/satellite	Agency	Launch year
ETM+	60 m	16 d	185 km	Landsat-7	USGS, NASA	1999
TM	120 m	16 d	185 km	Landsat 5	USGS, NASA	1984
TIRS	100 m	16 d	185 km	Landsat 8 (LDCM)	USGS, NASA	2013
ASTER	90 m	4–16 d	60 km	Terra	NASA	1999
IRMSS	160 m	26 d	120 km	CBERS-1, 2, 2b	CRESDA, INPE	1999-2003, 2003, 2007-2010
IRSCAM	80 m	26 d	120 km	CBERS-3 and 4, 4b	CRESDA, INPE	2012, 2014, 2016
MERSI	250 m	1 d	2800 km	FY-3A, FY-3B	NRSCC, CAST, NSM a.o.	2008, 2010
Infrared Cam	300 m	31 d	720 km	HJ-1B	CRESDA, CAST, NRSCC	2008
NIRST	351 m	<1–2 d	182–1,060 km	Aquarius	NASA, CONAE	2011
BIRD	370 m	10 d	190 km	BIRD	DLR	2001-2004
TET-1	336 m	10 d	180 km	TET-1	DLR	2012
VIIRS	1.6 km	<1 d	3,000 km	Suomi NPP	NASA/NOAA	2011
CrIS	14 km	<1 d	2,200 km	Suomi NPP	NASA/NOAA	2011
CERES	20 km	<1 d	3,000 km	Suomi NPP	NASA/NOAA	2011
IIR	1 km	16 d	64 km	CALIPSO	CNES	2006
MODIS	1 km	4 per day	2,330 km	Terra, Aqua	NASA	1999, 2002
ATSR-2	1 km	3 d	512 km	ERS-2	ESA, UKSA, CSIRO	1995-2011
AATSR	1 km	35 d	500 km	Envisat	ESA, UKSA	2002-2012
AVHRR/1	1.1 km	<1 d	2,600 km	TIROS-N, NOAA 6,8,10	NOAA	1978-1986
AVHRR/2	1.1 km	<1 d	3,000 km	NOAA 9,10,11,12,13,14	NOAA	1984-2005
AVHRR/3	1.1 km	<1 d	3,000 km	NOAA 15-19, Metop A,B	NOAA, EUMETSAT	1998, 2000, 2002, 2005, 2006, 2012
MSG-SEVIRI	1-4 km	<1 d	Full earth disk	Meteosat-8/9/10	EUMETSAT	2002, 2005, 2012
MVIRI	5 km	ev. 30 min	Full earth disk	Meteosat-5/6/7	EUMETSAT, ESA	1988, 1989, 1991, 1993, 1997
MSU-MR	1 km	37 d	3,000 km	Meteor 3 M, and -M N1	ROSHYDROMET a.o.	2001, 2009
MSU-GS	4 km	geost., <1 d	Full earth disk	Elektro-L N1	ROSHYDROMET a.o.	2011
IMAGER	4 km	geost., <1 d	Full earth disk	MTSAT-1,2,3	JMA	1999, 2005, 2015
MVISR	1.1 km	3-4 d	3,200 km	FY-1C, 1D	CMA, NRSCC	1999, 2002
IVISSR	5 km	1 d	Full earth disk	FY-2C, 2D, 2E, 2F	NRSCC, CAST, NSMC	2004, 2006, 2008, 2012
VISSR	8 km	ev. 30 min	Full earth disk	Insat-2A, B, E, -3A	IMD	1992, 1993, 1999, 2003
IASI	25 km	29 d	2,052 km	MetOp-A/B	CNES, EUMETSAT	2006, 2012
HIRS/3	20.3 km	<1 d	2,240 km	NOAA 15,16,17	NOAA	1998, 2000, 2002
HIRS/4	20.3 km	<1 d	2,240 km	NOAA 18/19, MetOp A,B	NOAA, EUMETSAT	2005, 2006, 2009, 2012
ScaRaB	40 km	1 d	2,200 km	Meteor-3, Resurs-01, Meteo Technosat	CNES	1994, 1998, 2011

LANDSAT THEMATIC MAPPER(TM): Images consist of seven spectral bands with a special resolution of 30 m for bands for 1 to 5 and 7. However, spatial resolution for band 6 (thermal infrared) is 120 m, but is resample to 30m pixels. The approximate scene size is 170km north-south by 183km east west.

Table 4.3: Detail overview of LANDSAT THEMATIC MAPPER (TM)

	LANDSAT 4-5	WAVELENGTH (micrometer)	RESOLUTION (meters)
THEMATIC MAPPER(TM)	Band 1	0.45-0.52	30
	Band 2	0.52-0.60	30
	Band 3	0.63-0.69	30
	Band 4	0.76-0.90	30
	Band 5	1.55-1.75	30
	Band 6	10.40-12.50	120* (30)
	Band 7	2.08-2.35	30

- ETM+: Enhanced Thematic Mapper plus (on board the U.S. Landsat 7)

LANDSAT ENHANCED THEMATIC MAPPER PLUS (ETM+): Images consist of 7 spectral bands with a special resolution of 30 m for bands for 1 to 7. The resolution for Band 8 (panchromatic) is 15m. However, all bands can collect one of two gain settings (high or low) for increased radiometric sensitivity and dynamic range, while band 6 collects both high and low gain for all scenes. The approximate scene size is 170km north-south by 183km east west.

Table 4.4: Detail overview of LANDSAT ENHANCED THEMATIC MAPPER PLUS (ETM+)

	LANDSAT 7	WAVELENGTH (micrometer)	RESOLUTION (meters)
THEMATIC MAPPER(ETM+)	Band 1	0.45-0.52	30
	Band 2	0.52-0.60	30
	Band 3	0.63-0.69	30
	Band 4	0.77-0.90	30
	Band 5	1.55-1.75	30
	Band 6	10.40-12.50	60 * (30)
	Band 7	2.09-2.35	30
	Band 8	.52-.90	15

- TIRS: Thermal Infrared Sensor (on board the U.S. Landsat DCM)
- ASTER: Advanced Space borne Thermal Emission and Reflection Radiometer (On board the American-Japanese sensor of the same name, on the Terra platform)
- IRMSS: Infrared Multi Spectral Sensor (on board the Chinese CBERS 1, 2, and 2b)
- IRSCAM: Infrared Medium Resolution Camera (on board the Chinese CBERS 3, and future CBERS 4 and 4b)
- Infrared Camera (on board the Chinese HJ-1B satellite)
- MERSI: Medium Resolution Spectral Imager (on board the Chinese Feng Yun satellites)
- NIRST: New Infrared Sensor Technology (on board the American Aquarius)
- BIRD: Bi-spectral Infrared Detection (on board the German sensor of the same name)
- TET: Technologie Entwicklungstra¨ger (on board the German sensor of the same name)
- VIIRS: Visible/Infrared Imager Radiometer Suite (on board the U.S. Suomi NPP)
- CrIS: Cross-track Infrared Sounder (on board the U.S. Suomi NPP)
- CERES: Cloud's and Earth's Radiant Energy System (on board the U.S. Suomi NPP)
- IIR: Imaging Infrared Radiometer (on board the French CALIPSO satellite)
- MODIS: Moderate Resolution Imaging Spectroradiometer (on the U.S. platforms Terra and Aqua)
- AATSR: Advanced Along-Track Scanning Radiometer (on board the European Envisat)
- AVHRR: Advanced Very High Resolution Radiometer (on board the U.S. NOAA satellites)
- MSG-SEVIRI: Meteosat Second Generation – Spinning Enhanced Visible and InfraRed Imager (on board the European METEOSAT Second Generation satellites)
- MVIRI: Meteosat Visible and Infrared Imager (on board the geostationary European METEOSAT satellites)

- MSU-MR: Multispectral scanning imager-radiometer (on board the Russian orbiting Meteor-M N1 meteorological satellite)
- MSU-GS: Multispectral scanning imager-radiometer (on board the Russian geostationary Elektro-L N1 meteorological satellite)
- Imager: Multiband Imager (on board the MTSAT Japanese meteorological satellites)
- MVISR: Multispectral Visible and Infra-red Scan Radiometer (on board the Chinese FengYun meteorological satellites)
- IVISSR: Improved Multispectral Visible and Infra-red Scan Radiometer (on board the operating Chinese FengYun meteorological satellites)
- VHRR: Very High Resolution Radiometer (on board the Indian National Satellite System INSAT)
- IASI: Infrared Atmospheric Sounding Interferometer (on board the European Metop-A, Metop-B satellites)
- HIRS: High Resolution Infrared Radiation Sounder (in different versions as HIRS/2/3/4 on board the U.S. NOAA and European Metop series)
- ScaRaB: Scanner for Earth's Radiation Budget (on board the French satellite MeghaTropiques)



CHECK YOUR PROGRESS

Q. No. 6: Fill in the blanks:

I. Factors affecting the kinetic temperature are _____and thermal properties of the materials.

II. TK stands for _____ temperature.

III. _____ depends on actual or kinetic temperature of the body and its emissivity.

IV. Thematic Mapper is a _____.

Q. No. 7: State True or False:

I. Lots of natural substance is an ideal black body.

II. ASTER stands for Advanced Space borne Thermal Emission & Reflection Radiometer.

III. Very limited number of sensors available which allow for the acquisition of data in the thermal infrared.

4.6 OPTOMECHANICAL CCD ARRAYS

Special optical-mechanical or electronic scanners are used to detect and record images in thermal IR region. A Thermographic camera (also called an infrared camera or thermal imaging camera) is a device that forms an image using infrared radiation, similar to a common camera that forms an image using visible light. Instead of the 400–700 nanometer range of the visible light camera, infrared cameras operate in wavelengths as long as 14,000 nm (14 µm). Generally speaking, the higher an object's temperature, the more infrared radiation is emitted as black-body radiation. A special camera can detect this radiation in a way similar to the way an ordinary camera detects visible light. It works even in total darkness because ambient light level does not matter. This makes it useful for rescue operations in smoke-filled buildings and underground. Thermographic cameras can be broadly divided into two types: those with uncooled infrared detectors and those with cooled infrared image detectors.

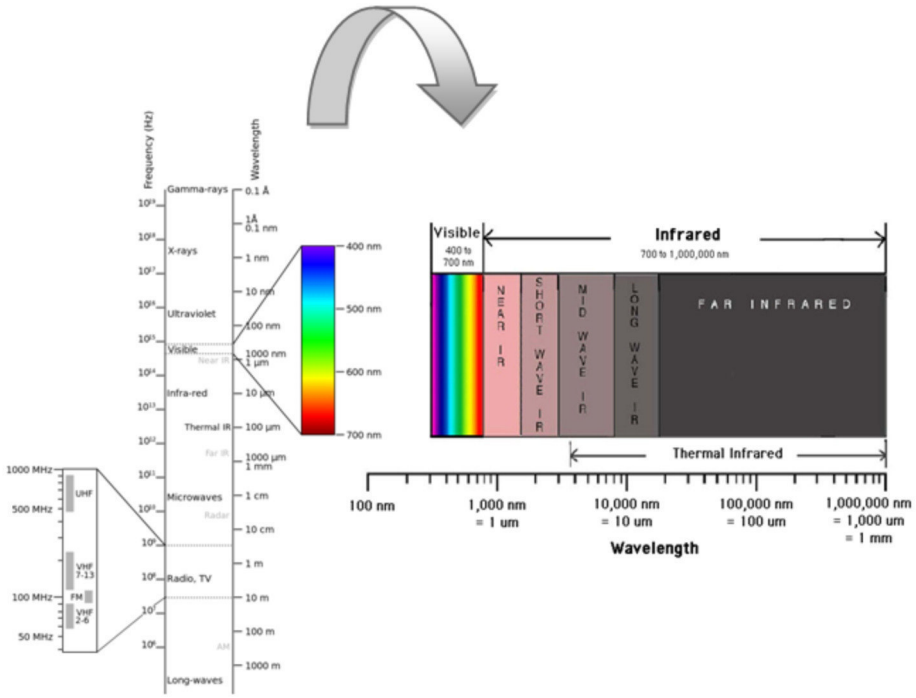


Fig. 4.5: Thermal IR region use by Thermographic camera to detect data

4.6.1 Uncooled Infrared Detectors

Uncooled thermal cameras use a sensor operating at ambient temperature, or a sensor stabilized at a temperature close to ambient using small temperature control elements. Modern uncooled detectors all use sensors that work by the change of resistance, voltage or current when heated by infrared radiation. These changes are then measured and compared to the values at the operating temperature of the sensor. Uncooled infrared sensors can be stabilized to an operating temperature to reduce image noise. Uncooled detectors are mostly based on pyroelectric and ferroelectric material or microbolometer technology. The materials are used to form pixels with highly temperature-dependent properties, which are thermally insulated from the environment and read electronically. Some of the materials used for the sensor arrays are:

- amorphous silicon (a-Si)
- vanadium (V) oxide (VOx)
- lanthanum barium manganite (LBMO)
- lead zirconatetitanate (PZT)
- lanthanum doped lead zirconatetitanate (PLZT)
- lead scandium tantalate (PST)

4.6.2 Cooled Infrared Detectors

Cooled detectors are typically contained in a vacuum-sealed case or Dewar and cryogenically cooled. The cooling is necessary for the operation of the semiconductor materials used. Typical operating temperatures range from 4 K to just below room temperature, depending on the detector technology. Most modern cooled detectors operate in the 60 K to 100 K range, depending on type and performance level. However, the resolution and image quality of cooled detectors tend to be far higher than uncooled

Photo detectors:
A device capable of registering a specific substance or Earth surface features.

detectors. This is due to difference in their fabrication processes, limited by currently available technology. Materials used for cooled infrared detection include ***photo detectors*** based on a wide range of narrow gap semiconductors including:

- Indium antimonide (3-5 μm)
- Indium arsenide
- Mercury cadmium telluride (MCT) (1-2 μm, 3-5 μm, 8-12 μm)
- Lead sulfide
- Lead selenide

Originally developed for military use during the Korean War, Thermographic cameras have slowly migrated into other fields as varied as medicine and archeology. More recently, the lowering of prices have helped fuel the adoption of infrared viewing technology. Advanced optics and sophisticated software interfaces continue to enhance the versatility of IR cameras.



CHECK YOUR PROGRESS

Q. No. 8: What is a thermographic camera?

.....

Q. No. 9: What are the two types of thermographic camera?

.....

Q. No. 10: What are the materials used for sensor array in uncooled infrared detectors?

.....

4.7 APPLICATION OF THERMAL SCANNER IMAGERY

Thermal imagery can be successfully used in various field of application. Interpretations of thermal imagery in most cases are of qualitative in nature in which it is not necessary to know absolute ground

temperature and emissivities. Interpretations of various features of interest are discriminated in the basis of their relative differences in the radiant temperature.

One of the most salient features in the interpretation of thermal images is that at what time of the day or height the particular image is acquired, because of variation of diurnal radiant temperature of various feature types which behave differently. For example, the temperature curve for water has two distinctive reasons. First, its range of temperature is very small compared to that of soil and rocks. Second, it reaches its maximum temperature one hour or two after the other materials. Therefore, it is seen that terrain temperatures are normally higher than those of water during the day and lower than water during the night. However, after dawn and near sunset, both the curves intersect with each other. These intersection times indicates that there is no any difference of radiant temperature between most of the feature types. These intersection points are called thermal "cross-overs". Therefore, during the acquisition of thermal images, these thermal cross-over timings should be avoided.

Thermal remote sensing is mostly carried out using two atmospheric windows, viz., 8 to 14 □m and 3 to 5 □m region of EMR. Most feature type usually show more or less constant emissivity in the 8 to 14 □m range and therefore, it is used for most thermal operation. However, if objects are heated above ambient temperature, their emissive radiation peaks shift towards shorter wavelength. Therefore, in certain application such as forest five mapping, 3 to 5 m atmospheric window is preferable.

Day time thermal imagery may show variation of radiant temperature by the same feature type due to thermal shadow effect. Cooler areas shaded from direct sun light by objects such as trees, buildings and some topographic features emit less radiant temperature. Therefore, for the application of thermal imagery predawn images are preferred because thermal shadow effect is considered to be minimized.

4.8 APPLICATION OF THERMAL DATA

Thermal property of a material is representative of upper several centimeters of the surface. Now a day's Thermal remote sensing proves to be more complementary to other remote sensing data's as it measures the emitted radiations. It is even very much helpful to identify surface materials and features such as rock types, soil moisture, geothermal anomalies etc. The ability to record variations in infrared radiation has advantage in extending our observation of many types of phenomena in which minor temperature variations may be significant in understanding our environment. Thermal remote sensing reserves immense potential for various applications. The following is a list of some of the areas in which thermal data is put to use:

- Agriculture e.g. useful in crops stresses analysis, indicative of crops moisture content etc.
- Soil moisture studies e.g. soil moisture discrimination, urban heat island analysis as well as land use land cover change using LST (Land Surface Temperature) calculation.
- Identification of geological units and structures: Differentiation of rock types and structure, volcanic terrain, underground fires, Locating geologic faults, Locating hot springs and geysers as in Fig. 4.6.



Fig.4.6: Geological units and structures

The thermal inertia mapping is particularly sensitive to the effects of tectonic disturbance and to lithological boundaries.

- **Hydrology:** Determining extent and characteristics of thermal plumes in lakes and rivers, Studying natural circulation patterns in water bodies.

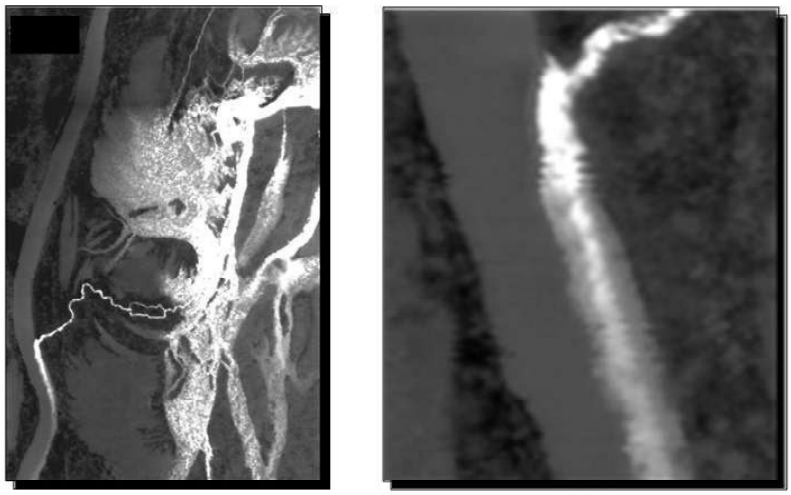


Figure 4.7: Pre-dawn Thermal Infrared Image of Effluent Entering the Savannah River Swamp System

- **Coastal zones:** SST (Sea Surface Temperature), PFZ (Potential Fishing Zone), oil spills, modelling climatic change.
- **Volcanic Studies:** Determining extent of active Volcano, Locating subsurface fires in landfills.

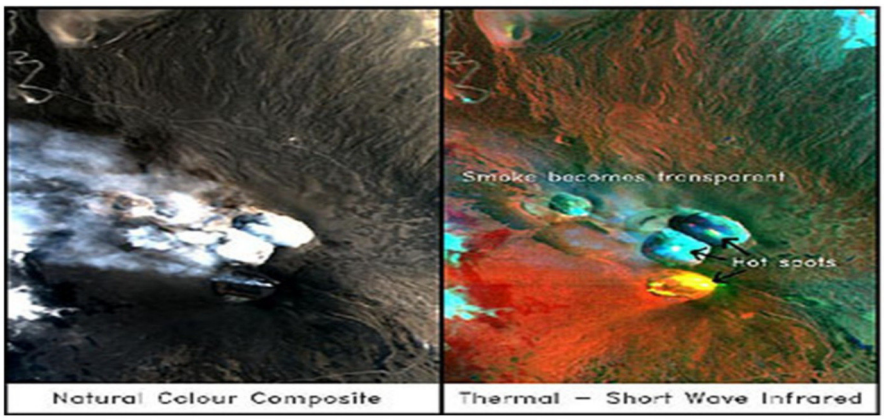


Figure 4.8: Thermal images in volcanic studies

- Forest fires: Forest fires, their assessment and control, biomass burning.
- Coal fires
- Seismology
- Environmental modeling
- Meteorology: Thermal images from weather satellites are used to determine cloud temperature/height and water vapiul concentrations, depending on the wavelength.
- Medical sciences
- Vetenary sciences
- Intelligence / military applications and Law enforcement and anti-terrorism
- Quarantine monitoring of visitors to a country
- Military and police target detection & acquisition: Forward looking infrared, Infrared search and track
- Condition monitoring and surveillance
- Technical surveillance counter-measures
- Thermal weapon sight
- Search and rescue operations
- Firefighting operations
- Heat loss from buildings

Thermal remote sensing is also useful for urban environment studies such as:

- Aerial thermal scanning used to study heat loss from buildings.
- Inadequate or damaged insulation and roof material.
- Aerial thermal scanning can be used to estimate energy radiated from roofs.
- Emitted of roof materials must be known to determine kinetic temperature of roof surfaces.
- The use of aerial thermal scanning to study heat loss from buildings has been investigated in many cities.



4.9 LET US SUM UP

- Thermal remote sensing is the branch of remote sensing that deals with the acquisition, processing and interpretation of data acquired primarily in the thermal infrared (TIR) region of the electromagnetic (EM) spectrum.
- In thermal remote sensing we measure the EMR 'emitted' from the surface of the target instead of the 'reflected' EMR.
- The basic Thermal Properties of Materials are emissivity, heat capacity, thermal conductivity, thermal diffusivity, and thermal inertia.
- Thermal inertia is a measure of the thermal mass and the velocity of the thermal wave which controls the surface temperature of a material. In simple words, Thermal Inertia is a measure of the responsiveness of a material to variations in temperature.
- Black body is a theoretical object that absorbs and then emits all incident energy at all wavelengths.
- Factors Affecting the Kinetic Temperature can be categorised in two broad groups - heat energy budget and thermal properties of the materials.
- Radiant Temperature (TR) is the actual temperature obtained in a remote sensing measurement and, as mentioned earlier, depends on actual or kinetic temperature (TK) of the body and its emissivity.
- Optical-mechanical or electronic scanners are used to detect and record images in thermal IR region.
- Thermographic cameras can be broadly divided into two types: those with cooled infrared image detectors and those with uncooled detectors.



4.10 FURTHER READING

1) Thermal Infrared Remote Sensing by Claudia Kuenzer and Stefan Dech
2) Thermal Remote Sensing in Land Surface Processes By Dale A. Quattrochi and Jeffrey C. Luvall



4.11 ANSWERS TO CHECK YOUR PROGRESS

Q. No.1:

I. True
II. False
III. True
IV. False

Q. No.2:

I. emmited
II. emissivity
III. Thermal diffussion

Q. No.3: Emissivity is the ratio of radiant energy emitted from a real body to radiant energy emitted from a reference black body.

