EARTH RESOURCE SATELLITES

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Abstract : Since the first balloon flight, the possibilities to view the earth's surface from above had opened up new vistas of opportunities for mankind. The view from above has inspired a number of technological developments that offer a wide-range of techniques to observe the phenomena on the earth's surface, under oceans, and underneath the surface of the earth. While the first imagery used for remote sensing came from balloons and later from airplanes, today the satellites or spacecraft are widely used for data collection. The uniqueness of satellite remote sensing lies in its ability to provide a synoptic view of the earth's surface and to detect features at electromagnetic wavelengths, which are not visible to the human eye. Data from satellite images can show larger areas than aerial survey data and, as a satellite regularly passes over the same area capturing new data each time, changes in the land use /land cover can be periodically monitored.

In order to use remotely sensed data, the user has to understand the characteristics of the system being used. The most important system characteristic the user has to understand is resolution. Resolution is measured in four ways, spatial, spectral, radiometric and temporal. The article describes the characteristics of satellite orbits and sensor systems, data capturing mechanisms and then highlights some of the commercially available satellites and future missions to be undertaken.

INTRODUCTION

Remote sensing is defined as the science which deals with obtaining information about objects on earth surface by analysis of data, received from a remote platform. Since the launch of the first remote sensing weather satellite (TIROS-1) in 1960 and the first Earth resources satellite in 1972 (Landsat-1), various platforms with a variety of remote sensing sensors have been launched to study the Earth land cover, the oceans, the atmosphere or to monitor the weather.

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In the present context, information flows from an object to a receiver (sensor) in the form of radiation transmitted through the atmosphere. The interaction between the radiation and the object of interest conveys information required on the nature of the object. In order for a sensor to collect and record energy reflected or emitted from a target or surface, it must reside on a stable platform away from the target or surface being observed. Important properties of sensor system are the number of spectral bands, the spectral position of these bands, the spatial resolution or pixel size and the orbit of the satellite.

Two satellite orbits are important for remote sensing observation of the Earth: the geo-stationary orbit and the polar orbit. The geo-stationary orbit is such a position for a satellite that it keeps pace with the rotation of the Earth. These platforms are covering the same place and give continuous near hemispheric coverage over the same area day and night. These satellites are put in equatorial plane orbiting from west to east. Its coverage is limited to 70^{o}N to 70^{o}S latitudes and one satellite can view one-third globe (Figure 1). As a result it is continuously located above the same geographical position.

These are mainly used for communication and meteorological applications. Weather satellites such as Meteosat, MSG and GOES are normally positioned in this orbit. It enables the sensor aboard the satellite to take every 30 minutes a picture of the weather conditions over the same locations. This geo-stationary orbit is located at an altitude of 36,000 km above the equator.

The following are the major geo-stationary satellites:

Satellite program Launch Agency	Current Satellite	Country	Operational	Agency
METEOSAT	METEOSAT-7	International	EUMETSAT	ESA
INDOEX	METEOSAT-5	International	EUMETSAT	ESA
GOMS	GOMS-1 (ELEKTRO)	Russia		
INSAT	INSAT Series	India		
Feng-Yun*	Feng-Yun-2B	China		
GMS	GMS-5	Japan		
GOES (WEST)	GOES-10	U.S.A.	NOAA	NASA
GOES (EAST)	GOES-8	U.S.A.	NOAA	NASA

* Failed mission

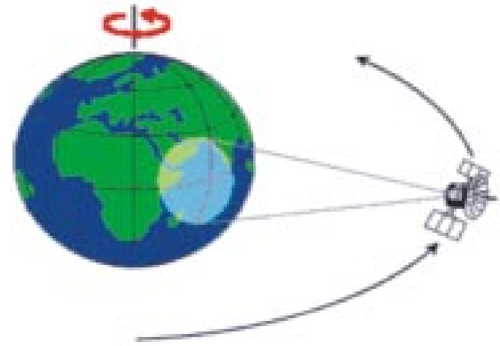

Figure 1. Geo-stationary Orbit (source CCRS website)

The second important remote sensing orbit is the polar orbit. Satellites in a polar orbit, cycle the Earth from North Pole to South Pole. The polar orbits have an inclination of approximately 99 degrees with the equator to maintain a sun synchronous overpass i.e. the satellite passes over all places on earth having the same latitude twice in each orbit at the same local sun-time. This ensures similar illumination conditions when acquiring images over a particular area over a series of days (Figure 2). Image acquisition mostly takes place in the morning when the sun position is optimal between 9.30 and 11.00 hr local time. The altitude of the polar orbits varies from approximately 650 to 900 km although spy-satellites are in a much lower orbit.