Q. No.4: The thermal inertia is the product of the three factors-energy needed to raise the temperature of a material by 1 C (heat capacity c) per mass unit of the substance, the density of a material p, and the thermal conductivity k, of the object.

Q. No. 5: Radiant temperature is the actual temperature obtained in a remote sensing measurement and depends on actual or kinetic temperature (TK) of the body and its emissivity.

Q. No. 6:

I. Heat energy budget
II. Kinetic Temperature
III. Radiant Temperature
IV. Sensor

Q. No.7:

I. False

II. True

III. False

Q. No.8: A thermographic camera is a device that forms an image using infrared radiation, similar to a common camera that forms an image using visible light.

Q. No.9: Two different types of Thermographic camera are cooled infrared image detectors and uncooled infrared detectors.

Q. No. 10: Some of the materials used for the sensor arrays in uncooled infrared detectors are:

- Amorphous silicon (a-Si)
- Vanadium(V) oxide (VOx)
- Lanthanum barium manganite (LBMO)
- Lead zirconatetitanate (PZT)
- Lanthanum doped lead zirconatetitanate (PLZT)
- Lead scandium tantalate (PST)



4.12 MODEL QUESTIONS

1. Give a brief description about the Thermal Infrared Region with proper diagram.
2. What do you mean by remote sensing? Explain Thermal Remote Sensing.
3. Describe the basic thermal properties of materials.
4. Define Thermal Inertia with suitable example.
5. What do you mean by “Black Body”? Prepare a suitable diagram showing Radiated Energy of Black body.
6. What is Radiant temperature? Classify Radiant energy in different categories.

7. Describe five most commonly used Thermal Sensors.
8. Differentiate between Cooled Infrared Image Detector and Uncooled Infrared Image Detector.
9. List or mention some applications of thermal Remote Sensing data in Earth Science.
10. Explain how Thermal Remote Sensing is useful in Urban Studies.

---x---

UNIT- 5: INTRODUCTION TO MICROWAVE REMOTE SENSING

UNIT STRUCTURE

5.1 Learning Objectives

5.2 Introduction

5.3 Basic Concepts of Microwave Remote Sensing

5.4 Microwave Sensors

5.5 Spectral and Spatial Resolution

5.6 Microwave Data Sets

5.7 Application of Microwave Satellite Data

5.8 Let us Sum up

5.9 Further Readings

5.10 Answers to Check Your Progress

5.11 Model Questions

5.1 LEARNING OBJECTIVES

After going through this unit, you will be able to –

- explain the basic concepts of microwave remote sensing
- describe about microwave sensors
- discuss the spectral and spatial resolution of microwave satellite data
- identify the different types microwave data set
- explain the applications of microwave remote sensing data.

5.2 INTRODUCTION

In the previous unit, we have discussed the thermal remote sensing and how the data is acquired in such process. In this unit, we will consider the concept of microwave remote sensing. This unit provides you the basic principles , theory and factors effecting microwave along with the utility of

microwave remote sensing. This unit also provides the use of different types of microwave sensors. This unit also deals with spectral and spatial resolutions and its characteristics. In this unit, you will also learn the various types of microwave data sets along with the applications of microwave remote sensing data.

5.3 BASIC CONCEPT OF MICROWAVE REMOTE SENSING

Microwave being a component of solar spectrum was being used since world war -II as RADAR (**R**adio **D**etection And **R**anging) to identify remote objects like fighter plane, submarines, warship etc. during war. Its civilian use started with development of microwave sensors to put it in satellite to identify objects on earth surface from space through cloud cover which is a major obstruction in case of optical remote sensing.

The solar spectrum consists of various electromagnetic radiation viz. Gamma rays, X-rays, UV rays, visible rays, reflected infrared rays, thermal infrared rays, microwave, radio etc. But all these rays cannot reach earth's surface and maximum are attenuated by the atmosphere. Only few of them can pass through the atmosphere to reach the earth surface which is called atmospheric windows. For the purpose of remote sensing, these are visible, reflected infrared, thermal infrared and microwave.

Microwave is a long wave in the solar spectrum ranging from 1 cm to 100 cm which has 100% transmission through atmosphere. Unlike visible range, it can pass through cloud. Maximum remote sensing satellites use passive sensors which records reflected solar radiations of earth features. But the visible range of solar spectrum cannot penetrate cloud; thereby shows cloud covered satellite data during rainy season. This creates problem in conducting remote sensing survey during rainy season. To overcome this problem, microwave region specifically radio wave of solar spectrum is being used by means of putting active sensor in satellite.

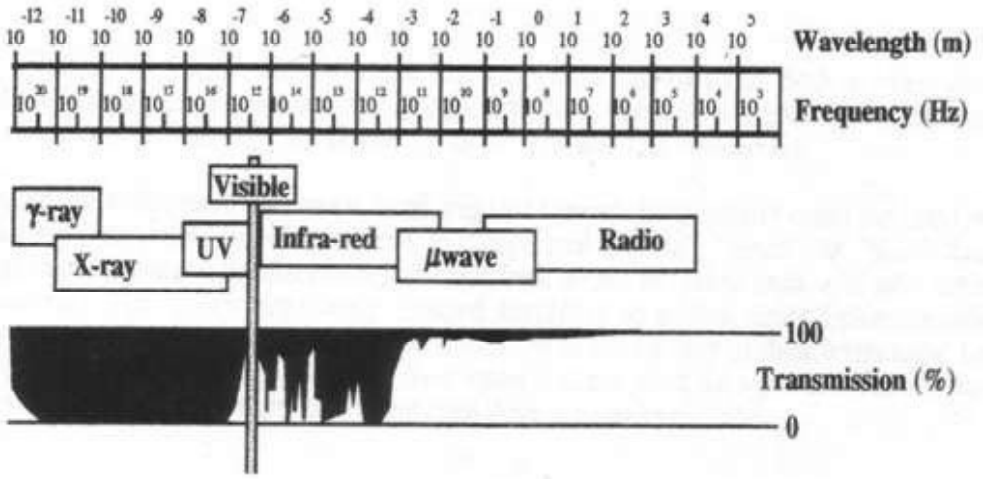


Figure 5.1 Solar Spectrum

This active sensor emits micro-wave towards earth in an angular direction and measures the returned signal which is also called backscatter. The entire system is called RADAR system (Radio Detection and Ranging) i.e. any system which emits a microwave of known frequency and a receiver which records some property of the returned signal. So, RADAR is a device which provides measurement of-

(i) Time delay, (ii) Power (intensity of backscatter) and (iii) Phase.

Time delay measures the distance between sensor and object. The equation is of time delay is,

$$\tau_d = \frac{2 R_0}{c}$$

where τ_d = Time Delay

R_0 = Slant Range

c = Speed of light

Secondly, **power or intensity** of backscatter gives the information about the shape and geometry of the object. Unlike optical remote sensing, RA-

DAR works with texture not with colour. Texture is the only key of interpretation of RADAR image because texture directly influences the amount of backscatter (db). The RADAR equation is as follows:

$$P_r = \frac{\lambda^2}{(4\pi)^3} \int \frac{P_t G^2}{R^4} \sigma^o d_A$$

where P_t = Transmitted Power
P_r = Received Power
R = Range
G = Electrical Gain
λ = Wave length
σ^o = Back Scatter Co-efficient

Stereo image: Stereo image is an image proposed to give a 3-dimensional visual impression.

Lastly, **Phase** of RADAR is used when multi dimensional data is used. The utility is to produce ***stereo image*** and to generate contour and 3-D intended ***terrain model***.

Terrain model: When elevation component of the surface of the earth is represented in geospatial data, it is termed as terrain model. Here , besides (x, y) component of space, it gives the third component, z representing the elevation.

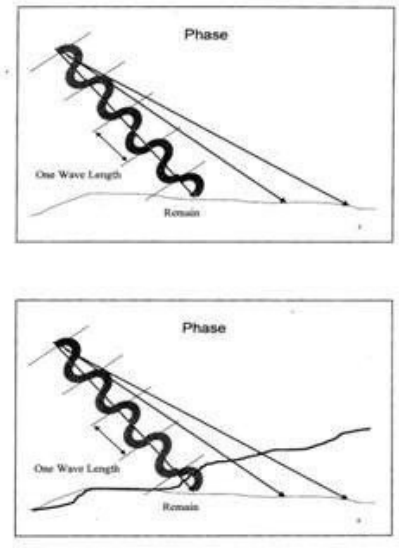


Figure 5.2: Measure of phase difference for terrain height

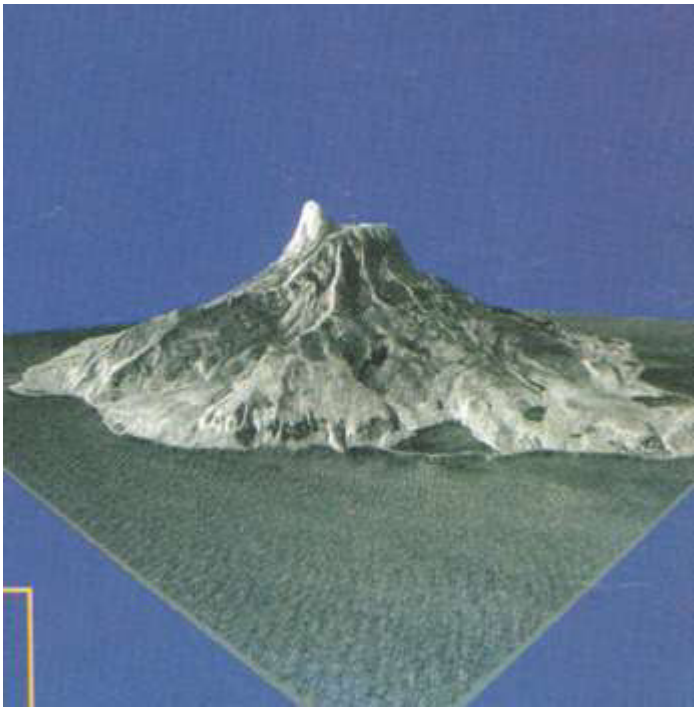


Figure 5.3: Use of phase property of microwave



CHECK YOUR PROGRESS

Q. 1: Mention the electromagnetic radiations of solar spectrum that can reach the earth surface.

.....

.....

Q.2: Which sensor is used in satellite to overcome the problem of rainy season?

.....

.....

Q.3: What do you mean by backscatter?

.....

.....

Q.4: Define the power of backscatter.

.....

.....

5.4 MICROWAVE SENSORS

Generally micro-wave sensors are the backscatter measuring instruments and they are usually called scatterometers, radiometers and altimeters. Some of scatterometers are Radarsat scan SAR, ENVISAT, ASAR etc. In addition, some other microwave measuring instruments are altimeter, radiometer etc. are used to measure height, pulse, phase etc.

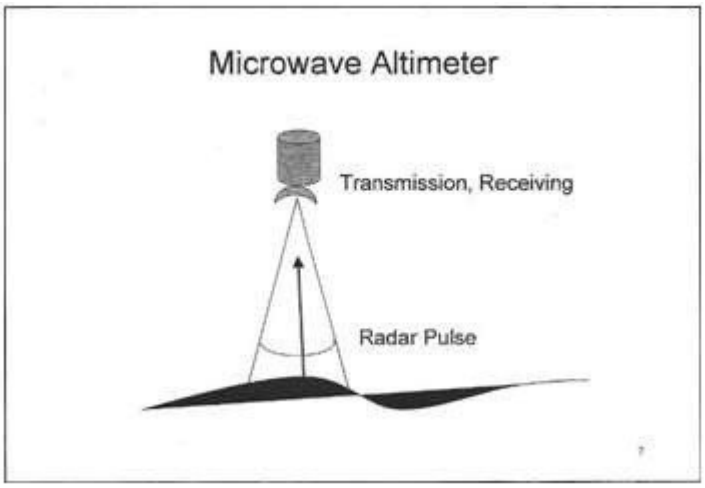
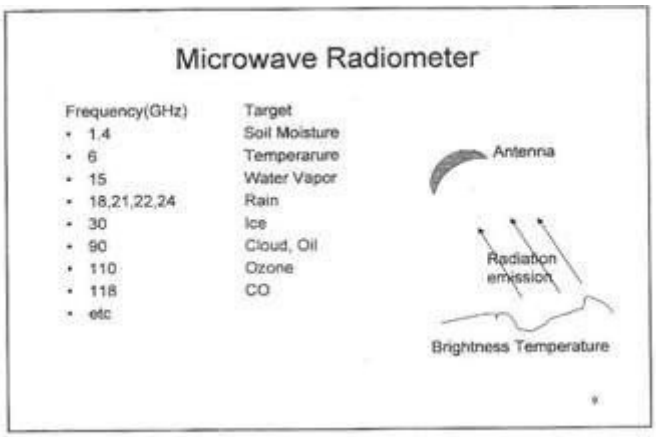


Figure 5.4: Altimeter to measure height



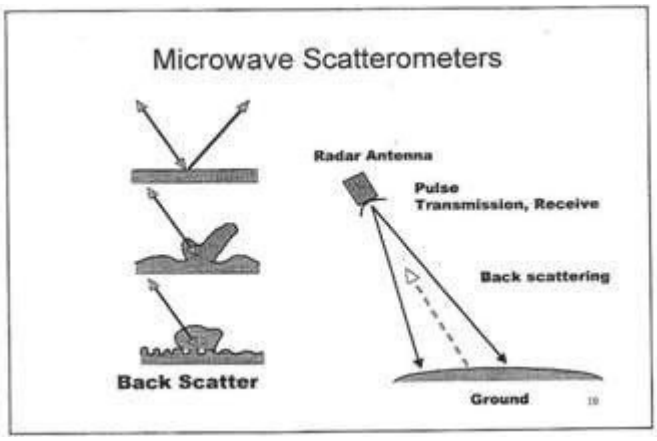
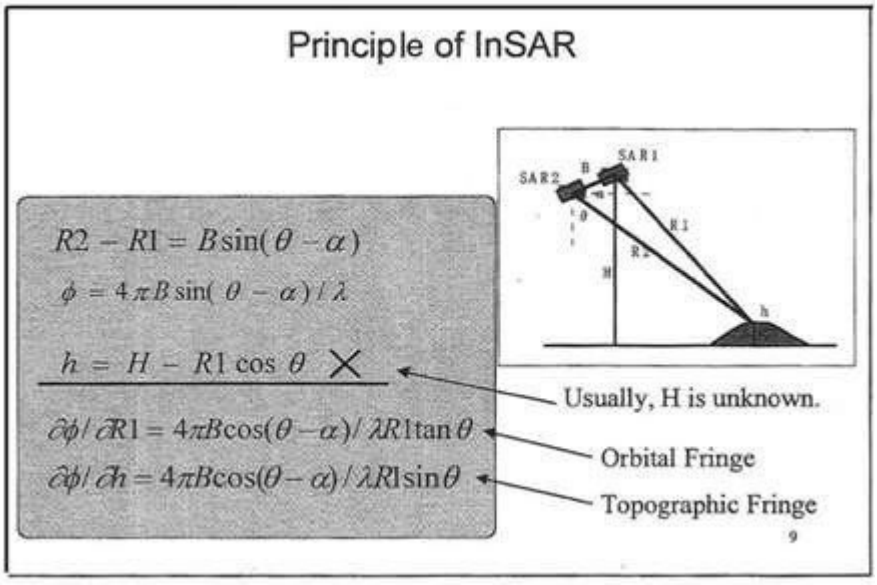


Figure 5.5: Microwave Radiometer is used to measure radiation emitted by different features and scatterometer is used to measure backscatter of different objects



FACTORS INFLUENCING RADAR BACKSCATTER:

Various factors that influence RADAR backscatter are discussed below:

(1) Surface roughness: In principle, a smooth surface will reflect almost total energy incident upon it, in the same way that a mirror reflects light. If viewed from an angle instead of straight where incidence angle is zero,

then none of the energy hitting the surface will return to the viewer. A rough surface reflects energy in a scattered way so that some of its portion will become detectable to the viewer. Backscatter increases with surface roughness. Smooth object do not scatter, but rough objects scatter.

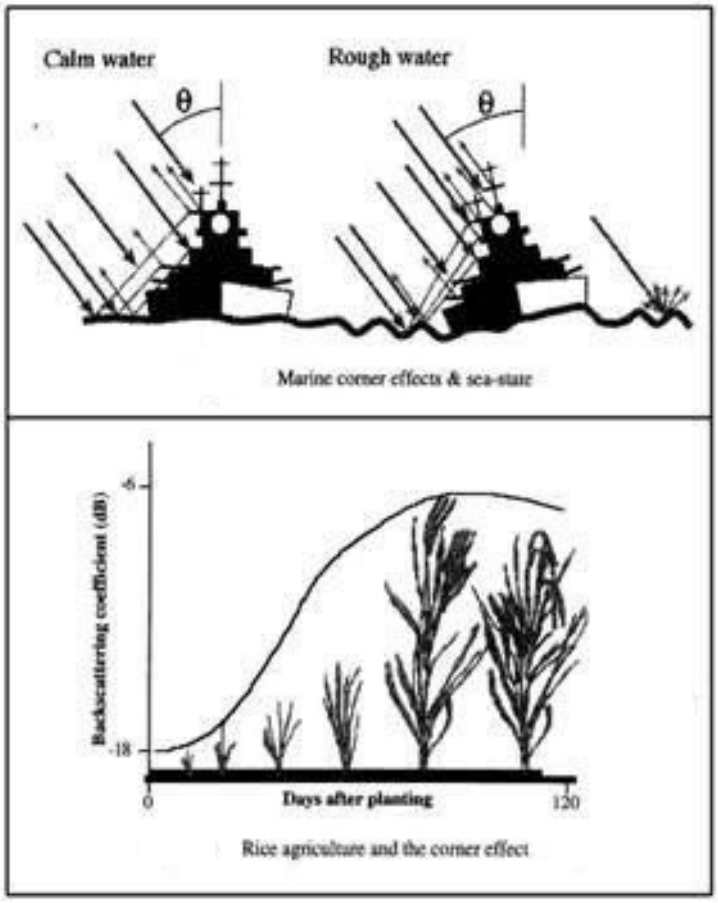


Figure 5.6: Backscatter increases with increase roughness and corners. Roughness of rice plants increases with growing stage because of increase nos. of tillers. This phenomenon is used to identify rice plant in field using multi temporal microwave data along the rice growing period.

(2) Angle of incidence: Backscattering increases with the increase in incidence angle. But very high incidence angle may produce noise (speckle). Again penetration of microwave into volume decreases with increase in incidence angle.

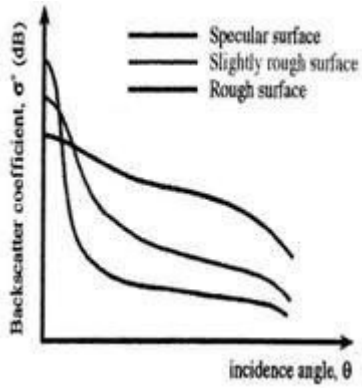


Figure 5.7 Backscatter vs incidence angle for surfaces of different roughness

(3) Aspect angle: Backscattering also depends on ***aspect angle*** of RADAR sensor.

Aspect angle: The direction of back scatter is known as aspect angle

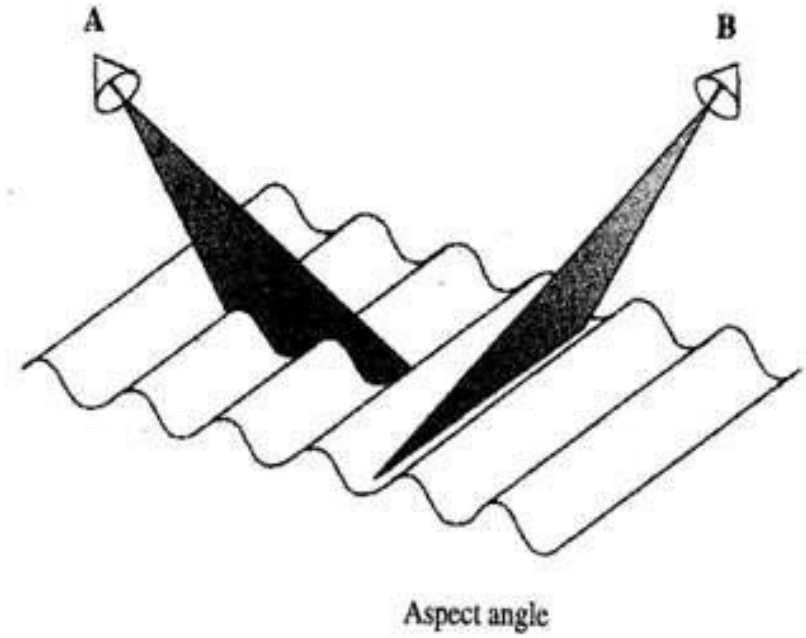


Figure 5.8: Aspect Angle

At point A, backscatter is more than at point B because of creation of roughness due to wavy structure.

(4) Moisture content of object: Moisture content in an object produces high backscatter.

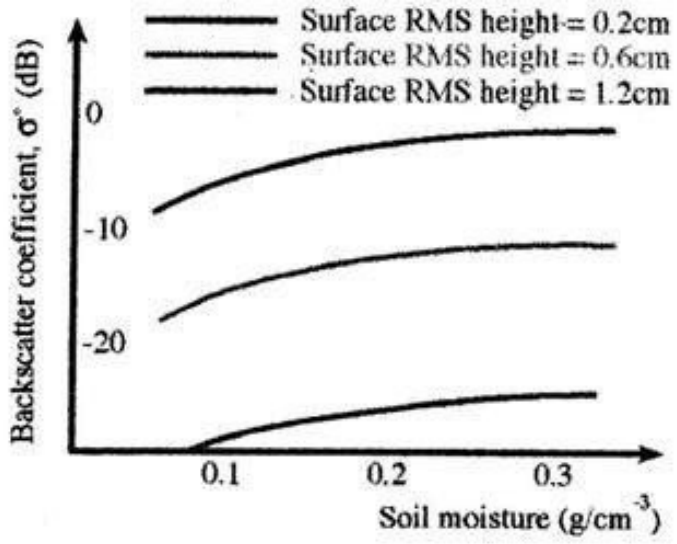


Figure 5.9: Showing three surface heights where Backscatter increases with moisture content

(5) Effect of wave length: Larger wave can penetrate more into volume (land or vegetation) than smaller wave. The bands used in RADAR satellite are X-band, C-band, L-band.

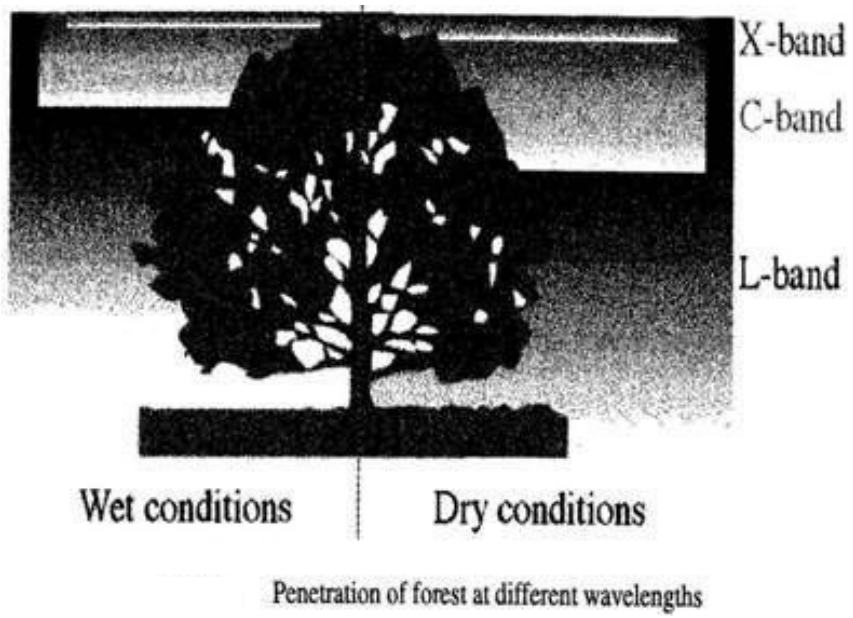


Figure 5.10: Volume penetration capacity of different microwave band

(6) Polarization: The mode of emission of RADAR beam known as polarization is of two types - Vertical and Horizontal. Depending upon applications two modes is used. Vertical polarization is useful for vertical structure like ***crop canopy***.

(7) Population density: Population density of features like vegetation density also increases backscatter.

(1) *Crop canopy*: Different layers of habitat of plant communities above the ground with various elevations. For example, grass canopy is lower than the tree canopy.



CHECK YOUR PROGRESS

Q. 5: What is scatterometer? Give two examples of scatterometer.

.....

.....

Q.6: What are the factors that influence the RADAR backscatter?

.....

.....

5.5 SPECTRAL AND SPATIAL RESOLUTION

Entire microwave region can be divided into following spectral resolutions or bands. Each band has its own characteristics. Longer the wavelength, longer is the volume of penetration.

Band	frequency (GHz)	Wave length (cm)
P	0.300 - 1.000	100.00 – 30.00
L	1.000 - 2.000	30.00 – 15.00
S	2.000 – 4.000	15.00 - 7.50
C	4.000 – 8.000	7.50 - 3.75
X	8.000 – 12.50	3.75 – 2.40

Spatial resolution of microwave data depends on pulse length and antenna beam width. The spatial resolution in the range direction is also dependent upon the ***depression angle*** of the antenna and angle of incidence. As the depression angle decreases, the pulse length represents progressively

Depression angle: It is the angle below the horizontal plane (angle of declination). The angle above horizontal plane is angle of inclination.

shorter distances on the ground (de Loor, 1976). The spatial resolution in the range direction (SRr) can be calculated using formula–

$$SRr = \frac{ct}{2 \cos \gamma}$$

Where, γ represents depression angle, t represents the pulse length and c denotes the speed of the microwave pulse which is at the speed of light 3 x 10^8 ms^{-1}

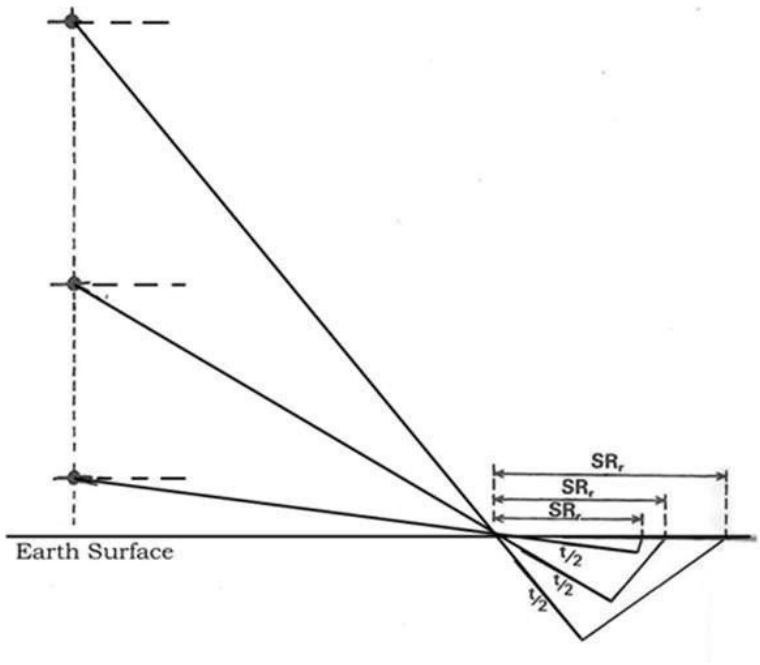


Figure 5.11 Spatial resolution depends on depression angle and angle of incidence

Azimuth direction: It is along track direction within antenna field of view. It represents linear distance or image scale parallel to the radar flight path.

Spatial resolution in the ***azimuth direction*** depends on the width of the antenna beam (β) in the azimuth direction (SR_a). As the beam fans out from the antenna, the spatial resolution decreases with ground distance (GD), from a minimum directly below the aircraft. The spatial resolution in the azimuth direction can be calculated by using the following formula-

$$SR_a = GD\beta$$

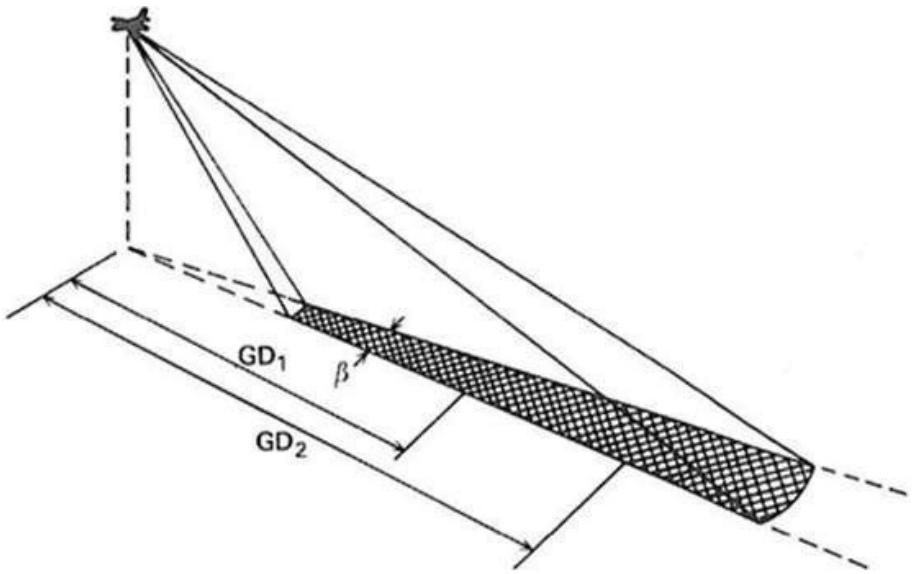


Figure 5.12: Spatial resolution in Azimuth direction depends on width of antenna beam.

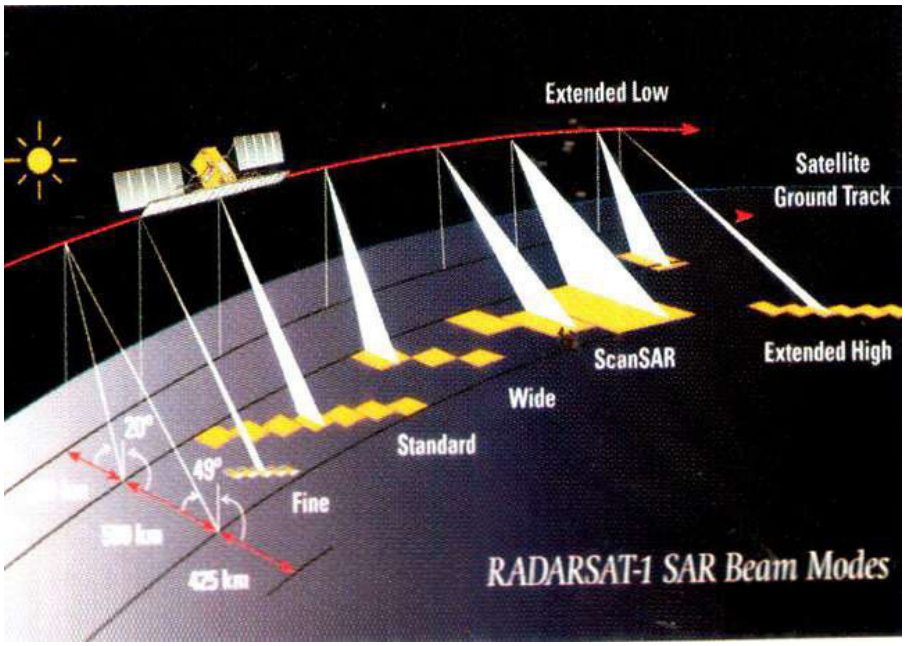


Figure 5.13: Different Spatial resolutions of RADARSAT satellite depending on different angle of incidence.

Advantages of RADAR satellite data:

(i) All weather capability to acquire data. Unique advantage of cloud penetration capacity.

(ii) Day and night capability to acquire data.

(iii) Absolute calibration

(iv) Penetration to volume of object.

Disadvantages:

(1) Single band data

(2) Noisy appearance

(3) No standard method.

(4) Difficulties in interpretation



CHECK YOUR PROGRESS

Q.7: State True or False:

i. The frequency range of S band is 2GHz to 4GHz.

ii. Spatial resolution of microwave data depends on pulse length and frequency.

iii. The speed of light is 3×10^8 ms^{-1}.

iv. The spatial resolution is inversely proportional to the pulse length.

v. Noisy appearance is a disadvantage of RADAR satellite.

5.6 MICROWAVE DATA SETS

Side Looking Airborne Radar (SLAR):

A Side Looking Airborne Radar (SLAR) was first developed in 1950 to sense the terrain to the side of an aircraft's track. This was done by pulsing out long, upto radio wavelengths of electromagnetic radiation and then recording strength of the pulse return to the aircraft to detect the object and also the time it takes for the pulse to return to give the range of the object from the aircraft. During the 1950, development of SLAR was made for military purpose as it is independent of sunlight and weather conditions ideal for

reconnaissance survey. SLAR was released for civilian purpose in 1960 (Fischer, 1975) and got wide spread use in 1970.

Synthetic Aperture Radar (SAR):

As like aerial photograph, airborne SLAR also had the same disadvantage of geometric errors owing to unstable platform of aircraft. Also flight was mostly weather dependent though the sensor was weather independent. To remove such difficulties satellite RADAR sensors were developed which not only provided a stable platform but also weather independent and cost effective. A SLAR is usually operated within a limited range of altitudes and depression angles and at the fastest possible pulse rate which is a limitation for improving spatial resolution. Therefore, to improve spatial resolution it needs to decrease the beam width. The beam width (β) is determined by the wavelength of the microwaves (λ) and the antenna length (AL). The formula is–

$$\beta = \frac{\lambda}{AL}$$

Therefore, to decrease the beam width (β) there must be a large decrease in the wavelength (λ) used, or a large increase in the antenna length (AL). A large decrease in the wavelength is impractical as it may be affected by atmosphere. On the other hand, large increase in antenna length may cause aviation hazard. To overcome this problem, the effective length of the antenna can be increased by taking advantage of the motion of the aircraft (Harger, le1970). As an aircraft flies past an object on the ground, the object will enter antenna's beam, move through and leave it. During the time, it will have backscattered a number of microwave pulses, each at slightly different frequency. The information on backscatter and frequency can be used to synthesize electronically, an antenna that is as long as the flight line of the aircraft and has beam that is as wide at the source as it is at the sensor. Such SLAR is called a Synthetic Aperture radar or SAR (Lodge, 1981).

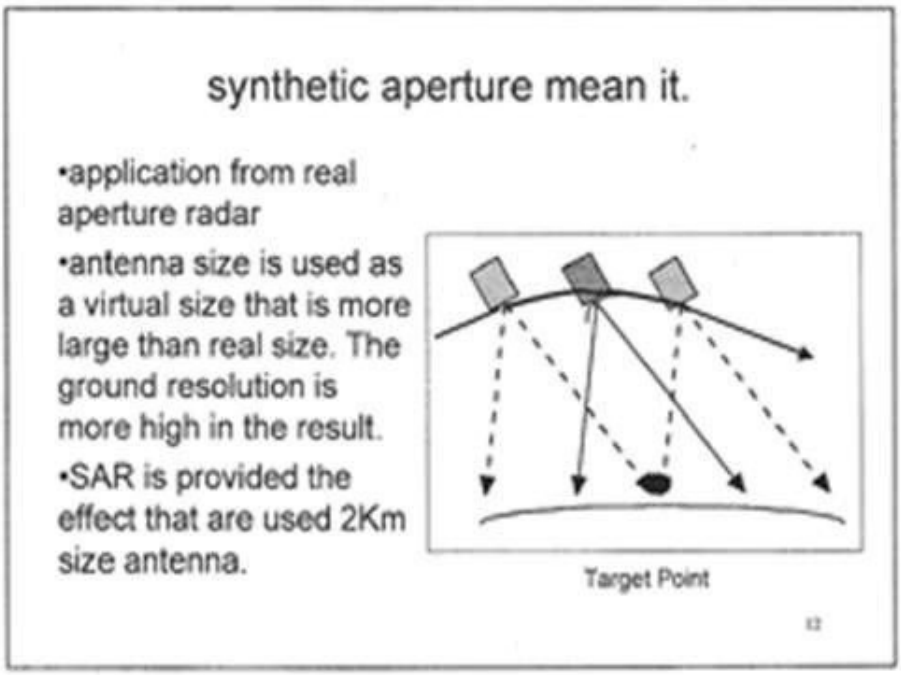


Figure 5.14: Working principles of Synthetic Aperture Radar

Satellite based RADAR viz. SAR (Synthetic Aperture Radar) was developed in 1978 named as SEASAT. After that continuous effort was made to develop improved high resolution microwave sensor. SIR (Shuttle Imaging Radar), SIR-A in 1981 and SIR-B in 1984 were developed for terrain mapping. Operational microwave remote sensing satellites came as under

(i) RADARSAT -1(Nov, 1995)- Canadian satellite
(ii) ERS –1 (July, 1991)
(iii) ERS-2 (April, 1995)
(iv) JERS –1 (1998)
(v) ENVISAT (2000)
(vi) RADARSAT – 2 (2001)

Specifications of microwave satellites:

		ERS-SAR	RADARSAT
-Altitude	:	785 Km	800Km
-Frequency	:	5,3 GHz	5.3 GHz
- Wavelength	:	C band	C band
- Depr. Angle	:	23 degree	10 to 60 deg
- Swath		100 Km	45 to 510 Km
- Spatial Res.	:	30 m	9x9m to 100x100m
-Polarization	:	VV	HH

Major Microwave data acquisition mission:

Shuttle Radar Topography Mission (SRTM) for acquisition of elevation data of earth surface. It was a 11 day continuous mission started in February, 2000 through space shuttle “Endeavour”. It was a collaborative effort of NASA, Italian Space Agency and German Aerospace Centre. The data had 3 resolutions viz. 30m and 90m and 1 km.

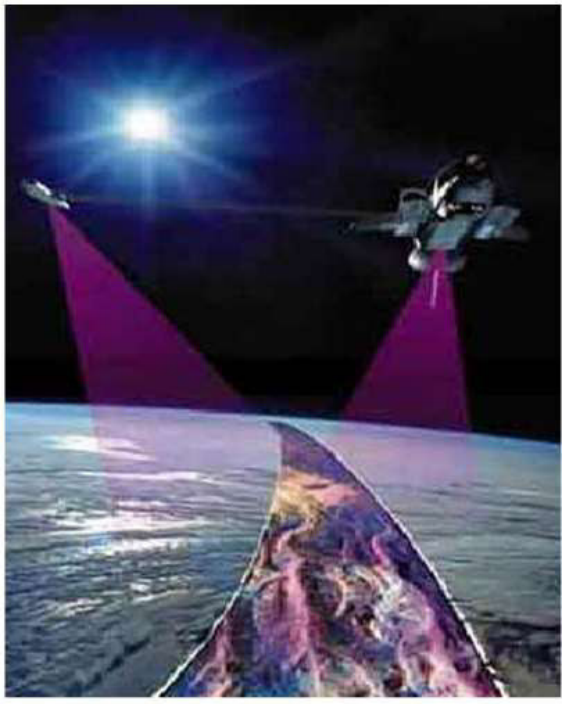


Figure 5.15: Acquisition of SRTM data from space shuttle

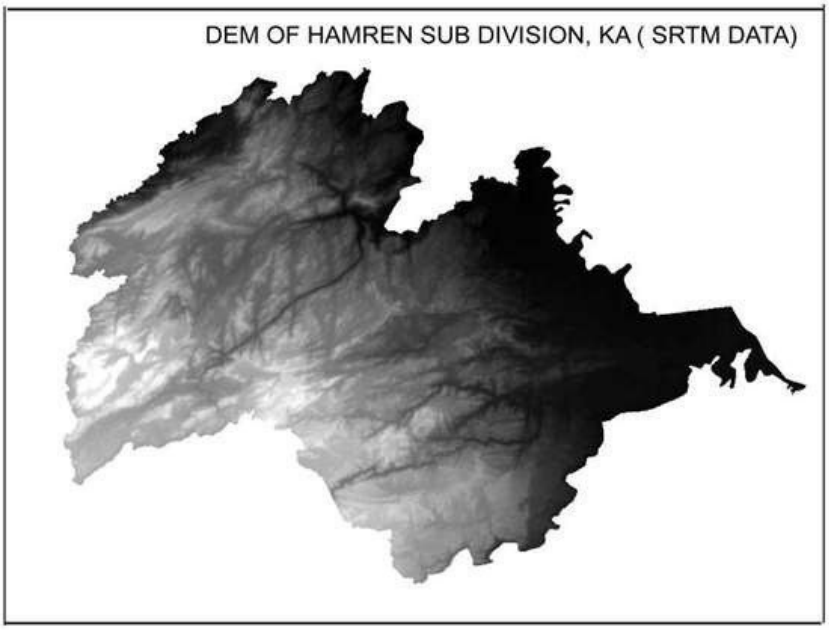
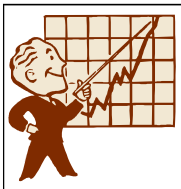


Figure 5.16: Digital elevation model of SRTM data



CHECK YOUR PROGRESS

Q. 8: Fill in the blanks:

i) The beam width (β) is determined by the _____ of the microwaves (λ) and the _____.

ii) Large increase in antenna length may cause ____ hazard.

iii) The full meaning of SIR is _____.

iv) The altitude of microwave satellite ERS-SAR is _____.

v) ___ Mission was started in February, 2000 for acquisition of Elevation data of earth surface.

5.7 APPLICATIONS OF MICROWAVE SATELLITE DATA

Applications of Microwave satellite data are discussed below:

(1) Disaster Management: Microwave data is now being used in flood and cyclone monitoring study. Since both the phenomena occur during rainy

season, therefore, it is very difficult to get cloud free optical data. Only microwave satellite data can serve the purpose since it can penetrate cloud. Flood map can be prepared and damage can be estimated using RADAR data.

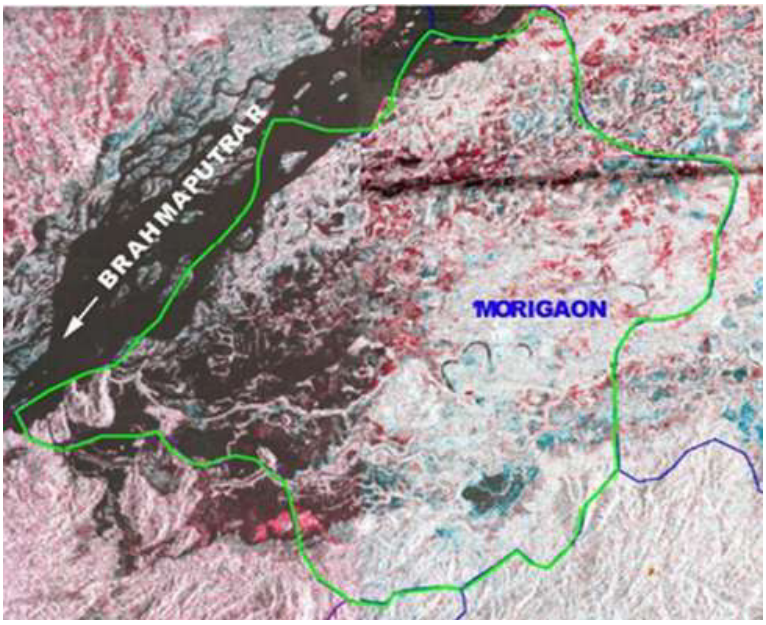


Figure 5.17: Flood inundation of Morigaon District viewed by RADARSAT

Oil spill in ocean also can be detected using microwave data as oil creates smooth surface over wavy ocean, therefore backscatter is very low in oil spill area and can be easily detected in microwave image.

(2) Crop acreage Estimation: Using multidate RADAR data it has now been possible to estimate the acreage of rice crop grown in rainy season. As the crops grow, number of tillers increases, thus creating more corners and roughness effect thereby increases amount of backscatter. Observing this steady increase of backscatter along the growing period over multidate microwave satellite data, crops can be identified during rainy season.

(3) Geological structure mapping: RADAR data is very useful in geological mapping. The oblique view of RADAR imagery gives very good idea about terrain structure and rock type.

Biomass: It is the total quantity of organic mass / materials available in an area or within a given volume.

(4) Forest mapping: RADAR data has been found to be useful for identifying forest type. Changes in radar backscatter are related to ***biomass.*** The range of biomass level can be estimated by P band backscatter.

(5) Land cover mapping: Using multidate radar imagery or combination of band combination is helpful to identify different land cover type. Sometimes fusion of optical and radar data also gives important clues for identification of various earth's feature.



CHECK YOUR PROGRESS

Q.9: Give some applications of microwave satellite data.

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5.8 LET US SUM UP

- Microwave is that portion of solar spectrum whose wavelength is 1cm to 100 cm and it has 100% transmission through atmosphere.
- Microwave is used to measure distance as well as to identify object.
- Microwave being long wave in nature can penetrate through volume up to some extent.
- Microwave is an active remote sensing, where the censor itself emits microwave or radar energy which strike an object and scattered and that amount of backscatter is again measured by the same censor.
- Amount of backscatter is the only key of interpretation of microwave satellite data backscatter can be obtained only when the microwave beam is emitted in angular direction.