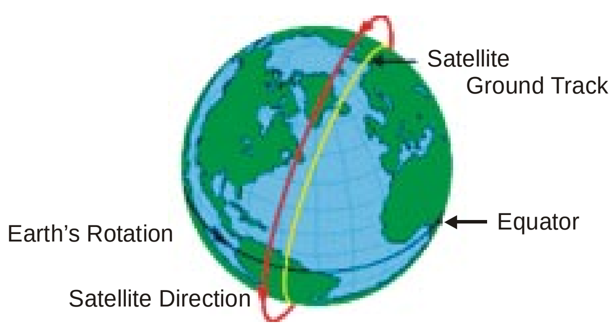

Figure 2. Near Polar Orbits (source CCRS website)

As the satellite orbits the Earth from pole to pole, its east-west position would not change if the Earth did not rotate. However, as seen from the Earth, it seems that the satellite is shifting westward because the Earth is rotating (from west to east) beneath it. This apparent movement allows the satellite swath to cover a new area with each pass (Figure 3). The satellite's orbit and the rotation of the Earth work together to allow complete coverage of the Earth's surface, after it has completed one complete cycle of orbits (Figure 4). Through these satellites the entire globe is covered on regular basis and gives repetitive coverage on periodic basis. All the remote sensing earth resource satellites may be grouped in this category. Few of these satellites are LANDSAT series, SPOT series, IRS series, NOAA, SEASAT, TIROS, HCMM, SKYLAB, SPACE SHUTTLE etc.

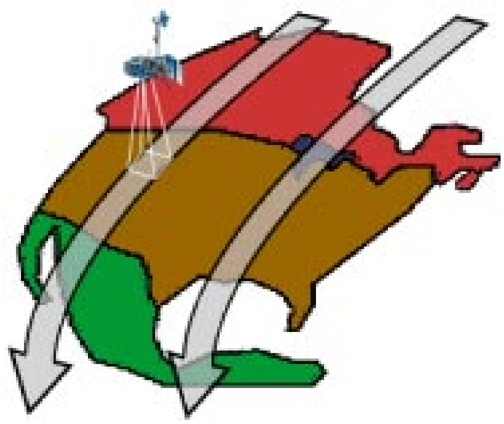

Figure 3. Area Coverage on each Consecutive pass (source: CCRS website)

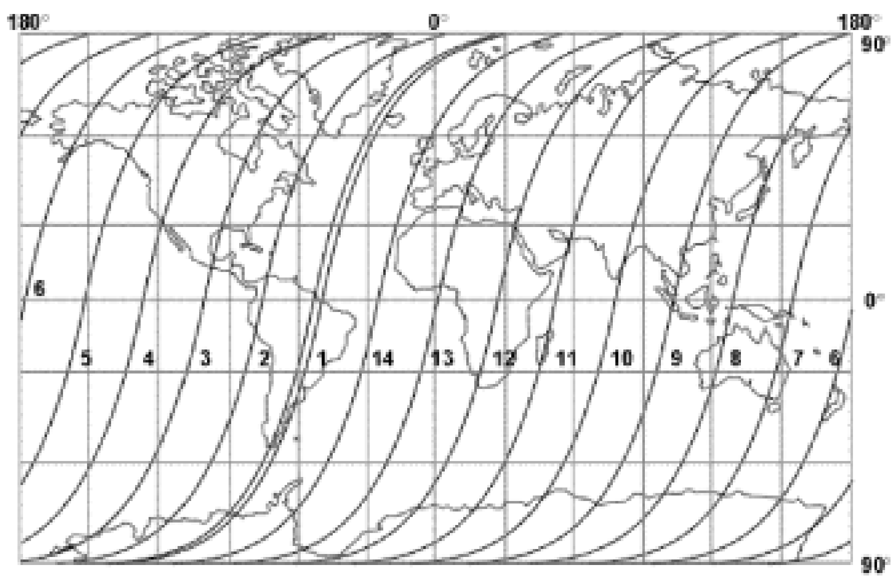

Figure 4. Complete Coverage of Earth Surface by Sun Synchronous Satellites

REMOTE SENSING SENSORS

Sensor is a device that gathers energy (EMR or other), converts it into a signal and presents it in a form suitable for obtaining information about the target under investigation. These may be active or passive depending on the source of energy.