- Several factors like angle of incidence, aspect angle, structure of object, surface roughness, polarization, population density etc. affects the microwave energy beam.
- Microwave is a single band data, and texture is the only key of interpretation of microwave data. Hence its interpretation is complicated.
- The major advantage of microwave data is its cloud penetration capacity and day and night acquisition capability and not weather dependant.
- Microwave is useful for flood mapping, DEM generation, Crop acreage estimation during rainy season, geological mapping, soil moisture assessment etc.



5.9 FURTHER READINGS

1) Principles of Remote Sensing by Paul J. Curran, published by English language Book Society, England
2) Quegan, S., "An introduction to SAR theory and statistical properties of ERS SAR data". course work notes , AIT, (1997)
3) Spaceborne radar remote Sensing by Elachi (1989)
4) "Understanding Synthetic Aperture Radar Images" by Oliver, C and Quegan, S (1998) Published by Artech House



5.10 ANSWERS TO CHECK YOUR PROGRESS

Q. No.1: The electromagnetic radiations of solar spectrum that reach the earth surface are visible, infrared, thermal and microwave.

Q. No.2: Active sensor.

Q. No.3: The active sensor in the satellite that emits radio wave towards earth in an angular direction and measures the returned signal which is also called backscatter.

Q. No.4: The power or intensity of backscatter gives the information about the shape and geometry of the object.

Q. No.5: The backscatter measuring instruments of microwave are usually called scatterometer. Two examples of scatterometers are Radarsat scan SAR and ENVISAT ASAR.

Q. No.6: The factors that influence the RADAR backscatter are- surface roughness, angle of incidence, aspect angle, moisture content of object, effect of wave length, polarization and population density.

Q. No.7:

i) True ii) False iii) Trueiv) False v) True

Q. No.8:

i) Wavelength, antenna length.
ii) Aviation
iii) Shuttle Imaging Radar
iv) 785 km
v) Shuttle Radar Topography

Q. No. 9: Some applications of microwave satellite data are-

Disaster management
Crop acreage estimation
Geological structure mapping
Forest mapping
Land cover mapping



5.11 MODEL QUESTIONS

1) What is Microwave remote sensing? How it differs from optical remote sensing?
2) Write the factors effecting on microwave data.
3) Describe RADAR equation and speak about its importance.
4) What is the difference between SLAR and SAR?
5) Name the bands used in microwave and their characteristics.
6) Write few applications of microwave remote sensing.

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UNIT- 6: WHAT AND WHY OF HYPERSPECTRAL REMOTE SENSING

UNIT STRUCTURE

6.1 Learning Objectives

6.2 Introduction

6.3 Basic Concepts of Hyperspectral Remote Sensing

6.4 Hyperspectral Missions and Sensors

6.5 Data Characteristics and Processing

6.5.1 Radiometric Corrections

6.5.2 Geometric Corrections

6.5.3 Image Classification

6.6 Applications of Hyperspectral Remote Sensing

6.7 Let us Sum up

6.8 Further Reading

6.9 Answers to Check Your Progress

6.10 Model Questions

6.1 LEARNING OBJECTIVES

After reading this unit, you will be able to-

- discuss the concept of hyperspectral remote sensing
- describe the hypersprectral missions, sensors and data characteristics
- discuss the radiometric and geometric corrections of images
- explain the basic principles of classification of hyperspectral images.

6.2 INTRODUCTION

In the previous unit, you have learnt about microwave remote sensing and its applications. In this unit, we are going to discuss hyperspectral remote sensing, another advanced remote sensing technology which is in use today. The unit deals with the basic concepts of hyperspectral remote sensing and sources of data. The unit will also give an overview of different techniques of hyperspectral data processing along with the applications of this technology.

6.3 BASIC CONCEPTS OF HYPERSPECTRAL REMOTE SENSING

Hyperspectral Remote Sensing (HRS) is a type of remote sensing that involves the use of tens to hundreds of different wavelengths for imaging. The imaging wavelengths which are used may be at a fixed distance from each other in the electromagnetic spectrum. HRS is also known as the "Imaging Spectroscopy" as it works on the principle of Spectroscopy. Spectroscopy is the technique of producing spectra, analyzing their constituent wavelengths as well as using them for chemical or physical analysis or the determination of energy levels and molecular structure. All objects have a unique reflectance and absorption pattern of electromagnetic radiation at different wavelengths. If this unique signature of objects could be captured, the identification of them would be easier. This led to the evolution of HRS, a technology which captures the reflection and absorption pattern of light at different wavelengths by different objects. The "Hyper" in hyperspectral means "too many" and refers to the large number of measured wavelength bands. In the case of conventional multispectral images only certain portions of the electromagnetic spectrum are captured which leads to loss of information on spectral profile of objects. A typical example showing the differences between multispectral and hyperspectral images is shown in Figure 6.1.

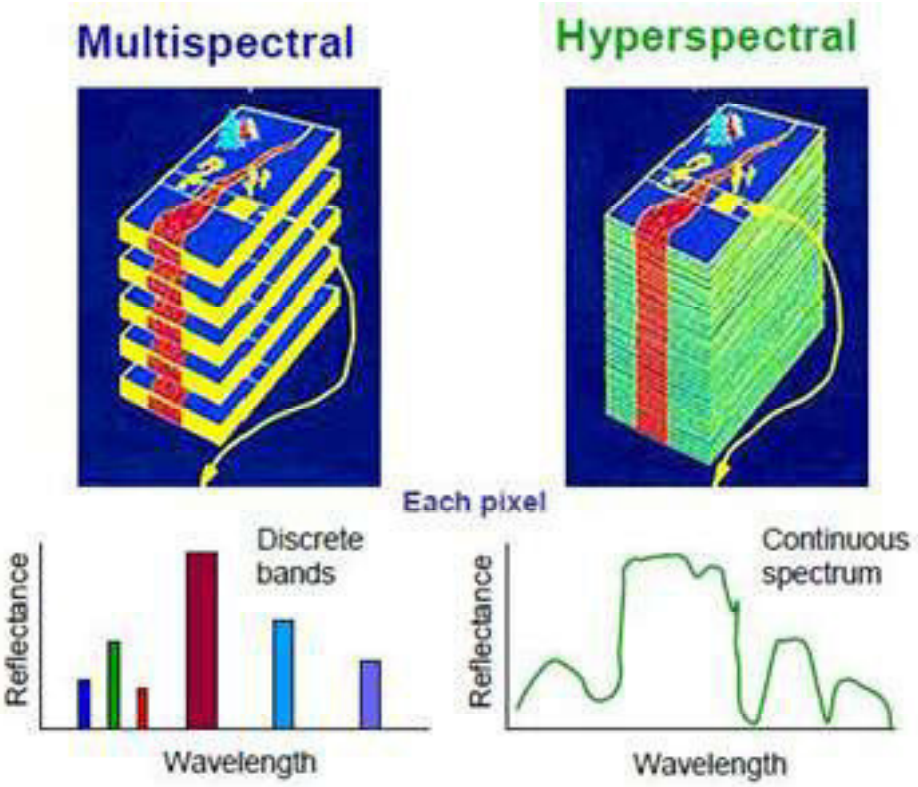


Figure 6.1: Multispectral vs. Hyperspectral remote sensing

In the 1980s, due to the limitations in spectral resolution of multispectral remote sensing, scientists at the Jet Propulsion Laboratory (JPL), getting support from NASA began, to develop instruments that could create images of the earth's surface at very high spectral resolutions. Whereas previous multispectral sensors were able to collect data in a few rather broadly defined spectral regions, these new instruments could collect data in 200 or more very precisely defined spectral regions. The invention of these instruments or sensors led to the start of 'Hyperspectral Remote Sensing' process. As the first airborne hyperspectral imaging spectrometer starts its operation, the earth observation community embraced the new technique in the 1990s. In recent years, HRS is being used for varied applications with major domains under geology, ecology, geomorphology, limnology, pedology, atmospheric science and forensic science.

Most of the sensors operate in narrow bands of the visible, near infrared regions and short wave infrared regions of the electromagnetic spectrum. The analysis of hyperspectral data involves using the reflectance of each pixel in each of the hundreds of bands, with many 'spectral reflectance curves' of various materials on the surface of the earth. Different bands in hyperspectral images can be visualized in 3D space as a data cube. The data cube represents spatial information in the x and y directions. The spectral information of various features can be seen in the z direction. An example of a data cube is given in Figure 6.2.

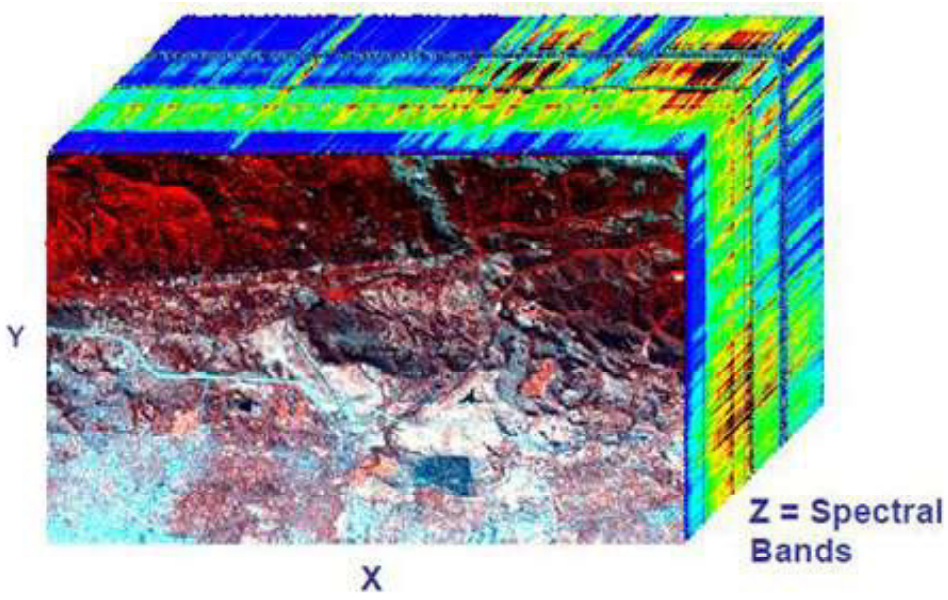


Fig. 6.2: Image Data Cube

At its core, spectroscopy works on the fact that different materials are made up of different constituents and structure. Thus they interact differently with light. The unique pattern of reflectance and absorption of light at different wavelengths by different objects is known as spectral signature of the object and the curve obtained by plotting the reflectances in the y-axis against the respective wavelengths in the x-axis is known as a spectral reflectance curve. Typical spectral reflectance curves of different land features are shown in Figure 6.3.

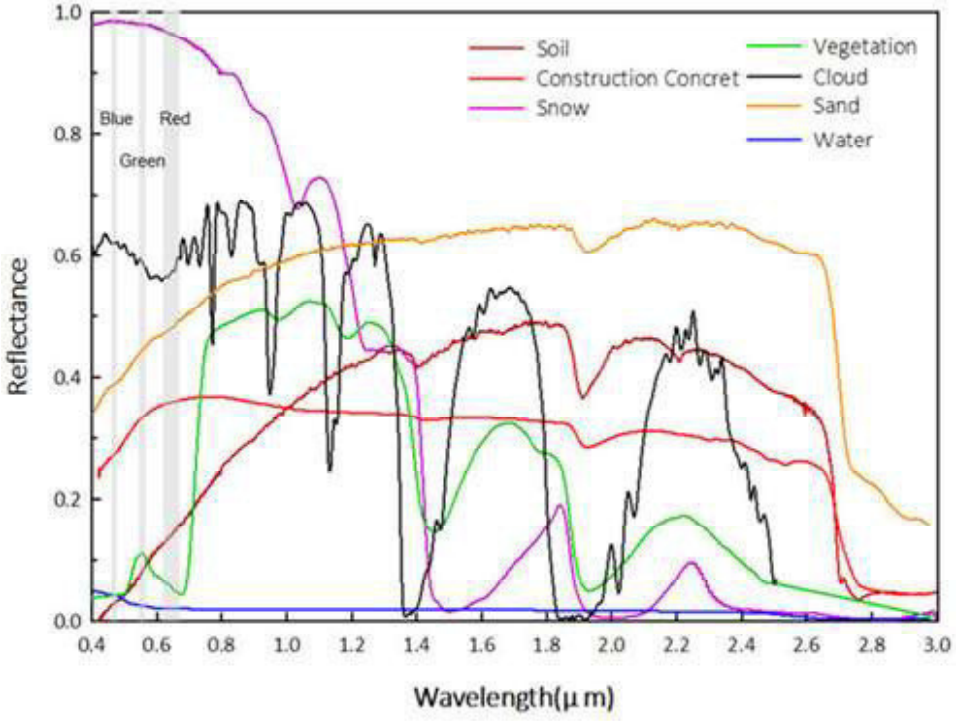


Figure 6.3: Typical spectral reflectance curves of earth materials

The reflectance spectra of most materials on the Earth's surface contain characteristic or diagnostic absorption features in the 400 to 2500 nm range of the spectrum. Since these diagnostic features are typically of a very narrow spectral appearance, those surface materials can be identified directly. Now-a-days sampling of the spectrum at a sufficiently high spectral resolution becomes possible by using imaging spectrometers. Remote sensors capable of acquiring complete reflectance spectra over large areas offer a powerful tool for study of the Earth and the environment. Reflectance spectrum absorption features can be used to identify a number of features on the earth's surface such as minerals, vegetation moisture and nutrient content, soil composition, detection of soil and water pollution etc.



CHECK YOUR PROGRESS

1. Fill in the blanks:

i. Hyperspectral remote sensing is also known as the Imaging _____.

ii. Hyperspectral images contain _____ of bands.

iii. _____ was the first organization to develop instrument for imaging in high spectral resolution.

iv. The curve obtained by plotting reflectance against respective wavelength is known as _____.

v. Different features on the earth's surface can be identified by the _____ features in the reflectance spectrum.

6.4 HYPERSPECTRAL MISSIONS AND SENSORS

The development of hyperspectral sensors was driven by geologists and geophysicists who discovered the potential of hyperspectral data for exploring minerals in the earth's surface. In the beginning, hyperspectral data could only be obtained through laboratory spectro-radiometers. Spectro-radiometers are instruments that can measure the reflectance of light by an object in different wavelengths of the electromagnetic spectrum. Various spectral libraries were developed with the help of these spectro-radiometers which provided the reflected spectral response of different objects on the earth. The airborne hyperspectral sensors were developed later.

The first HRS airborne sensor AIS 1 (Airborne Imaging Spectrometer) was developed by NASA which collected information in the SWIR region and became operational in 1984. AIS-1 provided images in 128 contiguous bands of the spectral region from 1.2 to 2.4 µm with a spectral resolution of 9.3 nm. A second generation instrument, AIS 2, started operating from 1986 and captured image over the spectral region from 0.8-2.4 µm, with a spectral resolution of 10.6 nm. A milestone in HRS development was the launch of AVIRIS (Airborne Visible / Infrared Imaging Spectrometer) by NASA in 1987

which captured images of 224 bands with a bandwisth of 10 nm in the 0.4-2.5 μm range. A number of airborne hyperspectral remote sensors were later developed by various organizations in different countries but the AVIRIS is still considered as one of the most successful airborne hyperspectral sensor for its timely maintenance and upgradation of the sensor over the years and the growing interest of the HRS community in using the data gathered through it. Other airborne hyperspectral sensors include the GERIS (Geophysical Environment Research Imaging Spectrometer) built by the GER Corp, USA in 1987, CASI (Compact Airborne Imaging Spectrometer) built by the ITRES Research Ltd., Canada in 1988, HYDICE (Hyperspectral Data Image Collection Experiment) developed by the Naval Research Lab, USA in 1996, Hymap Airborne Imaging Spectrometer developed by Australia in 1999 and ISRO's Airborne Imaging Spectrometer (AIMS) in 1996.

After airborne hyperspectral sensors, initiatives were undertaken by NASA in the 1990s to place an AVIRIS type sensor in the space. The TRW Lewis satellite was meant to be the first hyperspectral satellite system in 1997 but unfortunately the mission failed as NASA lost contact with it. But NASA later had a successful launch of the EO-1 satellite with the Hyperion sensor on board. It is one of the longest surviving HRS sensors in the space with 244 bands in the VIS-NIR-SWIR range of 10 nm bandwidth and a spatial resolution of 30 m. Other space-borne HRS sensors include ESA's CHRIS (Compact High Resolution Imaging Spectrometer) on board PROBA with 62 bands of 10 nm bandwidth and spatial reolution of 18 m in 2001, HSI (Hyperspectral Imager) with 384 bands of 5 nm bandwidth and 30 m spatial resolution and ISRO's HYSI (Hyperspectral Imager) on board IMS-1 (Indian Mini Satellite) launched in 2008 with 64 bands of 8 nm bandwidth in the VIR region.

Hyperspectral sensors are also used in planetary missions such as the HYSI and Moon Mineralogy Mapper (M3) onboard the Chandrayaan by ISRO, CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) onboard the Mars Reconnaisance Orbiter by NASA and OMEGA onboard Mars Express by ESA.

6.5 DATA CHARACTERISTICS AND PROCESSING

The main characteristic of hyperspectral data is the spectral resolution which is expressed in the form of number of bands. The spectral range and central wavelength covered by the sensor and bandwidth are other important characteristics of the data. All sensors suffer from random errors of which the predominant error is the sensor noise. The signal to noise ratio describes this error and the image data quality. One of the main challenges in processing Hyperspectral data is the complexity in data volume. Because of the high data dimensionality, data handling is a tedious task. Hyperspectral data pre-processing consists of two basic processes: **Radiometric Corrections** and **Geometric Corrections**.

6.5.1 Radiometric Corrections

Hyperspectral radiometric corrections can be of two types:

- Bad band removal and destriping
- Atmospheric corrections

Bad band removal and destripping:

Presence of bad bands are the inherent property of hyperspectral data. They are the bands comprising of no data in the absorption bands. Total image bands are finally resized by excluding bands, having no information. Just like bad bands, hyperspectral data might also have no information in certain columns due to problems in sensor calibration. A typical Hyperion data with missing data is shown in figure 6.4. These vertical stripes might be continuous or intermittent in nature. To correct the stripping, the corrupted pixels are replaced by the average of Digital Numbers values of their immediate left and right neighbouring pixels as neighbouring pixels have the highest spatial autocorrelation with the centre pixel.

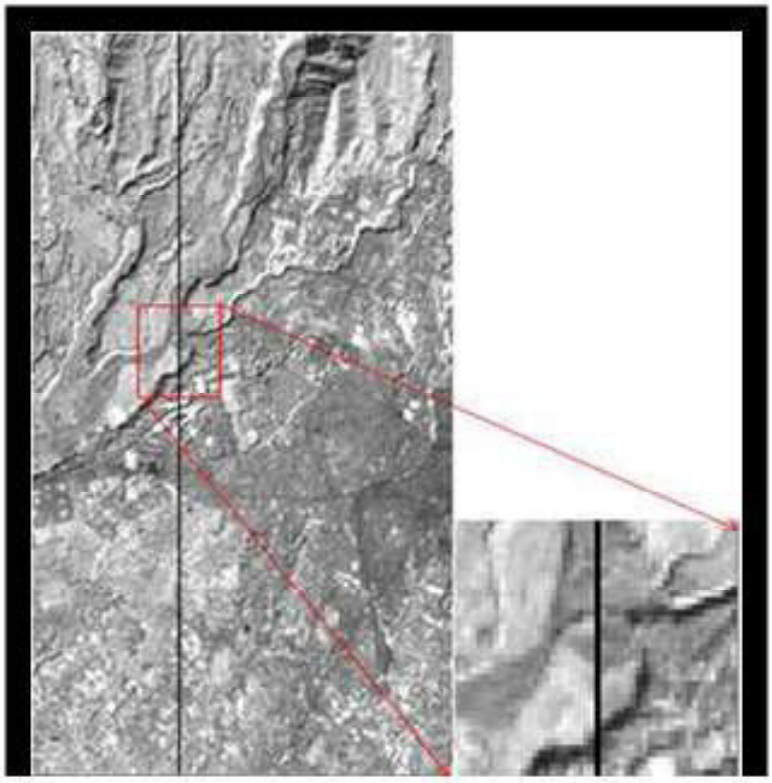


Figure 6.4: Missing data in a column of Hyperion image

Atmospheric corrections:

Atmospheric corrections in hyperspectral data is the correction of errors arising in the data due to changes in illumination, absorption and scattering at different wavelengths. Atmospheric gases, aerosols and clouds, usually scatter and absorb solar radiation and can therefore change the reflectance from targets. Figure 6.5 shows a hyperspectral image before and after atmospheric correction. Atmospheric correction of hyperspectral images essentially means the conversion of Digital Numbers (DN) to reflectance. The process involves the use of onboard calibration, in the absence of which various algorithms has been developed based on radiative transfer modelling. Atmospheric correction techniques can be divided into two types: relative and absolute.

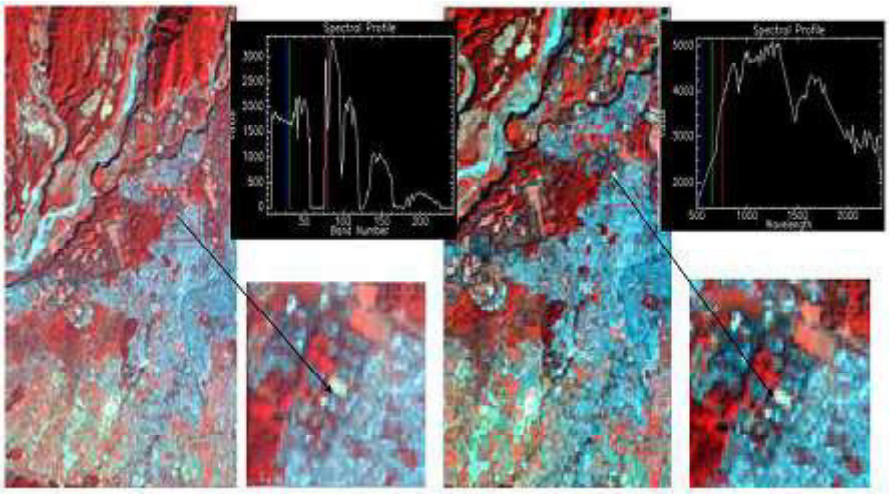


Figure 6.5: Part of Hyperion image (a) before and (b) after atmospheric corrections

Relative atmospheric corrections are scene based empirical approaches involving the image statistics, average spectrum, spectra of 'flat fields' (objects with no or very little variation in reflectance across wavelengths) or using field measurements for spectra of bright and dark objects.

Absolute atmospheric corrections take into consideration the actual atmospheric condition as well as sensor gain and offset, solar irradiances and solar zenith angle at the time of image acquisition to calculate surface reflectance. Several models have been developed for atmospheric correction using radiative transfer models. Some of the widely used models are Atmospheric and Topographic correction (ATCOR), Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercube (FLAASH) and High Accuracy Atmospheric Correction for Hyperspectral data (HATCH).

6.5.2 Geometric Corrections

The Geometric Correction is the correction in position of a pixel in image or geographical space. Geometric corrections may be needed for systematic errors such as scan skew due to the earth's rotation/ sensor velocity and panoramic distortions. These distortions are constant in nature and can be

predicted. Therefore, their correction only involves the use of mathematical functions for positioning. Image corrections on the basis of the Ground Control Points (GCP) involves the use of geographical coordinates for location of identifiable image points. The image to image registration is the relative positioning or alignment of two images with respect to each other so that same points on both images are lying on top of each other. Geometric corrections are necessary for various analysis involving change detection as it is absolutely necessary to determine the exact position of each point for detecting changes.

6.5.3 Image Classification

Due to the high data volume in different bands of hyperspectral images, reduction in data dimensionality is an integral part of the hyperspectral data processing. It is the first step before image classification methods are employed for feature extraction. The most widely used methods for reduction of data minesionality are **Principal Component Analysis (PCA)** and **Minimum Noise Fraction (MNF).** PCA is the transformation of data bands containing information into components based on variability. The first component measures the highest variation in the data and it is the component which contains the highest information. Less correlated data is represented in subsequent components and the last component basically contains only the noise in the data. Figure 6.6 shows a part of an AVIRIS hyperspectral image with two highly correlated images and a low corelated image depicting noise. Thus only those components which capture required information can be utilized for further analysis. The disadvantage of this procedure is that it does not make distinction between information and noise. MNF transformation is a two-step PCA which is better suited for reducing the dimensionality of hyperspectral data. It is a linear transformation that orders the data on the basis of signal to noise ratio. It partitions the data space into two parts: one associated with coherent images and other associated with noise dominated images. By using only the coherent images

in subsequent processing, the moise is separated from the data thus improving the results of the spectral processing.

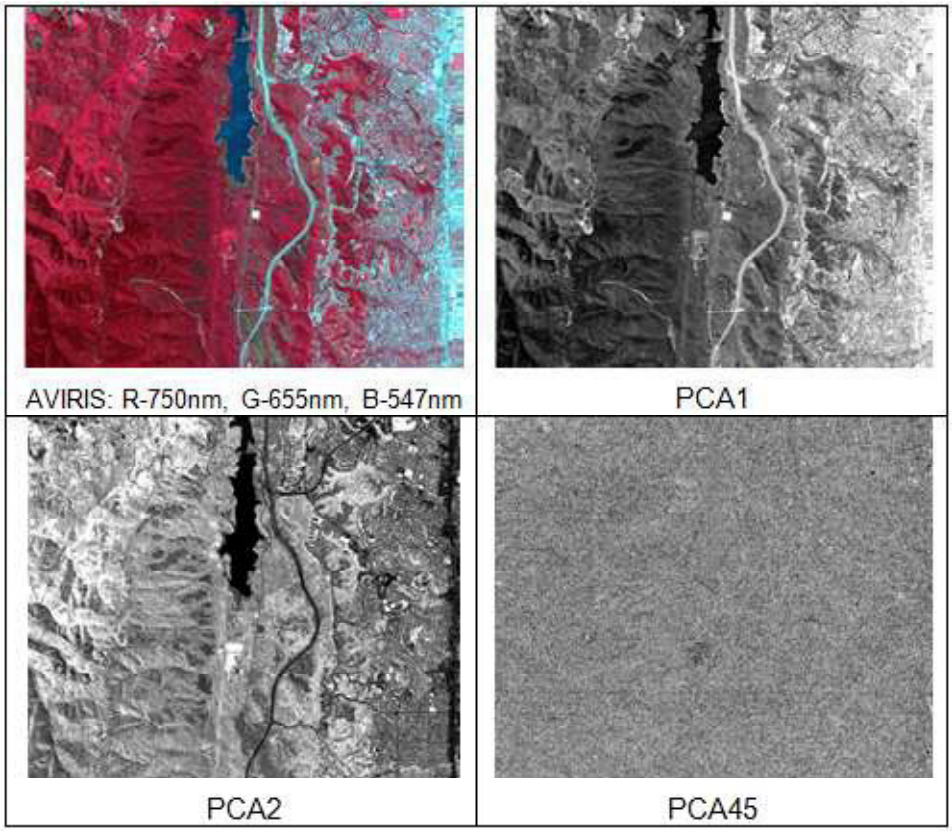


Figure 6.6: PCA components of a part of an AVIRIS image

Image classification is the categorization of data in an image into different feature classes on the ground. This involves the identification of pure homogenous pixels known as **end members** representing each feature class that can be used for classifying the entire image. The **Pixel Purity Index (PPI)** has been widely used for end member extraction to find the most “spectrally pure” pixels in the MNF image. Various classification techniques are used for classifying hyperspectral images. A few important classifying methods are:

- Spectral Angle Mapper (SAM)
- Artificial Neural Network (ANN)

- Support Vector Machine (SVM)
- Spectral Feature Fitting (SFF)
- Mixture Tuned Matched Filtering (MTMF)
- Linear spectral unmixing

The Spectral Angle Mapper (SAM) classifier calculates the spectral similarities between the reference spectrum (ASD spectrum) and the image spectrum. The angle between two spectra is used as a measure of discrimination. The Artificial Neural Networks (ANN) are widely used for landuse classification. It is a fuzzy classifier working on the principle of neural networks. It consists of a set of three or more layers, each made up of multiple nodes. Layers included one input layer, one or more hidden layers and one output layer. The nodes in the input layer represent variables used as input to the neural network and the nodes in the output layer represent the range of possible output categories to be produced by the network. The Support Vector Machine (SVM) is a classification technique in which classes are separated with a surface that maximises the margin between them. It uses boundary pixels to create the decisive surface. The data points that are closest to the hyperplane are termed as the “support vectors”. The SVM provides good classification results from complex and noisy data. The Spectral Feature Fitting (SFF) is an absorption-feature-based method for matching the image spectra to the reference end members spectra. The pixel spectra are compared to the target spectrum using two measurements: the depth of the feature in the pixel is compared to the depth of the feature in the target and the shape of the feature in the pixel is compared to the shape of the feature in the target (using a least squares technique). The Mixture Tuned Matched Filtering (MTMF) technique performs a partial unmixing - it maximizes the response of the known end member and suppresses the response of the composite unknown background, thus “matching” the known signature. It produces a series of gray-scale images with values ranging from zero to one where 1 is the perfect match with the reference spectrum and 0 is a no match. The linear spectral unmixing method is used for solving the mixed pixel problem. A linear relation is used to represent the spectral mixture of targets within the pixel of remote sensing

system. It is possible to model each pixel spectrum of the hyperspectral image as a linear combination of a finite set of components.



CHECK YOUR PROGRESS

2. State whether the following statements are true or false:

i. The first successful space-borne hyperspectral sensor was the Hyperion sensor onboard EO-1.

ii. The HYSI and the Moon Mineralogy Mapper are hyperspectral sensors launched by NASA.

iii. Bad line correction is a type of atmospheric correction method.

iv. Pixel Purity Index is a criterion for selecting end members.

v. Artificial neural network is a type of crisp classifier.

3. Give the full forms of the following abbreviations:

i. AVIRIS

ii. HYSI

iii. FLAASH

iv. MNF

v. SAM

6.6 APPLICATIONS OF HYPERSPECTRAL REMOTE SENSING

The first applications of hyperspectral remote sensing were primarily in the field of Geology for mineral identification. With the advancement in image analysis methods, the scope of using hyperspectral images in various fields have emerged. Some of the major application areas where hyperspectral data are used are given below:

Atmospheric sciences: In the field of atmospheric sciences, hyperspectral remote sensing method can be used for various studies related to atmospheric composition, study of cloud characteristics like structure and distribution, aerosol properties, water vapur content and detecting variations in atmospheric gases.

Geology: In geology, hyperspectral remote sensing method has been used for a long time for identification of different minerals. Mineral mapping, lithological mapping and geobotanical mapping are some of the areas in which hyperspectral images have been effectively utilised.

Agriculture and land: Hyperspectral remote sensing method has been widely used for vegetation studies including species identification, nutrient analysis, biochemistry, pest and disease identification, moisture content analysis, crop growth and yield estimation studies, etc. The HRS has also been used for estimating soil properties including moisture, organic content, and salinity.

Forestry: In forestry, the HRS method has been widely used for species identfication, chlorophyll content, canopy chemistry and to detect vegetation stress.

Environmental monitoring: Besides monitoring of pollutants in the atmosphere and soil, the HRS method can also be used for detecting oil spills, suspended matter, water quality assessment and detection of photosynthetic potential.

Water resources: Spatial distribution of snow cover, surface albedo and snow water equivalent, calculation of energy balance of a snow pack, estimation of snow properties-snow grain size, snow depth and liquid water content are some of the HRS applications in the cyrosphere.



6.7 LET US SUM UP

- Hyperspectral Remote Sensing (HRS) is the type of remote sensing which utilizes information from hundreds of bands in different wavelengths and is also known as the 'Imaging Spectroscopy'.
- The HRS may be of three types: terrestrial (handheld), airborne (aircrafts/UAVs) and space-borne (satellites).
- Hyperspectral data is composed of hundreds of bands which can be visualized in the 3-D space as a data cube.
- The HRS uses the spectral curves of different materials on the earth's surface to identify them.

- Different countries have developed their own hyperspectral sensors of which the Hyperion sensor developed by NASA is the most popular and widely used.
- Two types of pre-processing is required for hyperspectral data: radiometric and geometric corrections.
- Reduction in data dimensionality is an integral part of the hyperspectral data processing before the feature extraction.
- End member selection is the first step before doing image classification which involves the selection of purest pixels from the hyperspectral data.
- Various types of advanced classification techniques are available for handling the huge data volume associated with the hyperspectral data.
- The of HRS applications are used in geology, atmosphere, vegetation and environmental monitoring. Its application is increasing with newer emerging analysis methodologies.



6.8 FURTHER READINGS

1. Campbell, J.B., *Introduction to Remote Sensing*, Published by Taylor & Francis.
2. Manfred Wendisch and Jean-Louis Brenguier, eds., *Airborne Measurements for Environmental Research: Methods and Instruments*, Published by Wiley-Verlag.
3. Richards, John. R, and Jia, X., *Remote Sensing Digital Image Analysis,* Published by Springer.
4. Thomas Lilesand, Ralph W. Kiefer and Jonathan Chipman, *Remote Sensing and Image Interpretation*, Published by Willey.
5. Ruiliang Pu, *Hyperspectral Remote Sensing – Fundamentals and practices*, Published by Taylor & Francis

6.9 ANSWERS TO CHECK YOUR PROGRESS

Q. No. 1: Fill in the blanks:

i. Spectroscopy

ii. Hundreds

iii. NASA

iv. Spectral curve

v. Absorption

Q. No. 2:True or False:

i. True

ii. False

iii. False

iv. True

v. False

Q. No. 3: Full forms of abbreviations:

i. Airborne Visible/Infrared Imaging Spectrometer

ii. Hyperspectral Imager

iii. Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercube

iv. Minimum Noise Fraction

v. Spectral Angle Mapper

6.10 MODEL QUESTIONS

Q.1. What is hyperspectral remote sensing? How does it differ from multispectral remote sensing?

Q.2. Give a brief outline of the history of development in hyperspectral sensors.

Q.3. What is a data cube? How can spectral curves be used for identification of features?

Q.4. What are the types of radiometric corrections that can be performed on hyperspectral images?

Q.5. What is an end member? Name different data dimensionality reduction methods used to gather hyperspectral data?

Q.6. Give a summary on the classification methods that can be used for extracting features from hyperspectral data?

Q.7. What are the major application areas that the hyperspectral remote sensing method is used?

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UNIT- 7: AERIAL PHOTOGRAPHS

UNIT STRUCTURE

7.1 Learning Objectives

7.2 Introduction

7.3 Basic Concepts of Aerial Photography

7.4 Types of Aerial Photography

7.4.1 Vertical photographs

7.4.2 Oblique Photographs

7.5 Photogrammetry

7.6 Let us Sum up

7.7 Further Reading

7.8 Answers to Check Your Progress

7.9 Model Questions

7.1 LEARNING OBJECTIVES

After reading this unit, you will be able to-

- explain the concept of Aerial Photography
- describe about different types of aerial photos
- illustrate about photogrammetry
- get the idea of the applications of aerial photography.

7.2 INTRODUCTION

In the previous unit, you have learnt about the Hyperspectral Remote Sensing method and its applications. In this unit, we are going to discuss Aerial Photographs and Photogrammetry which are parts of another type of remote sensing technology. The unit deals with the basic concepts of Aerial Photographs and different types of aerial photos. The unit is also going to put some light on Photogrammetric techniques in remote sensing methods along with applications of technology.

7.3 BASIC CONCEPTS OF AERIAL PHOTOGRAPHY

Aerial Photography is capturing photos from any aerial platform. Platforms of such photography may be anything from pigeons and hot air balloons in earlier times to Unmanned Aerial Vehicles (UAVs) in recent times. The most common aerial platform is an aircraft or a helicopter or drones. Though aerial photographs are also a type of remote sensing dataset, it has the advantage of synoptic, top view for small areas in larger scale. Taking pictures from the ground gives us only a perspective view of an object. While studying spatial relationships it is important to see things in a larger view and a top view gives the best view of the landscape so that all features on the ground can be seen and mapped by using the principles of **photogrammetry**. Aerial photographs have an advantage over satellite images in the context of data availability as these can be obtained for whichever dates required by doing a fly-through. It is also possible to get 3-D images from aerial photographs. So height estimations and creation of Digital Elevation Models (DEM) can be done using aerial photos. Figure 7.1 shows an area in Mumbai in perspective and top view. The top view image (below) clearly captures the geographical and land use changes in comparison to the perspective image (top).



Figure 7.1: Perspective and top (nadir view) in photographs
(*Source: https://unequalscenes.com/mumbai (c) Johnny Miller*)

Gasper Felix Tournachon was the first person to take an aerial photograph in 1858 of a village in France from a hot air balloon. During the first world war, aerial photographs were extensively used for ***reconnaissance*** and were taken by tying cameras to pigeons. The cameras were automated to capture photos in certain time intervals and photographs were captured as pigeons flew over an area. Fighter planes were also used for capturing photos during the World War I. Aerial photography in India goes back to 1920 when large scale aerial photographs of Agra city were first captured. Soon after, the Air Photo unit of the Survey of India took a lot of aerial photos of different parts of India for various purposes.

Reconnaissance : It is the initial step of any land survey, where it is tried to get the overview and basic information of the area.

In earlier times, a camera with a large roll of special photographic film was mounted on an aerial platform like aircrafts for aerial photography. Now-a-days since the invention of digital sensors in photography, aerial photographic film is replaced by digital sensors. A major difference between remote sensing sensors and aerial cameras is that aerial camera sensors are frame based just like general as well as mobile phone cameras. On the other hand, remote sensing sensors used in satellite based platforms are based on technologies like the scanning or the pushbroom. The major benefit of the frame based sensor is that it preserves geometry. The geometry of an aerial photograph is basd on the fundamental concept of collinearity. In vertical aerial photography, three points must always fall on a straight line: the imaged point on the ground, the focal point of the camera lens, and the image of the point on the film or imaging array of a digital camera. Figure 7.2 shows the geometry of vertical photographs for a ***flightline***. At every instant of exposure, the camera photographs an area on the ground known as the Field of View (FOV).

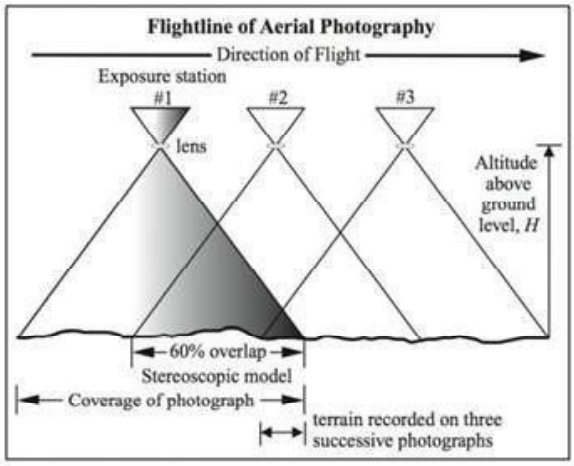


Figure 7.2: Flightline of aerial photography (*Source: Jensen, 2007, Remote Sensing of Environment*)

Flightline:
It is a planned path for conducting aerial photography.

The scale of aerial photographs is dependent on the altitude from which the photograph is captured. High altitude photography produces small scale images and covers a larger area on the ground whereas low altitude photographs cover smaller areas on the ground with larger scale.

The advantage of aerial photography is the generation of stereo pairs with sufficient side overlaps between two adjacent images. Stereo pairs can be used for height estimations and creating 3-D models (DEM). Another advantage of aerial photography is that higher resolutions can be achieved because of the close proximity of the platform in comparison to satellite images. It also has the advantage of acquiring images whenever required irrespective of time and place.

Aerial photography is increasingly used in recent times for various applications. In agriculture, it is used for precision farming and crop monitoring. It can be easily used to identify problem areas of any event of interest. During the time of disasters such as floods, landslides, earthquakes, etc. aerial photography can be used to map areas affected and for timely implementation of rescue and relief operations. Since 3-D models can be prepared from aerial photographs it also becomes easy to compute areas displaced or removed in terms of volume for landslides. In archeology, aerial photographs can be used to find signs of underground monuments and ruins. In urban studies, aerial photography has high scope right from mapping infrastructure to creating 3-D city models which are termed as Digital Surface Models (DSM). The high resolution availability of vertical photographs from aerial platforms can be effectively used for detailed mapping of small areas.



CHECK YOUR PROGRESS

1. Fill in the blanks:

i. Aerial photos can be used to create Digital _____ Models of the earth's surface.

ii. The first aerial photo was captured from a ____.

iii.During the World War I, _____ were used for taking pictures for reconnaissance.

iv. The scale of aerial photos is dependent on the _____ of the aircraft.

v. Aerial photos can be used to generate ____ using two images with sufficient side overlap.

7.4 TYPES OF AERIAL PHOTOGRAPHY

Aerial photos may be classified into two distinct types based on the position of the camera axis during the photo capturing moment. These are: (1) Vertical Aerial Photographs and (2) Oblique Aerial Photographs.

7.4.1 Vertical Photographs

Vertical aerial photos are such photos which are taken from directly above the object. So the position of the camera is perpendicular to the object on the ground. In these photos what we see is the top view or the plan view with no perspective of objects on the ground and everything looks flat. So objects at a height cannot be distinguised from objects at ground level.

Figure 7.3 shows the geometry of a vertical photograph. The vertical axis is perpendicular from the camera lens in the aerial platform to the ground whereas the camera axis is perpendicular from the camera lens to the object captured by the camera at a certain instant. For vertical photographs, the camera axis and the vertical axis have to be the same.

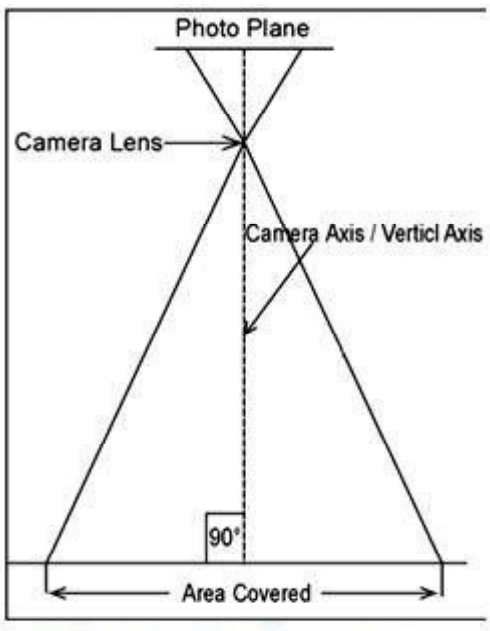


Figure 7.3: Vertical photographs

In reality, maintaining a truly vertical camera axis is practically not possible due to continuous movement of the aerial platform. Therefore, a tolerance

of 3 degrees is allowed for capturing vertical images. The advantage of vertical photograph is that maps can be easily created from them as its gives a plan view of the ground. Vertical photos capture a square area on the ground and the scale of the objects in the image corners remains relatively uniformed unless lens distortions are involved. They can be used for creating stereo pairs which can be used for height estimations and creating 3D images.

7.4.2 Oblique Photographs

Oblique photographs are those aerial photos which are taken at an angle to get a wider and perspective view of the object. In such aerial photos, the camera axis and the vertical axis are not the same as an angle is created between them. Oblique photos give a perception of the height of objects. They are mostly used for reconnaissance surveys to get a wider context of features and the area around it as well as to provide depth. Oblique aerial photographs are: low oblique and high oblique photographs.

Low oblique photos are those aerial photos in which the angle between the camera axis and the vertical axis is more than 3 degrees but less than 30 degrees. This type of photography covers a larger area on the ground compared to vertical photographs. It gives an idea on the perspective of objects on the ground. The coverage of these photographs on the ground is trapezoidal and scale decreases from the foreground to the background, creating a distortion in image features.

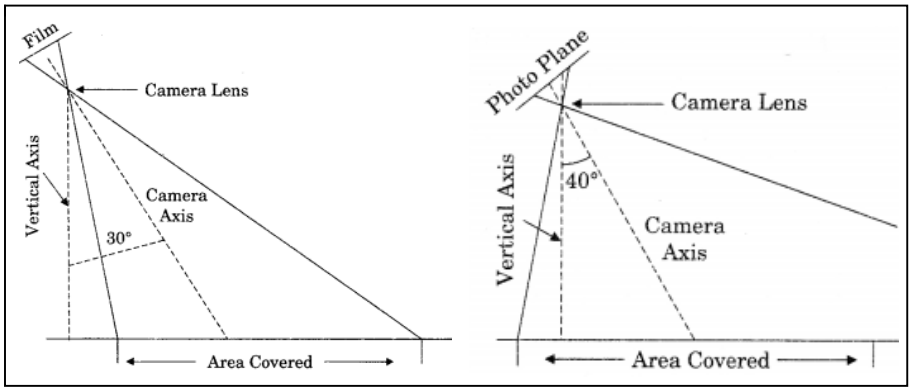


Figure 7.4: Low oblique and high oblique photography

High oblique photos are aerial photos in which the angle between the camera axis and the vertical axis is greater than 30 degrees. This type of photography covers the largest area on the ground and the horizon is visible in such photos. These type of images has the largest distortion in image scale and are mostly used for capturing illustrative and panoramic visuals. Choosing the appropriate time of the day and position of the sun relative to the camera is very important for such photographs as shadows and other radiometric problems can be easily introduced in such type of photography. Figure 7.5 (a), (b) and (c) show different types of aerial photographs, (i.e. vertical, low oblique and high oblique respectively for the same area).