Sensors used for remote sensing can be broadly classified as those operating in Optical-Infrared (OIR) region and those operating in the microwave region. OIR and microwave sensors can further be subdivided into passive and active.

Active sensors use their own source of energy. Earth surface is illuminated through energy emitted by its own source, a part of it is reflected by the surface in the direction of the sensor, which is received to gather the information. Passive sensors receive solar electromagnetic energy reflected from the surface or energy emitted by the surface itself. These sensors do not have their own source of energy and can not be used at nighttime, except thermal sensors. Again, sensors (active or passive) could either be imaging, like camera or sensor, which acquire images of the area and non-imaging types like non-scanning radiometer or atmospheric sounders.

Resolution

Resolution is defined as the ability of the system to render the information at the smallest discretely separable quantity in terms of distance (spatial), wavelength band of EMR (spectral), time (temporal) and/or radiation quantity (radiometric).

Spatial Resolution

Spatial resolution is the projection of a detector element or a slit onto the ground. In other words, scanner's spatial resolution is the ground segment sensed at any instant. It is also called ground resolution element (GRE).

The spatial resolution at which data are acquired has two effects – the ability to identify various features and quantify their extent. The former one relates to the classification accuracy and the later to the ability to accurately make mensuration. Images where only large features are visible are said to have coarse or low resolution. In fine resolution images, small objects can be detected.

Spectral Resolution

Spectral emissivity curves characterize the reflectance and/or emittance of a feature or target over a variety of wavelengths. Different classes of features and details in an image can be distinguished by comparing their responses over distinct wavelength ranges. Broad classes such as water and vegetation can be separated using broad wavelength ranges (VIS, NIR), whereas specific classes like rock types would require a comparison of fine wavelength ranges to separate them. Hence spectral resolution describes the ability of the sensor to define fine wavelength intervals i.e. sampling the spatially segmented image in different spectral intervals, thereby allowing the spectral irradiance of the image to be determined.

Radiometric Resolution

This is a measure of the sensor to differentiate the smallest change in the spectral reflectance/emittance between various targets. The radiometric resolution depends on the saturation radiance and the number of quantisation levels. Thus, a sensor whose saturation is set at 100% reflectance with an 8 bit resolution will have a poor radiometric sensitivity compared to a sensor whose saturation radiance is set at 20% reflectance and 7 bit digitization.

Temporal Resolution

Obtaining spatial and spectral data at certain time intervals. Temporal resolution is also called as the repetivity of the satellite; it is the capability of the satellite to image the exact same area at the same viewing angle at different periods of time. The temporal resolution of a sensor depends on a variety of factors, including the satellite/sensor capabilities, the swath overlap and latitude.

Multispectral Scanning Principle

Cameras and their use for aerial photography are the simplest and oldest of sensors used for remote sensing of the Earth's surface. Cameras are framing systems (Figure 5a), which acquire a near-instantaneous "snapshot" of an area of the Earth's surface. Camera systems are passive optical sensors that use a lens (or system of lenses collectively referred to as the optics) to form an image at the focal plane, the "aerial image plane" at which an image is sharply defined.

Many electronic (as opposed to photographic) remote sensors acquire data using scanning systems, which employ a sensor with a narrow field of view that sweeps over the terrain to build up and produce a two-dimensional image of the surface. Scanning systems can be used on both aircraft and satellite platforms and have essentially the same operating principles. A scanning system used to collect data over a variety of different wavelength ranges is called a multispectral scanner (MSS), and is the most commonly used scanning system. There are two main modes or methods of scanning employed to acquire multispectral image data - across-track scanning, and along-track scanning.