Figure 7.5: Different types of aerial photos based on position of camera axis; (a) vertical, (b) low oblique, and (c) high oblique of the same area
(Copyright: Priyanuz Goswami)



CHECK YOUR PROGRESS

2. State whether the following statements are true or false:

i.In vertical aerial photos, the perspective view of objects is visible.

ii. For vertical photographs, the camera axis and the vertical axis are the same.

iii. A tolerance of 5 degrees from nadir is allowed for vertical images.

iv. Oblique aerial photos cover a smaller area on the ground compared to vertical photographs.

v. In high oblique aerial photos, the angle between the camera axis and the vertical axis is greater than 30 degrees.

7.5 PHOTOGRAMMETRY

Photogrammetry is the science of making measurements using photographs. Photogrammetry is as old as modern photography and can be dated to the mid-nineteenth century. Photogrammetry can be used to create 3-D models of the earth's surface and objects on it. It involves making precise measurements from photographs and its most common applications were making topographic and planimetric maps. Now-a-days, photogrammetry is used to make highly accurate 3-D models of the real world.

Photogrammetry primarily uses vertical photographs where the scale is maintained throughout the image for making measurements. Based on the type of vertical photographs used for measurements, photogrammetry may be classified into three types: Terrestrial Photogrammetry, Aerial Photogrammetry and Space Photogrammetry

Terrestrial photogrammetry is the type of photogrammetry where the camera used for capturing vertical photographs of the surface is mounted on a terrestrial platform. The height of the camera is known so it is possible to calculate distances and heights of objects on the photograph.

Aerial photogrammetry involves the measurement of features on vertical aerial photographs taken from an aerial platform such as an aircraft. Multiple photographs with overlaps along the flight line can be captured which can be used to obtain stereo pairs which in turn can be used to obtain 3-D models of the surface.

Space photogrammetry refers to measurements on satellite images. Satellite images are mostly vertical and some satellites also provide stereo images which can be used to create Digital Elevation Models (DEMs).

The basic requirements for photogrammetry are Vertical Photographs, **Ground Control Points** (GCPs) and **stereo pairs**. GCPs are easily identifiable prominent locations on the image whose actual location and height are known. They are needed to establish a relationship between the photograph and the actual ground. Stereo Pairs are pairs of overlapping images which are needed to create 3-D models. Standard overlap between

images required for creating 3-D models is 60% but for hilly terrain, an overlap of 80-90% may be required.

In reality, a truly vertical photograph is rarely attainable because of the camera movement. Such kind of error in a vertical photograph due to the camera tilt may be of three kinds: roll, pitch and yaw. Roll is the sideways tilting of the camera, pitch is the forward or backward tilting and yaw is the tilt in the direction of aircraft movement.

In the vertical aerial photography, central or perspective projection is used as shown in Figure 7.6. Therefore, besides change in the scale, change in the relative position and geometry of objects are also changed based on the location of the camera. The scale of aerial photographs is calculated by the formula: Photo distance/ ground distance, i.e. the distance between two points on the photograph to the distance of the same points on the ground or the actual distance between the points. The scale of the photograph can also be determined by the ratio between the camera lens' focal length and the altitude of the camera from the object being photographed on the ground.

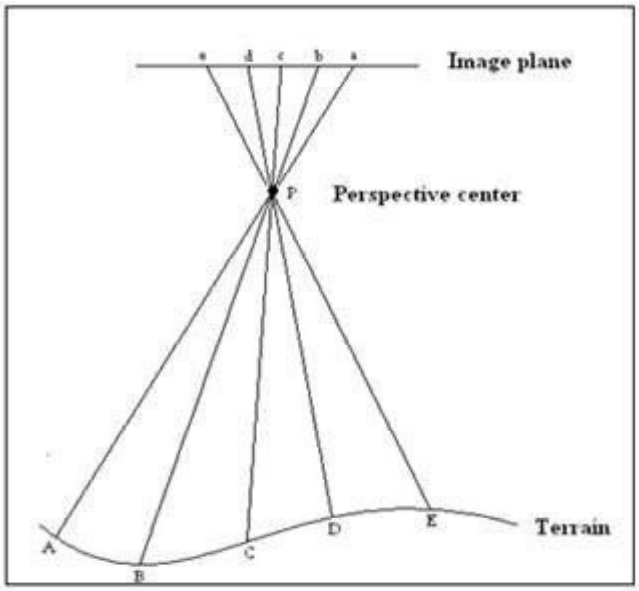


Figure 7.6: Central Perspective projection in aerial photography

Due to the central perspective projection in aerial photography, the objects on the surface with a certain height appear displaced in the photograph. This displacement due to relief or surface undulations is known as the **relief displacement**. The Relief displacement is used for measurement of height of objects and is useful in creating height models. The Relief displacement is directly related to the distance of the object from the nadir and also the

flying height. The Relief distortion is the minimum or absent in the nadir and it increases towards the edges. The Relief displacement is used for topographic mapping and stereo viewing.

The concept of **parallax** is very important for stereo-photogrammetry. Parallax refers to the apparent change in the relative position due to change in the viewing position. Stereo-photos use two images of the same location taken from different positions just like our two eyes have a distance between them in order to view the same object from two different angles to help us to visualize objects in 3-D forms.

To depict objects in their true location and use aerial photographs as maps, it is important to convert the central perspective projection of the image into an orthographic one. This is achieved by normalising the height which is done using the DEM. This results in removing relief displacements in order to depict objects in their true location. The scale remains constant in all parts of the photograph. Such an image which gives true locations of surface objects without distortions is known as an **orthophoto**. Orthophotos are increasingly being used in the field of GIS for creating maps of areas photographed with uniform scale.



CHECK YOUR PROGRESS

3. Answer the following in one word:

i. Name the type of photogrammetry where the camera used for capturing vertical photographs of the surface is mounted on a platform on the ground.

ii. Name the points on an image whose actual location and height are known.

iii. Which type of photo distortion is caused due to the sideways tilting of the camera?

iv. Which term is used to refer to the apparent change in the relative position due to change in the viewing position?

v. What is generated after normalizing the heights in an aerial photograph?



7.6 LET US SUM UP

- Aerial photography is the process of taking images from an air-borne platform and dates back to as far as modern photography.
- Aerial photography is also a type of remote sensing technology which has the advantage of choosing the time and place of coverage and covering relatively smaller areas with higher details as it is possible to go near the object.
- Aerial photography has a wide application field and is mostly used in agriculture, geology, forestry, archaeology, disaster management and in urban studies mostly for building 3-D city models.
- The geometry of aerial photography is based on the fundamental concept of collnearity. The focus of the camera lens, the object and the image lie on the same axis and they are known as the camera axis. The angle of the camera axis with the vertical axis determines the type of aerial photography.
- Based on the position of the camera axis there are two types of aerial photography: vertical and oblique.
- Vertical aerial photographs can be used for various remote sensing applications and creating maps. Overlapping vertical images can be used as stereo pair to generate digital elevation models.
- Photogrammetry is the science of measurements using images. It may be of three types based on the type of image used for measurements: terrestrial, aerial and space.
- Photogrammetry primarily uses vertical photographs where the scale is maintained throughout the image for making measurements.
- Ground Control Points are required to locate the accurate position of the image and stereo pairs are required to obtain the height from images.
- The scale of an aerial photograph can be determined from the focal length of the lens and the altitude of the lens from the object.

- A lot of distortions arise in aerial photos due to the camera tilt, movement of the aerial platform as well as the height of the objects in the image.
- The image obtained after correcting the relief displacement in aerial photos is known as ortho-photo. Ortho-photos can be used to create maps.



7.7 FURTHER READINGS

1. David P. Paine and James D. Kiser, 2003. *Aerial photography and image interpretation,* 3rd Edn. Published by John Wiley & Sons.
2. John R. Jensen, 2000, *Remote Sensing of the Environment: An Earth Resource Perspective*. Published by Prentice Hall.
3. Manfred Wendisch and Jean-Louis Brenguier, eds., *Airborne Measurements for Environmental Research: Methods and Instruments*, Published by Wiley-Verlag.
4. Thomas Lilesand, Ralph W. Kiefer and Jonathan Chipman, *Remote Sensing and Image Interpretation*, Published by Willey.



7.8 ANSWERS TO CHECK YOUR PROGRESS

Q. No. 1:

i. Elevation
ii. Hot air balloon
iii. Pigeons
iv. Altitude
v. Stereo-pair

Q. No. 2:

i. False
ii. True
iii. False
iv. False
v. True

Q. No. 3:

i. Terrestrial photogrammetry
ii. GCP (Ground Control Points)
iii. Roll
iv. Parallax
v. Ortho-photo



7.9 MODEL QUESTIONS

Q.1. What is an aerial photography? Explain the geometry of an aerial photograph?

Q.2. What are the types of aerial photographs?

Q.3. Give an account of the history of aerial photography. What are the major application areas of aerial photography?

Q.4. What is photogrammetry? Briefly describe the types of photogrammetry.

Q.5. What are the basic requirements for photogrammetry? How is the scale of aerial photographs determined?

Q.6. What is the scale of an aerial photograph if the flying height is 300 m and the focal length of the camera is 15 cm? What would be the actual length of a bridge measuring 2 cm on the image?

Q.7. What are the major distortions that might be seen in an aerial photograph?

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UNIT- 8: IMAGE ENHANCEMENTS AND INTERPRETATION

UNIT STRUCTURE

8.1 Learning Objectives

8.2 Introduction

8.3 Basic idea of Image Enhancement Techniques

8.4 Elements of Image Interpretation

8.5 Techniques of Visual and Digital Interpretation

8.6 Let us Sum up

8.7 Further Reading

8.8 Answers to Check Your Progress

8.9 Model Questions

8.1 LEARNING OBJECTIVES

After reading this unit, you will be able to-

- describe the basic principles of image interpretation
- explain the decoding techniques of different imagery
- list out the elements of image interpretation
- discuss the techniques of visual interpretation.

8.2 INTRODUCTION

In the previous unit you have learnt about the aerial photography. In this unit you will know about the image enhancement and interpretation process used in the remote sensing method. You will also be introduced to the decoding techniques of different imagery. In this unit you will also read about the elements of image interpretation. This unit will also help you to understand the techniques of visual interpretation.

8.3 BASIC IDEA OF IMAGE ENHANCEMENT TECHNIQUES

Image interpretation is the main and ultimate objective of remote sensing applications. Satellite imagery of different resolution and band combination are first enhanced through different image enhancement techniques to make images more interpretable to extract various information of the earth surface. Histogram equalization, filtering and contrast adjustmennt are some of the techniques of image enhancement. Interpretation keys like colour, tone texture, association, shape etc. are used to extract information. The outcomes of image interpretation help not only to generate maps in desired scale but also provide correct area statistics of different earth's features.

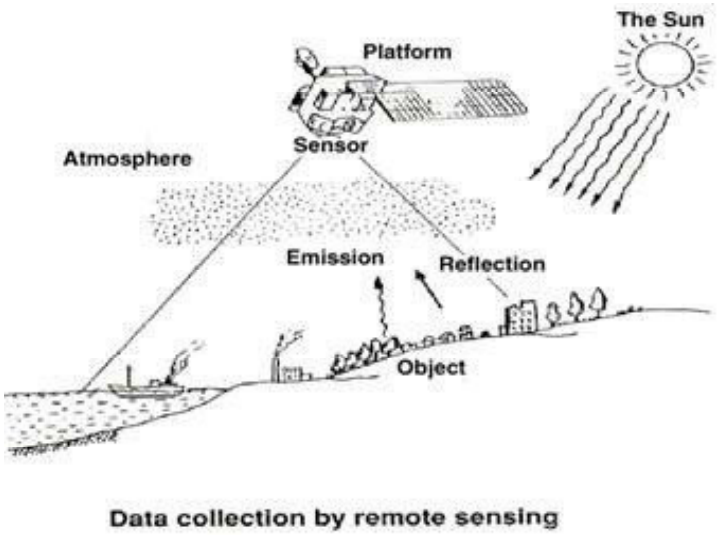


Figure 8.1 Data collection by remote sensing method.

In the figure, rays of the sun falling upon the earth surface are reflected by different earth features like vegetation, water body, building etc. Different amount of sun beams are detected and recorded by sensors of space platform, i.e. satellite, and sent back to the earth's receiving centre for generation of satellite image.

Different earth features behave differently in different bands. Based on the spectral behaviour of different features in different bands different earth

features can be identified. This can be easily understood from spectral reflectance curves of different features.

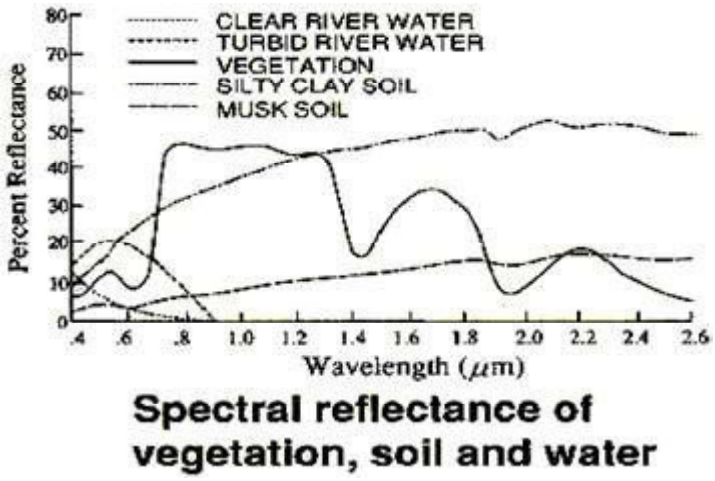


Figure 8.2: Spectral reflectance curve of different earth's features.

The figure 8.2 shows that both water and vegetation show almost the same amount of reflection in green and red band i.e. upto 0.6 μm (micrometer), but in the infrared region vegetation shows high reflection whereas water shows continuous decline in reflection towards the infrared band. This makes the interpreter convenient to identify water body from vegetation in the infrared band. Similarly, same features at different stage also may behave differently in different wave lengths or bands which make us enable to identify crops at different stage or we can separate different crops from the same area. This principle can be applied in identification of different forest species. Hence, it can be inferred that more is the numbers of bands more is the possibilities to extract information.

The image enhancement techniques are discussed in details in unit 6 of course 3 of this programme.



CHECK YOUR PROGRESS

Q. No.1: Name some image enhancement techniques.

.....

.....

8.4 ELEMENTS OF IMAGE INTERPRETATION

The elements or keys of image interpretation are colour, tone, texture, association, pattern, shape, size etc. All these elements are discussed below.

Colour: The colour composite assigns three primary colours namely blue, green and red to three different bands. These three bands are used to extract information of earth features. The standard FCC (False Colour Composite) is composed with green, red and Infra red band by assigning blue colour to green band, green colour to red (band 3) band and red colour to infra red (band 4) band. Since, blue (band 1) and green (band 2) bands show high correlation, therefore blue band is discarded to avoid data redundancy. As vegetation shows high reflection in infra red band, therefore, red colour implies vegetation in FCC.

Tone: Tonal variation within the same colour indicates variation within the same feature. For example, deep red tone indicates dense vegetation whereas, light pink indicates grass.

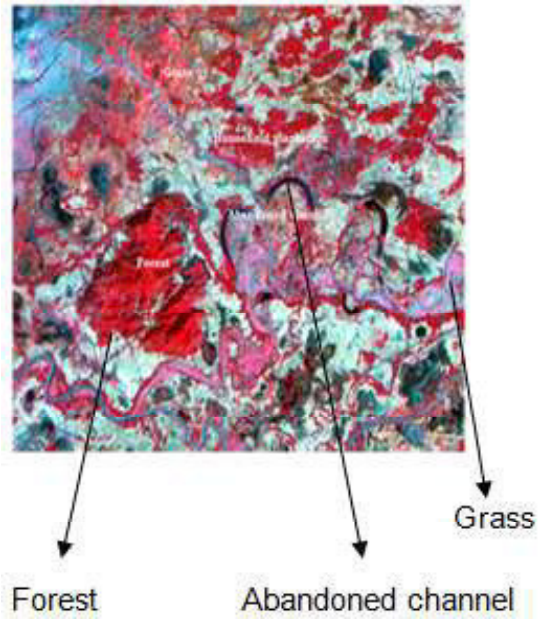


Figure 8.3: Different earth's features exhibit different colours, tonal variation seen in a FCC satellite image

Texture: Textural variation within the same colour also may be a key to identify different features. For example, smooth textured red colour indicates grassland, whereas coarse textured red colour may indicate homestead plantation or forest.

Shape: Shape is another key to identify some features like reservoir, river, wetland, abandoned channel, railway, road etc.

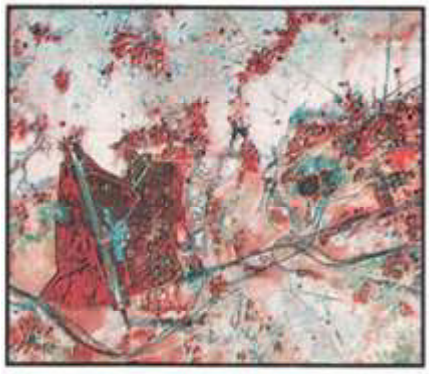


Figure 8.4: Airport Runway is clearly visible because of its linear shape.

Association: Blackbody features within a forest may not be a wetland but may be burnt grasses. Similarly, cloud is associated with black shadow which might be sometimes misinterpreted as a water body.

Pattern: pattern may also be an interpretation key to identify high land or low land. Rivers have meandering patterns.

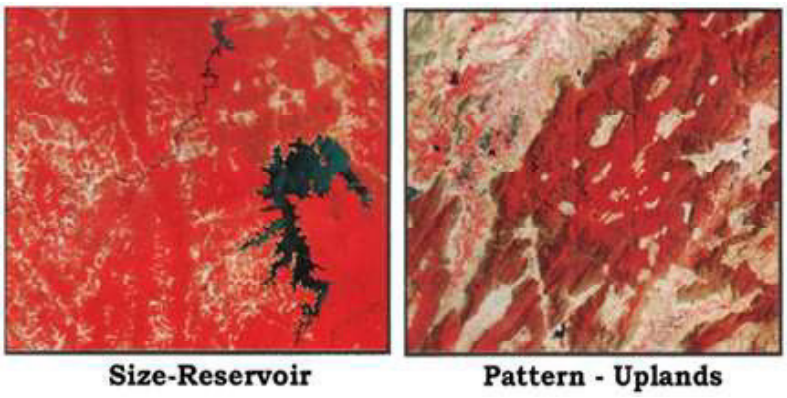


Figure 8.5: Interpretation key for reservoir and upland by means of size and pattern.

Size: straight line may indicate a railway or airport. But it also may be a dyke or a geological fault.



CHECK YOUR PROGRESS

Q. No.2: What are the elements of image interpretation?

.....

8.5 TECHNIQUES OF VISUAL AND DIGITAL INTERPRETATION

Interpretable satellite data comes in two formats. They are–

(1) Paper print or photographic print either as black & white imagery or false colour composite photographic product. Visual interpretation technique is used to interpret this kind of satellite data.

(2) Computer compatible digital data. Digital Image processing technique is used to interpret this kind of data.

Visual interpretation is done on a FCC (False colour composite) paper product. The vector polygons may be created for various features by considering digital data in GIS platforms. The FCC is an image formed by assigning colours arbitrarily to two or more black and white images of a single scene. This means that a particular band is assigned other than its normal colour so as to make the scene easily interpretable. For example, If band 2 or green band of the IRS data is assigned blue, band 3 or red band is assigned green and band 4 or infrared band is assigned red colour than the output product will be a false colour composite (i.e. bands are not assigned their true colour rather assigned false colour). Selection of bands for the FCC can be done by calculating the Optimum Index factor (OIF). The OIF is a parameter which ranks the three bands combinations. It is calculated as–

$$OIF = \frac{\sum_{k=1}^{3} S_k}{\sum_{j=1}^{3} Abs(r_j)}$$

Where S_k is the ***standard deviation*** for band k. r is the absolute value of correlation coefficient between any two of three bands. The three band combination with the largest OIF will have the most information (by variance) with least amount of duplication (by correlation).

Standard Deviation: It is a measure that is used to quantify the amount of variation of a set of data.

Earlier, Visual interpretation was done on the FCC paper print of fixed scale. The quality of such print could not be enhanced by contrast or edge enhancement or enlargement. Now-a-days, with the development of software, visual interpretation is done with the help of all kinds of enhancement and other image processing techniques.

Visual interpretation done by using the FCC paper print: It is a kind of satellite data product which was extensively used in initial remote sensing applications. Paper prints of different scales like 1:250,000 or 1:50,000 were used as per the requirement. In this process base maps are prepared using Survey of India's toposheet on transparent sheet in the scale at par with the FCC. Different features like agricultural land, urban land, forest, water body, wasteland etc. are drawn on the overlaid base map using elements of interpretation. Light table is used to make the interpretation convenient. The advantage of this technique is that the FCC can be carried to the field during ground truth for finalization of the map on the spot. However, disadvantage of the technique is that the data product cannot be enhanced to improve the quality of data. The scale too cannot be changed in the technique. Further, it needs experience and special skill of the interpreter.

Visual interpretation done by using digital satellite data: With the development of image processing and GIS software, it is now possible to undergo onscreen visual interpretation using all kinds of image processing and enhancement techniques. They are discussed below–

(1) Pre-processing :

Image pre-processing or image restoration is concerned with the correction of distortion, degradation and noise introduced to the date during the imaging process or data acquisition. Image restoration produces a corrected image that is as close as possible, both radio-metrically and geometrically to the real image.

(a) Geometric correction:

Remote sensing data usually contain two types of errors. They are called systematic and non-systemic errors. Systematic distortion occurs due to the change in the platform velocity, earth rotation, scan skewness etc. Non-systematic errors occur due to the change in the altitude or shift in the satellite orbit. These makes the geometric or orientation distortion. The correction or rectification is the process by which geometry of an image area is made planimetric i.e. registering the image to the real world coordinate. In the rectification process some ground control points need to be identified both in reference map and the satellite scene. A GCP or ground control point is a point on the surface of the earth where both image coordinates (measured in rows & column) and map coordinates (measured in lat/long) can be identified. This is also called the **image to map rectification**. Whenever accurate data, direction, distance measurement and registration of administrative boundaries over image are required then a geometric correction must be carriedout first. On the other hand, simple comparison of two scenes of the same area does not need any geometric correction. Instead image to image registration is required in such cases.

The difference is that in image to map rectification, the reference is a map in a standard map projection, whereas in image to image rectification, reference is another image.

(b) Radio-metric correction:

Radio-metric errors are associated with the sensor defect and atmospheric interference. There may be error in detector like line drop out, striping or line start problem. Again some atmospheric interference causes noise or haze to the digital data which makes it unusable or uninterpretable. Haze owing to atmospheric affect can be corrected by means of the regression adjustment and the histogram adjustment.

(2) Display and Enhancement: Generation of interpretable display by means of enhancement techniques either in black and white or the FCC is important in visual interpretation as it uses interpretation keys like colour, tone , texture, shape, size etc.

(3) Enlargement and reduction: Sometimes it is required to view the entire image at a glance. Then we need to reduce the image. This is done by the pixel thinning or line thinning process. But this reduces details as many pixels are omitted. Digital image magnification is usually performed to improve the scale of a display for visual interpretation purposes or occasionally to match the scale of another image. As row and column deletion is the simplest form of image reduction, similarly row and column replication represents the simplest form of digital image magnification. Magnification of original imagery is useful when the analyst is trying to obtain detailed information about the spectral reflectance of a small geographical area.

Image enhancement through histogram adjustment:

The fundamental histogram is a plot of the number of pixels occurring for each of the brightness values. A histogram is a useful graphic representation of the information content of a remotely sensed image. Histogram is a pre-requisite of image enhancement technique. The histogram has following utilities in image processing.

(1) It is a graphical representation of data distribution of a band.

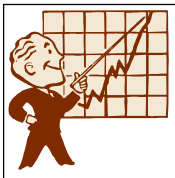
(2) It is used during the radiometric correction.

(3) It provides clues to assess quality of original data whether low in contrast or high in contrast or multi-modal in nature.

(4) It is used in image enhancement work, mainly in the contrast stretching.

(5) Various peaks of a histogram indicate various features and number of peaks indicates number of features.

The most important advantage of the on screen visual interpretation technique is that here digital satellite data can be used conveniently to get the classified map output at the desired scale with all cartographic inputs. This will not only help to save maps in a digital format but also help to put maps into a GIS environment as a layer for further GIS analysis.



CHECK YOUR PROGRESS

Q. No. 3: What is the difference between the systemic and non-systemic error?

.....

.....

Q. No. 4: What is the ground control point?

.....

.....



8.6 LET US SUM UP

- Image interpretation for generation of classified map can be achieved by Visual Interpretation and Digital interpretation.
- Visual interpretation can be done either by hand drawing of features on FCC paper print or through on screen digitization of digital satellite data.
- False colour composite is the base of an interpretation which can be prepared by assigning three primary colours to 3 bands which are not their true colours.
- All kinds of image processing and enhancement techniques can be applied in digital visual image interpretation.
- On screen visual interpretation has advantages of making maps at a desired scale under a GIS environment.
- Visual interpretation is done by using interpretation keys like colour, tone, texture, size, pattern, shape etc.



8.7 FURTHER READINGS

1) Fischer, W.A. (1975) History of remote Sensing: in Reeves, R.G. (ed) *Manual of Remote Sensing*, American Society of Photogrammetry, Falls Church, Virginia, pp. 27-50.

2) Principles of Remote Sensing by Paul J. Curran , published by English language Book Society, England.

8.8 ANSWERS TO CHECK YOUR PROGRESS

Q. No.1: Histogram equalization, filtering, contrast adjustment are some of the techniques of image enhancement.

Q. No.2: The elements or keys of image interpretation are colour, tone, texture, association, pattern, shape, size etc.

Q. No.3: The systematic distortion occurs due to the change in the platform velocity, earth rotation, scan skewness etc. Whereas the non-systematic error occurs due to the change in the altitude or shift in the satellite orbit.

Q. No.4: A GCP or ground control point is a point on the surface of the earth where the image coordinates and the map coordinates both can be identified.

8.9 MODEL QUESTIONS

Q. 1: What is a FCC? How can it be generated?

Q. 2: What is a spectral reflectance curve? Describe its significance in an image interpretation.

Q. 3: What are elements of interpretation?

Q. 4: Write the significance of a histogram in an image interpretation.

Q. 5: What are radiometric correction and Geometric correction?

---x---

UNIT- 9: BASICS OF GLOBAL NAVIGATION SATELLITE SYSTEM

UNIT STRUCTURE

9.1 Learning Objectives

9.2 Introduction

9.3 Introduction to the Global Positioning System

9.4 GPS Satellites Constellations

9.4.1 GPS Segments

9.5 Introduction to GLONASS, Galileo, GAGAN, IRNSS

9.6 GPS Antennas, Signals, and Codes

9.7 GPS Receivers

9.7.1 Types of Receivers

9.8 Modes of Measurements

9.9 Let us Sum up

9.10 Further Reading

9.11 Answers to Check Your Progress

9.12 Model Questions

9.1 LEARNING OBJECTIVES

After reading this unit, you will be able to-

- explain the Global Positioning System
- describe the outline of GPS Satellites Constellations
- illustrate about GPS Antennas, Signals, and Codes
- describe about GLONASS, Galileo, GAGAN, IRNSS
- identify different types of GPS receivers
- explain various modes of measurements.

9.2 INTRODUCTION

In this unit, you are going to learn about the basics of the Global Positioning System. The unit is also going to describe different components of the system and processes involved in the post-processing of the obtained data. GPS antennas, signals, and codes are same other topics of discussion of the unit. This unit also provides concepts of the GPS receiver and discusses about various types of the DGPS. Apart from these, the unit will help you to understand about how to compare different modes of measurements.

9.3 INTRODUCTION TO THE GLOBAL POSITIONING SYSTEM

The global navigation satellite system (GNSS) is the standard generic term for satellite based navigation systems that provide autonomous geospatial positioning with global coverage. The GNSS is a network of satellites that continuously transmits coded information, which makes it possible to precisely identify locations on the earth by measuring distance from the satellite. Among currently used GNSSs, the USA invented Global Positioning System (GPS) is the best known. The Global Positioning System (GPS) is a satellite- based radio-navigation system established by the U.S. Department of Defence for military positioning applications and has been made available to the civilian community as well as a by product. Navigation, surveying and integration with Geographic Information System (GIS) are few of the fields which have seen the successful application of the GPS technology.

Using the GPS following two values can be determined anywhere on the earth.

- One's exact location (longitude, latitude and height co-ordinates) accurate within a range of 20m to approx. to 1mm.
- The precise time also referred to as Universal Time Coordinated, (UTC) accurate within a range of 60ns to approx. 5ns (1ns = 1 nano-seconds = 10^{-9} second, that one billionth of a second).

The speed and direction of travel (course) can be derived from the coordinates, as well as, the time. The co-ordinates and time values are determined by these 28 satellites orbiting the earth.

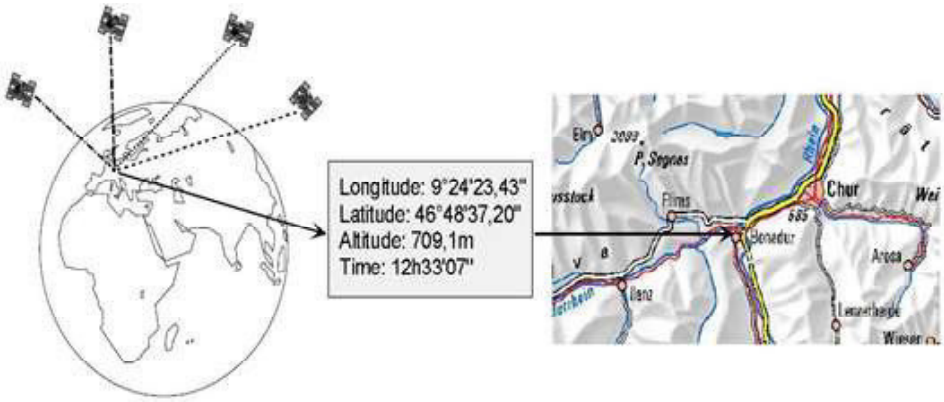


Figure 9.1 Basic functions of the GPS



CHECK YOUR PROGRESS

Q. 1: State True or False

a) The GPS is an active system.

b) Initially, the GPS was developed to fulfil military needs.

c) UTC stands for Universal Time Co-ordinates.

d) The co-ordinates and time values are determined by 20 satellites orbiting the earth.

e) Using the GPS, time and location can be determined anywhere on the earth.

9.4 GPS SATELLITES CONSTELLATIONS

A GPS consists of a constellation that comprises 24 operational satellites. This constellation is known as the "initial operational capability" (IOC). It was completed in July, 1993. However, the official IOC announcement was made on December 8, 1993. In order to ensure continuous world wide coverage, GPS satellites are arranged so that four satellites are placed in each of six orbital planes (Figure 9.2).

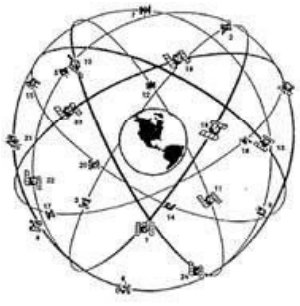


Figure 9.2 : GPS Constellation

With the constellation geometry, about four to ten GPS satellites are visible anywhere in the world, if an elevation of 10° angle is considered. There is a requirement of only four satellites to provide the positioning or location related information. The details are discussed in the later subsections.

The orbit of a GPS satellite is nearly circular (i.e. an elliptical shape with a maximum eccentricity of about 0.01), with an inclination of about 55° to the equator. The semi-major axis is about 26,560 km (meaning the satellite altitude of about 20,200 km above the earth's surface). The corresponding GPS orbital period has about 12 sidereal hours (~11 hours, 58 minutes).

On February 22, 1978, the U.S. Air Force Space Division, California, launched the first NAVSTAR (Navigation Satellite with Timing and Ranging) satellite with the GPS. The NAVSTAR is created to work optimally with a constellation of 24 satellites. NAVSTAR was declared fully functional on April 27, 1995, with a constellation of 24 Block II and Block IIA satellites.

9.4.1 GPS Segments

The GPS uses radio transmissions and its signals are sent to the receiver. The satellites transmit timing information and satellite location information. As given in Figure 2.3 a typical GPS is a satellite-based navigation system that consists of three segments:

(1) Space segment, (2) Control segment and (3) User segment.

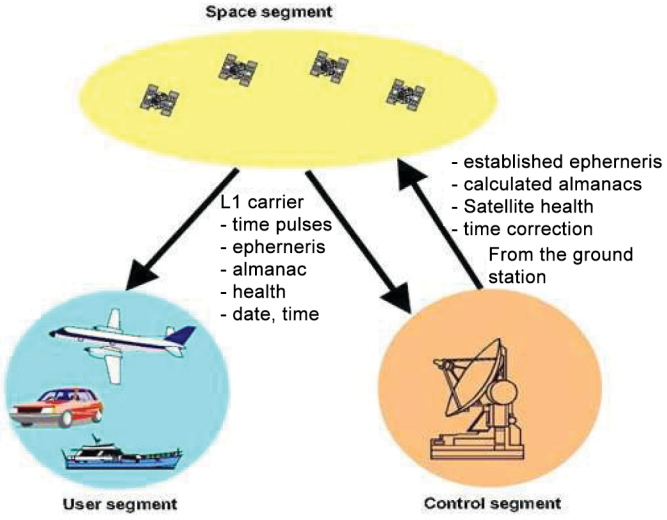


Figure 9.3: GPS Segments

1. Space segment:

The space segment consists of the 24-satellite constellation at an altitude of 20,200 km and with a period of 12 hours. They are about the size of a car. Each GPS satellite transmits a signal, which has a number of components namely two sine waves (carrier frequencies), two digital codes, and a navigation message. The codes and the navigation message are added to the carriers as binary bi-phase modulations. The main uses of the carriers and the codes are to determine the distance from the user's receiver to the GPS satellites.

2. Control Segment:

The control segment consists of a worldwide network of tracking stations. Its Master Control Station (MCS) is located in Springs, Colorado, USA. The task of the control segment is to track the GPS satellites in order to determine and predict satellite locations, system integrity and behaviour of the satellite atomic clocks, atmospheric data, the satellite almanac, and other considerations. Such information is then packed and uploaded into the GPS satellites through the S-band link.

Master Station

- Colorado Springs

Monitor Stations

- Diego Garcia
- Ascension Island
- Kwajalein
- Hawaii
- Colorado Springs



Figure 9.4: Control Segment Locations

3. User Segment:

The user segment includes users from military and civilian communities. With a GPS receiver connected to a GPS antenna, a user can receive GPS signals, which can be used to determine his or her position anywhere in the world. The receiver is usually used in conjunction with computer software to output the information to the user in the form of a map. The

GPS is available to all users world wide without any direct charge. The user can download locational information for events and later they can add the attributes for the events to do spatial analysis of various attributed data.



CHECK YOUR PROGRESS

Q. 2: Fill in the blanks:

i. The GPS consists, nominally, of a constellation that comprise _____satellites.

ii. In case of the GPS, _____ satellites are placed in each of _____ orbital planes.

iii. GPS satellite orbits are nearly circular with an inclination of about _____ to the equator.

iv. The semi major axis of a GPS orbit is about _____ km.

v. NAVSTAR stands for _____.

Q. 3: State True or False:

i. A GPS consists of four segments.

ii. The space segment consists of the 24-satellite constellation at an altitude of 20,200 m.

iii. The control segment packed and upload information into the GPS satellites through the S-band link.

iv. Colorado Springs is a Monitor Station.

v. The user segment includes all military and civilian users.

9.5 INTRODUCTION TO GLONASS, GALILEO, GAGAN, IRNSS

There are many satellite navigation systems in the world, the chief among them are discussed below:–

GLONASS (Globalnaya Navigazionnaya Sputnikovaya Sistema, or Global Navigation Satellite System) is a Russia's version of the GPS (Global Position System).

Galileo is Europe's global navigation satellite system, providing a highly accurate, guaranteed GPS under civilian control.

GAGAN (GPS Aided GEO Augmented Navigation) is an implementation of a regional satellite-based augmentation system (SBAS) by the Indian government. It is a system to improve the accuracy of a GNSS receiver by providing reference signals. The differences of the above GPS systems are compared in the table below.



CHECK YOUR PROGRESS

Q.4: State whether True or False

i. This is especially useful in hazardous areas, which pose as threat or danger to human lives.

ii. The GPS is not at all an essential element of the global positioning information infrastructure.

iii. The orbital altitude of GALILEO is 20,000 m.

iv. GAGAN is an Indian Navigational satellite.

v. GLONASS is a non-operational Satellite.

Table 9.1: The differences between different GPS systems

SYSTEM	GLONASS	GALILEO	GAGAN & IRNSS
OWNER	Russian Federation	European Union	India
CODING	FDMA	CDMA	CDMA
ORBITAL ALTITUDE PERIOD REVOLUTIONS PER SIDEREAL DAY	19,130 km (11,890 mi) 11.26 h (11 h 16 min) 17/8	23,222 km (14,429 mi) 14.08 h (14 h 5 min) 17/10	36,000 km (22,000 mi) 23.93 h (23 h 56 min) 1
NUMBER OF SATELLITES	**28** (at least 24 by design) including 24 operational 2 under check by the satellite prime contractor 2 in flight tests phase	8 test bed satellites in orbit, 22 operational satellites budgeted	3 geostationary orbit (GEO) satellites, 4 geosynchronous orbit satellites
FREQUENCY	Around 1.602 GHz (SP) Around 1.246 GHz (SP)	1.164–1.215 GHz (E5a and E5b) 1.260–1.300 GHz (E6) 1.559–1.592 GHz (E2-L1-E11)	1.17645 GHz (L5) 2.492028 GHz (S1)
STATUS	Operational	In preparation	4 satellites launched, 3 additional satellites planned to be launched by Early 2016

9.6 GPS ANTENNAS, SIGNALS, AND CODES

There are various critical components of the GPS navigation system, some of them are discussed below:–

GPS Antennas:

Antennas are a critical part of any GPS receiver. Even the best receiver cannot bring back what has been lost due to a poor antenna. GPS signals are extremely weak and present unique demands on the antenna. The choice of the antenna can ultimately play a significant role in a GPS performance. The antenna must have a clear view of the sky and thus be mounted on a roof, or in some cases a window. The antennas are relatively small about the size of a coffee cup or smaller, and are connected to the GPS receiver typically via coaxial cable.

Antenna Types: There are two basic antenna types used with GPS receivers; roof mounted and window mounted.

- The roof mounted antenna is required for the more accurate GPS clocks since at least three satellites are required to be in view at all times in order to maintain timing accuracy, typically nanoseconds.
- The window mounted antenna is applicable for the network time servers which operate with a lesser degree of accuracy, typically microseconds.

GPS Signals:

GPS signals include ranging signals, used to measure the distance to the satellite, and navigation messages. The navigation messages include ephemeris data, used to calculate the position of the satellite in orbit, and information about the time and status of the satellite constellation. Satellite signals basically consists of 3 components:

- Two micro wave L-band (also called Carrier) waves
    - L1 carrier: 1575.42 MHz
    - L2 carrier: 1227.60 MHz
- Ranging codes modulated on the carrier waves

C/A code, is one of the signals broadcast on the L1 carrier. This code is only broadcast on the L1 carrier. C/A code, the clear/access or coarse/

acquisition code modulated at 1.023 MHz, degraded code for civilian users, modulated on L1 only. P(Y) code, the private, protected, or precise code modulated at 10.23 MHz. It is modulated on both L1 and L2 carrier waves, for authorised military users.

GPS Codes:

The original GPS design contains two ranging codes: the C/A, which is freely available to the public, and the restricted Precision code, or P-code, usually reserved for military applications. Each GPS satellite transmits a microwave radio signal that is composed of two carrier frequencies (or sine waves) modulated by two digital codes and a navigation message as shown in Figure: 9.5. The frequencies are L1 and L2. The L1 channel produces a Carrier Phase signal at 1575.42 MHz as well as a C/A and P(Y) code. The L2 channel produces a Carrier Phase signal of 1227.6 MHz, but only P(Y) Code. The Binary data that is modulated or “superimposed” on the carrier signal is known as a Code.

- **C/A Code:** C/A or Coarse/Acquisition Code (or the civilian code), is modulated and repeated on the L1 wave every millisecond.
- **P(Y) Code:** The P-Code (or Precise Code) is modulated on both the L1 and L2 waves and is repeated every seven days. The (Y) code is a special form of P-code used to protect against false transmissions; special hardware, available only to the U.S. Government, must be used to decrypt the P(Y) code.

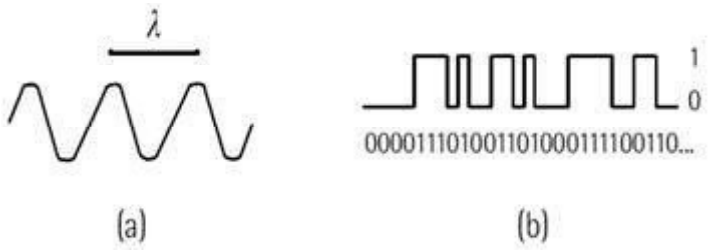


Figure 9.5: (a) A Sinusoidal Wave, (b) A Digital Code



CHECK YOUR PROGRESS

Q.5: What types of antenna are used for GPS receivers?

.....

.....

Q. 6: Name two GPS codes.

.....

.....

9.7 GPS RECEIVERS

The GPS receiver requires (either internal or external) antenna. The antenna receives the incoming satellite signal and then converts its energy into an electric current, which is handled by the GPS receiver. Commercially available GPS receivers can be categorized by their types in different ways and under different criteria.

A. Receiver types based on receiving capabilities:

1. Single-frequency code receivers
2. Single-frequency carrier-smoothed code receivers
3. Single-frequency code and carrier receivers
4. Dual-frequency receivers

Single-frequency receivers access the L1 frequency, while dual-frequency receivers access both the L1 and the L2 frequencies. Figure 9.6 shows examples of various types of GPS receivers.



Figure 9.6: Various types of GPS Receivers

B. Receiver types based on their number of tracking channels:

Channels vary from 1 to 12 channels. Normally, a good GPS receiver would be multichannel, with each channel dedicated to continuously tracking a particular satellite. Currently, most GPS receivers have 9 to 12 independent (or parallel) channels. Features such as cost, ease of use, power consumption, size and weight, internal and/or external data-storage capabilities, interfacing capabilities, and multipath mitigation (i.e. type of correlator) are to be considered when selecting a GPS receiver.

C. Receiver types based on accuracy:

- **DGPS (Differential Global Positioning System):** The DGPS is an enhancement to the GPS. It provides more accuracy than a traditional GPS.
- **Recreational Grade GPS:** It is designed to acquire location quickly without the need for pinpoint accuracy. Accuracy is < 15 meters. This unit is mostly used for outdoor sports, hiking, etc., It is cheaper than other GPS devices.

Types of DGPS:

- **Mapping Grade DGPS:** This GPS is more accurate than recreational GPS. Mostly used by government agencies, researchers, etc.
- **Survey Grade DGPS:** Mostly used where accuracy is crucial, e.g. Cadastral survey, Highway construction, etc. This GPS is most accurate and most expensive.



Figure 9.7(a): Survey Grade DGPS



Figure 9.7(b): Mapping Grade DGPS



CHECK YOUR PROGRESS

Q. 7: What are the types of GPS receivers?

.....

.....

9.8 MODES OF MEASUREMENTS

GPS satellites rotate the earth twice a day in a very precise orbit and transmit signal information to the earth. GPS receivers take this information and use triangulation to calculate the user's exact location. Essentially, the GPS receiver compares the time in which a signal is transmitted by a satellite to the time in which it is received. The time difference tells the distance from the satellite to the GPS receiver. With distance measurements from a few more satellites, the receiver can determine the user's position and display it on the unit's electronic map.

A GPS receiver must be locked on to the signal of at least three satellites to enable the calculation of a 2D position (that is latitude and longitude) and track movement. With four or more satellites in view, the receiver can determine the user's 3D position (latitude, longitude, and altitude). Once the user's position has been determined, the GPS unit can calculate other information, such as speed, bearing, track, trip distance, distance to destination, sunrise and sunset time and more.

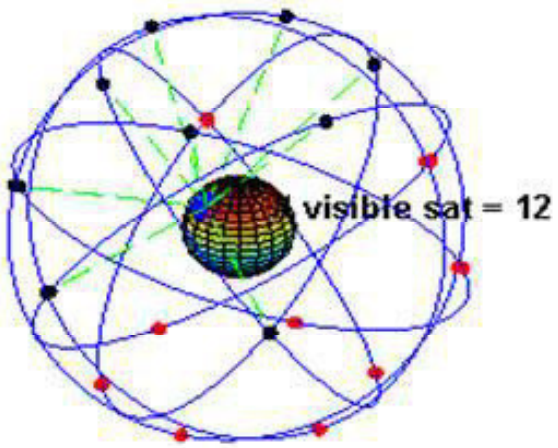


Figure: 9.8. Sample of locations of Satellites

Carrier Phase:

GPS uses microwaves, and just like all light and radio waves. Each signal has a unique frequency and wavelength. The distance S of an object to the satellite can be determined by using the known transit time T.

Distance = Travel time x Speed of light

S= T x *C*

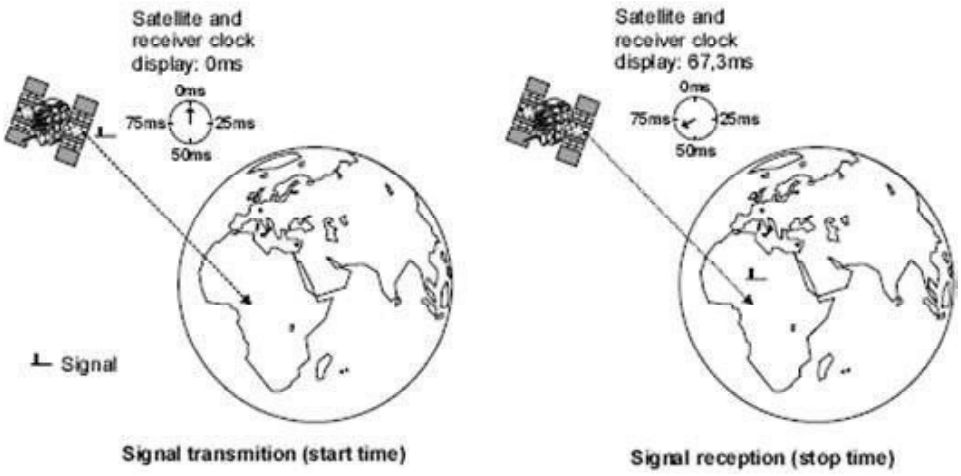


Figure 9.9: Transmission and reception of the signal

POST-PROCESSING OF DATA (DETERMINING POSITION IN A 3D SPACE):

To measure time precisely a highly accurate, synchronized clock is needed. If the transit time is out by just 1ìs, this produces a positional error of 300m. As the clocks on board, all three satellites are synchronized, the transit time in the case of all three measurements is inaccurate by the same amount.

If the time measurement is accompanied by a constant unknown error, we will have four unknown variables in a 3D space:

- Longitude (X)
- Latitude (Y)
- Height (Z)
- Time error Δt)

Thus, it follows that in a three-dimensional space four satellites are needed to determine a position.

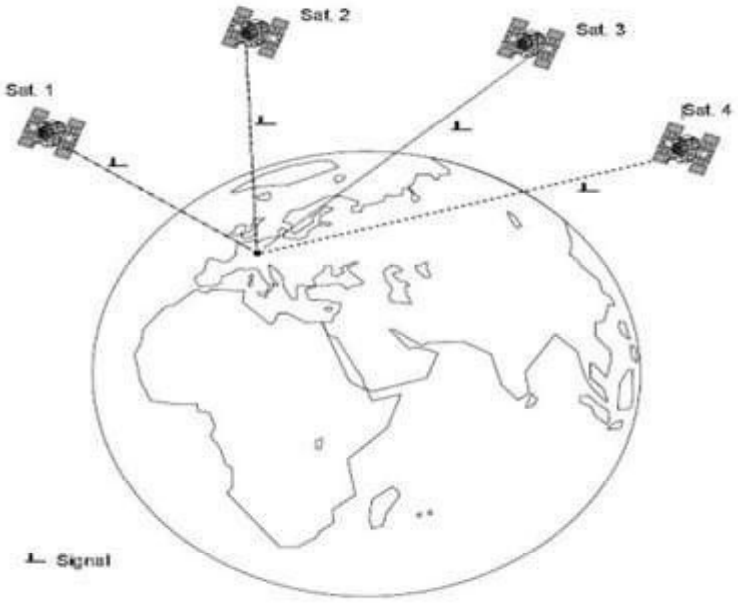


Figure 9.10: Four satellites are determining a position in a 3D space

To determine the unknown four variables, four independent equations are required. The four transit times required are supplied by four different satellites (sat.1 to sat.4). The 28 GPS satellites are distributed around the globe in such a way that at least 4 of them are always “visible” from any point on the earth.

FACTORS AND ACCURACY OF THE GPS:

Accuracy depends on a variety of factors coming together at a particular location and time. Some of the factors are the quality of the GPS receiver, the position of the GPS satellites at the time when the data was recorded, the characteristics of the surroundings (buildings, tree cover, valleys, etc.) and even the weather. Some of these factors can be categorized as given below.

- **ATMOSPHERIC CONDITIONS:**
  - Ionosphere - Change in the Travel Time of the Signal
  - Troposphere - Change in the Travel Time of the Signal

- **ORBITAL POSITION ERROR/CLOCK DRIFT/MEASUREMENT NOISE:**
  - Satellite Geometry - General Distribution of the Satellites
  - Satellite Health - Availability of Signal
  - Signal Strength - Quality of Signal
  - Radio Frequency (RF) Interference
  - Loss of Radio Transmission from Base
  - Minimum Number of satellites required Selective Availability Multipath
  - Multipath - Reflection of GPS Signals Near the Antenna
- **GPS RECEIVER QUALITY:**

  The quality of algorithms and circuitry used for processing satellite signals can cause or create an impact on accuracy. Most consumer grade receivers can do a good job at locating the position within about 25 feet most of the time. For applications where accuracy is critical, more sophisticated equipment can be used for better results.



CHECK YOUR PROGRESS

Q. 8: What are the four unknown variables in a 3D space used to determine a position?

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Q. 9: Mention some factors on which the accuracy of the GPS depend.

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9.9 LET US SUM UP

- The Global Positioning System (GPS) is a space-based navigation system developed by the US military in the early 90s.

- A GPS uses a constellation of 24 satellites on six different orbital planes at an altitude of 20,200 Kilometers above the earth surface.
- A GPS provides longitude, latitude, altitude and time information to the user.
- A GPS is an open source, and it levies no direct charges to the user.
- A control segment of the GPS consists of a worldwide network of tracking stations, having a master control station (MCS) located in Colorado Springs, the USA.
- The Differential Global Positioning System (DGPS) is an enhancement to the GPS. It provides more accuracy than a traditional GPS.
- Orbital position Error, Clock Drift, Measurement Noise and Atmospheric Conditions can affect the accuracy of GPS.
- In today's world, the GPS is widely used in different fields like Agriculture, Aviation, Environment, Marine, Public Safety and Disaster relief, Rail recreation, Roads and Highways, Space, Surveying, Mapping and Timing.
- Countries like Russia, Federation of European Union and India also have their own navigation systems called GLONASS, Galileo and GAGAN respectively.



9.10 FURTHER READING

1. GAGAN – The Indian Satellite-based augmentation system – K N Suryanarayana Rao.
2. INTRODUCTION TO GPS THE GLOBAL POSITIONING SYSTEM – Ahmed EL-Robbery

9.11 ANSWERS TO CHECK YOUR PROGRESS

Q. No.1:

a) False b) True c) True d) False e) True

Q. No.2:

i. 24, operational.
ii. Four, Six.
iii. 55°
iv. 26,560 km
v. Navigation System with Timing And Ranging Global Positioning System.

Q. No.3:

i. False
ii. False
iii. True
iv. False
v. True

Q. No.4:

i. True
ii. False
iii. False
iv. True
v. False

Q. No. 5: The two basic antenna types used with GPS receivers are roof mounted and window mounted.

Q. No. 6: The two GPS codes are C/A or Coarse/Acquisition Code and P-Code (or Precise Code).

Q. No. 7: Different types of commercially available GPS receivers are:

- Receivers based on receiving capabilities
- Receivers based on their number of tracking channels
- Receivers based on accuracy.

Q. No. 8: The four unknown variables in a 3D space to determine a position are:

- Longitude (X)
- Latitude (Y)
- Height (Z)
- Time error(Δt)

Q. No. 9: Some of the factors on which the accuracy of the GPS depend are:

- Atmospheric condition
- Quality of GPS receiver
- Orbital position error/ clock drift/ measurement noise



9.12 MODEL QUESTIONS

Q. 1: What is a GPS? Write a brief note on the history of the GPS.

Q. 2: Write about the values that can be determined using the Global Positioning System.

Q. 3: Write a short note on NAVSTAR.

Q. 4: Define GPS segments. Give suitable examples.

Q. 5: What do you understand by C/A Code and P(Y) Code? What are they used for?

Q. 6: Define GPS receivers. Write a brief note on the types of receivers.

Q. 7: What is the DGPS? Write a short note on the applications for DGPS.

Q. 8: Prepare a diagram showing the GPS signal transmission and signal reception process.

Q. 9: Write a short note on the major factors that affect the accuracy of the GPS.

Q. 10: How does a GPS determine a position in a 3D space? Draw a suitable diagram.

Q. 11: Write a detailed note on the application of the GPS in present day world.

Q. 12: Write short notes on the following:

I. GLONASS.

II. GALILEO.

III. GAGAN.

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UNIT- 10: GPS DATA AND APPLICATIONS

UNIT STRUCTURE

10.1 Learning Objectives

10.2 Introduction

10.3 Factors Affecting the Accuracy of the GPS Data

10.4 Post Processing of the GPS Data

10.5 Advantages and Disadvantages of the GPS

10.6 Applications of the GPS

10.7 Let us sum up

10.8 Answers to check your progress

10.9 Further Reading

10.10 Model Questions

10.1 LEARNING OBJECTIVES

After reading this unit, you will be able to-

- identify the factors affecting accuracy of the GPS data
- discuss the post processing of the GPS data
- illustrate advantages and disadvantages of the GPS
- describe the applications of the GPS in different fields.

10.2 INTRODUCTION

In the previous unit we have discussed about the global navigation satellite system. In this unit, we will focus on the GPS data and its applications. This unit will provide you various factors that affect the accuracy of the GPS data. It will also give you the idea of post processing operations of the GPS data. Advantages and disadvantages of the GPS data and applications of the GPS in different fields are also discussed at the end of this unit.

10.3 FACTORS AFFECTING THE ACCURACY OF THE GPS DATA

In the real world there are several factors that influence and could make the life of the GPS signal less than mathematically perfect. Many contributing factors add to the error associated with acquisition of a GPS location. They are:

- **Satellite clock**: The GPS position calculations depend on measuring signal transmission time from satellite to receiver. NAVSTAR satellites use atomic clocks, which are very accurate but can drift up to a millisecond. These errors are minimized by calculating clock corrections and transmitting the corrections along with the GPS signal to appropriately outfitted GPS receivers.
- **Upper atmosphere (ionosphere)**: As GPS signals pass through the upper atmosphere (the ionosphere 50-1000km above the surface), signals are delayed and deflected. The delay depends on how close the satellite is to being overhead. By modeling ionosphere characteristics, GPS monitoring stations can calculate and transmit corrections to the satellites, which in turn pass these corrections along to receivers.
- **Receiver clock**: GPS receivers are equipped with quartz crystal clocks that are less stable than the atomic clocks used in NAVSTAR satellites. Receiver clock error can be eliminated by comparing times of arrival of signals from two satellites whose transmission times are known exactly.
- **Satellite orbit**: GPS receivers calculate coordinates relative to the known locations of satellites in space. The GPS Control Segment monitors satellite locations at all times. It calculates orbit eccentricities and compiles these deviations in documents called ephemerides. An ephemeris is collected for each satellite and broadcast with the satellite signal. GPS receivers that are able to process ephemerides can compensate for some orbital errors.

- **Lower atmosphere**: The three lower layers of atmosphere (troposphere, stratosphere and mesosphere) extend from the earth's surface to an altitude of about 50 km. The lower atmosphere delays GPS signals, adding slightly to the calculated distances between satellites and receivers.
- **Multipath Error**: Ideally, GPS signals travel from satellites through the atmosphere directly to GPS receivers. In reality, GPS receivers must discriminate between signals received directly from satellites and other signals that have been reflected from surrounding objects, such as buildings, trees and even the ground. Antennas are designed to minimize interference from signals reflected from below, but signals reflected from above are more difficult to eliminate. For minimizing the multipath errors, only those satellites signals that are at least 15° above the horizon are tracked. It is known as the "mask angle."

- **Dilution of Precision**

The arrangement of satellites in the sky also affects the accuracy of the GPS positioning. The ideal arrangement (of the minimum four satellites) is one satellite directly overhead, three others equally spaced nearer the horizon (but above the mask angle).

User Equivalent Range Errors *(*UERE)**:** UERE is the error associated with satellite and receiver clocks, the atmosphere, satellite orbits, and the environmental conditions that lead to multipath errors.

The GPS coordinates calculated when satellites are clustered close together in the sky suffer from the **Dilution of Precision** (DOP). It is a factor that multiplies the uncertainty associated with the ***User Equivalent Range Errors***. The calculation of the DOP results in values that range from 1 to more than 20. According to Van Sickle (2001), the lowest DOP encountered in practice is about 2, which doubles the uncertainty associated with the UERE.

GPS receivers report several components of the DOP, including the Horizontal Dilution of Precision (HDOP) and the Vertical Dilution of Precision (VDOP). The combination of these two components of the three-

dimensional position is called the PDOP (Position Dilution of Precision). A key element of the GPS mission planning is to identify the time of the day when the PDOP is minimized. Since satellite orbits are known, the PDOP can be predicted for a given time and location. Professional surveyors use a variety of software products to determine the best conditions for the GPS work.



CHECK YOUR PROGRESS

Q.1. What is ephemeris data?

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10.4 POST PROCESSING OF THE GPS DATA

There are two methods of the GPS data processing. These are the Post Processing and the Real Time Processing methods. The Post processing method involves downloading of complete survey data and processing them in the office. While the Real Time Processing of GPS data involves the processing of data in real time or say when the GPS survey is going on. The method of the Real Time Processing of DGPS data is also known as Real Time Kinematics (RTK) surveying method. The standard scenario for the Real Time Kinematics (RTK) method requires the surveyor to operate two GPS receivers (one **reference receiver** and other **rover receiver**), as well as the data link. The reference receiver continuously transmits its carrier phase measurements to the roving receiver.

There are eight popular post processing free services available for GPS data.

They are discussed below.

1. AUSPOS:

AUSPOS is a free online GPS data processing service provided by Geoscience Australia. AUSPOS works with GPS data collected anywhere on the earth and reports are sent to the users immediately.

2. Trimble Centre Point RTX Post Processing:

Trimble RTX is a global GNSS technology providing centimeter-level positioning accuracy. This application allows users to upload GNSS observation data to the Center Point RTX post-processing service and receive positioning calculations.

3. CSRS – Precise Point Positioning:

Canadian Spatial Reference System – Precise Point Positioning (CSRS-PPP) is an online application for GNSS data post-processing that allows users to submit observation data over the Internet and recover, using precise GNSS Orbit and Clock information, enhanced positioning precisions in the Canadian Spatial Reference System (CSRS) and the International Terrestrial Reference Frame (ITRF).

4. Scripps Orbit and Permanent Array Center (SOPAC) – Scripps Coordinate Update Tool (SCOUT):

The Scripps Coordinate Update Tool (SCOUT) can be used to compute mean coordinates of a specific site by submitting a RINEX file of a particular day. SCOUT uses ultra-rapid orbits to allow near-real-time data processing. It does not use RINEX files from other models. SCOUT limits users to 10 uncompleted (queued) jobs at a time and average run time is 30 minutes.

5. Automatic Precise Positioning Service (APPS) – Jet Propulsion Laboratory

APPS accepts GPS measurement files and applies the most advanced GPS positioning technology from NASA's Jet Propulsion Laboratory to estimate the position of GPS receivers. It supports RINEX 2, RINEX 2.11 and GIPSY TDP input files.

6. Online Positioning User Service (OPUS):

The Online Positioning User Service provides simple access to high-accuracy National Spatial Reference System (NSRS) coordinates. OPUS requires minimal user input and uses software which computes coordinates for the NGS' Continuously Operating Reference Station (CORS) network. The resulting positions are accurate and consistent with other NSRS users.

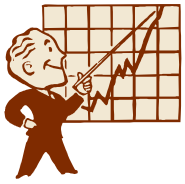
7. GPS Analysis and Positioning Software (GAPS):

The GPS Analysis and Positioning Software (GAPS) is used for the GPS data processing. It allows the user to estimate ionospheric delays, code biases, satellite clock errors and multipath errors.

8. magicGNSS/PPP:

The email version of magicGNSS/PPP (Precise Point Positioning), allows processing static and kinematic GPS and GLONASS real-time data in RINEX format. Only dual-frequency PPP is supported by the version at the moment.

All online GPS Processing Services use RINEX file format as input file standard from at the user's end.



CHECK YOUR PROGRESS

Q. 2. What are the methods of GPS data processing?

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10.5 ADVANTAGES AND DISADVANTAGES OF THE GPS

Some of the advantages and disadvantages of the GPS over conventional surveying methods are as follows–

Advantages:

Some major advantages of the GPS satellite surveying technique over conventional surveying are listed below:

- The GPS is extremely easy to navigate as it tells you the direction for each turns you take or turns you have to take to reach your destination.
- The GPS works in all-weather so you need not to worry about the climate as in other navigating devices.
- The GPS cost is very low in comparison to other navigation systems.
- The most attractive feature of this system is that it can offer 100% coverage of the planet.

- It also helps you to search nearby restaurants, hotels and gas stations and is very useful when you are in a new place.
- Due to its low cost, it is very easy to integrate into other technologies like the cell phone.
- The system is updated regularly by the US government and hence is very advanced.
- This is the best navigating system under water as in larger water bodies we are often misled due to the lack of proper directions.

Disadvantages:

Some disadvantages are also associated with the GPS surveying which are listed below:

- Sometimes the GPS may fail due to certain reasons and in that case you need to carry a backup map and directions.
- If you are using the GPS on a battery operated device, there may be a battery failure and you may need an external power supply which is not always possible.
- Sometimes the GPS signals are not accurate due to some obstacles to the signals such as buildings, trees and sometimes by extreme atmospheric conditions such as geomagnetic storms.

10.6 APPLICATIONS OF THE GPS

The GPS has a variety of applications on land, at sea and in the air. The GPS can be used everywhere except where it is impossible to receive the signal such as inside buildings, in caves, parking garages and other subterranean locations and underwater. The location is used to determine ground position and velocity even when there is obstruction in direct line of sight between the two observation stations. This system has enormous applications in various fields. Some of those fields are:–

Geodetic control surveys:

A control survey represents a class of survey for establishing point with high accuracy enabling support of activities i.e. mapping, construction, boundary surveys etc. Range of a control survey can vary by establishing few points to a network that may consist of numerous points or may cover a large extent of geographic area. For high order control surveys, high precision total stations are used. Static method is used in high order geodetic control surveys, but for low order control surveys such as in photogrammetric and other types of mapping, fast static techniques are used.

Cadastral Survey:

Cadastral survey is the discipline of land surveying which considers the definition of property boundaries and their ownership. It is the most important of all type of surveys, as the major dealing of land is done in real estate and cadastral surveys provide accurate results. It is common in most of the cases of real estate dealing where the conflict arises because of improper records of land sizes. To resolve such issues a cadastral survey has to be performed.

Photogrammetry, Remote sensing and Surveying:

The GPS technology is integrated with remote sensing to yield applications in various fields like precision farming & environmental modeling, disaster mitigation, emergency response, mobile mapping etc. GPS receivers are widely used in surveying everywhere, as it providing very accurate digital data.

Engineering and monitoring:

The GPS proves to be invaluable in development of maps as the military HQs keeps on changing by instantly providing accurate location. It tremendously boosts the updating rate of the maps. The GPS also proves

very efficient for the grid control locations establishment for various weapons and other gadgets and also for targeting location.

Military Applications: Military application includes:

Navigation:

One of the most difficult tasks for soldiers in the unknown enemy territory is to navigate the unfamiliar areas. It becomes really challenging when they have to navigate in the dark. The GPS plays an important role in giving the soldiers their precise location with respect to the surroundings. Advanced GPS receivers are used by specialized forces with crack teams to achieve goals and diffuse enemy installations. Navigation supports major application for military peoples.

Tracking:

In a military usage before declaring a target hostile and engaged by various weapon systems, it needs to be tracked for suspicious activities. These modern weapon systems of missiles and smart bombs are fed with the tracking data as input. The GPS based tracking system on mobile that provides up-to-date data with radio link & high computer technology enabling highly accurate and real time position information system on the basis of various objects.

Rescue:

The GPS always proves very worth in case of rescue and emergency response services. Emergency response team members can make the benefits of the GPS for reducing response time, by determining the location of a casualty during operations.

Map Updation:

The GPS proves to be invaluable in development of maps as the military HQs keeps on changing by instantly providing accurate location. It

tremendously boosts the updating rate of the maps. The GPS also proves very efficient for the grid control locations establishment for various weapons and other gadgets as well as for targeting location. For registration of images into absolute geo-coordinates, modern mapping techniques, e.g. remote sensing and the GIS consistently prefers the DGPS technology.



CHECK YOUR PROGRESS

Q.3: What are the applications of the GPS in different fields?

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10.7 LET US SUM UP

- Various factors that affect the accuracy of the GPS data are Satellite clock, Upper atmosphere, Receiver clock, Satellite orbit, Lower atmosphere, Multipath Error, Dilution of Precision etc.
- There are two methods of the GPS data processing, the post processing and the real time processing methods.
- The GPS survey results are more accurate. High accuracies from the GPS technology can be achieved with relatively less effort.
- The major advantage of the GPS survey over conventional surveying technique is that the line of sight does not have to be established between two stations while using the GPS.
- The applications of the GPS are endless, ranging from geodetic control surveying, cadastral surveying, photogrammetric survey, engineering and monitoring to military applications.
- The GPS can be used for rescue operations in different disasters and also for updation of maps.

10.8 ANSWERS TO CHECK YOUR PROGRESS

Q. No. 1: There are two methods of the GPS data processing. They are the Post Processing and the Real Time Processing methods.

Q. No. 2: The GPS satellites transmit information about their location, timing and health which are known as the ephemeris data.

Q. No. 3: The applications of the GPS in different fields are geodetic control surveys, cadastral Survey, Photogrammetry, remote sensing and surveying Engineering and monitoring, military applications etc.



10.9 FURTHER READINGS

1. Bhatta, B.(2008), Remote Sensing and GIS, Oxford University Press, pp.211
2. Kaplan, E.D. and Hegarty, C. (2005), Understanding GPS Principle and Applications, Artech House Publishers, Norwood, pp.706
3. Mc Namara J. (2008), GPS for Dummies, 2nd Ed., Willey Publishing Inc.,River Street Hoboken,pp. 408
4. Rabbany, A.E. (2002), Introduction to GPS: The Global Positioning System, Artech House, pp.176



10.10 MODEL QUESTIONS

1. Explain the application of the GPS in land use planning.
2. Explain the application of the GPS in disaster mitigation.
3. What are the errors introduced in a GPS? Explain in brief.
4. Explain about the 'intentional degradation of GPS satellite signal' and the GDOP.
5. What are the factors that affect spectral measurements? Explain in brief.

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