Across-track scanners scan the Earth in a series of lines (Figure 5b). The lines are oriented perpendicular to the direction of motion of the sensor platform (i.e. across the swath). Each line is scanned from one side of the sensor to the other, using a rotating mirror. As the platform moves forward over the Earth, successive scans build up a two-dimensional image of the Earth's surface. So, the Earth is scanned point by point and line after line. These systems are referred to as whiskbroom scanners. The incoming reflected or emitted radiation is separated into several spectral components that are detected independently. A bank of internal detectors, each sensitive to a specific range of wavelengths, detects and measures the energy for each spectral band and then, as an electrical signal, they are converted to digital data and recorded for subsequent computer processing.

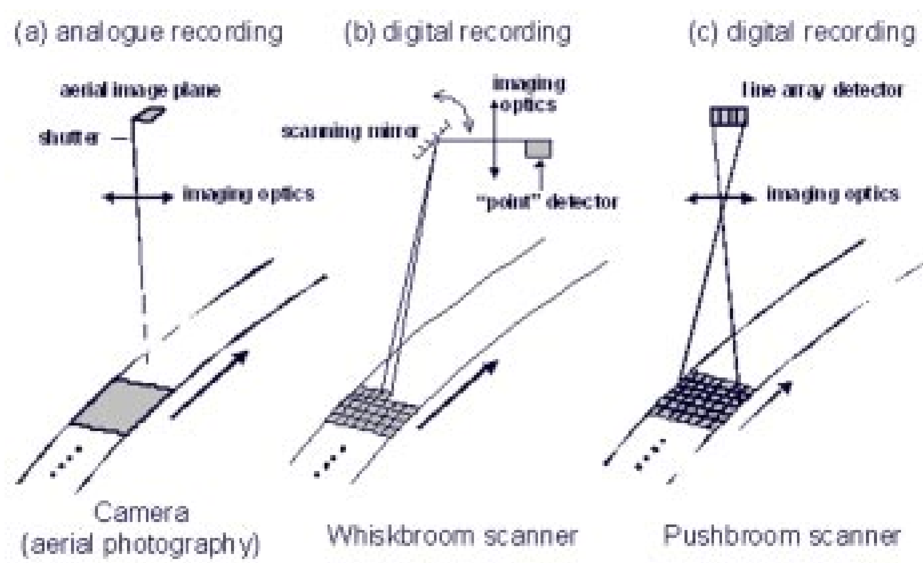

Figure 5. Principle of imaging sensor systems; (a) framing system, (b) whiskbroom scanner, (c) pushbroom scanner. (source :http://cgi.girs.wageningen-ur.nl/igi-new)

Along-track scanners also use the forward motion of the platform to record successive scan lines and build up a two-dimensional image, perpendicular to the flight direction (Figure 5c). However, instead of a scanning mirror, they use a linear array of detectors (so-called charge-coupled devices, CCDs) located at the focal plane of the image formed by lens systems, which are "pushed" along in the flight track direction (i.e. along track). These systems are also referred to as push broom scanners, as the motion of the detector array is analogous to a broom being pushed along a floor. A separate linear array is required to measure each spectral band or channel. For each scan line, the energy detected by each detector of each linear array is sampled electronically and digitally recorded.

Regardless of whether the scanning system used is either of these two types, it has several advantages over photographic systems. The spectral range of photographic systems is restricted to the visible and near-infrared regions while MSS systems can extend this range into the thermal infrared. They are also capable of much higher spectral resolution than photographic systems. Multi-band or multispectral photographic systems use separate lens systems to acquire each spectral band. This may cause problems in ensuring that the different bands are comparable both spatially and radiometrically and with registration of the multiple images. MSS systems acquire all spectral bands simultaneously through the same optical system to alleviate these problems. Photographic systems record the energy detected by means of a photochemical process which is difficult to measure and to make consistent. Because MSS data are recorded electronically, it is easier to determine the specific amount of energy measured, and they can record over a greater range of values in a digital format. Photographic systems require a continuous supply of film and processing on the ground after the photos have been taken. The digital recording in MSS systems facilitates transmission of data to receiving stations on the ground and immediate processing of data in a computer environment.

Thermal Scanner

Many multispectral (MSS) systems sense radiation in the thermal infrared as well as the visible and reflected infrared portions of the spectrum. However, remote sensing of energy emitted from the Earth's surface in the thermal infrared (3 μm to 15 μm) is different from the sensing of reflected energy. Thermal sensors use photo detectors sensitive to the direct contact of photons on their surface, to detect emitted thermal radiation. The detectors are cooled to temperatures close to absolute zero in order to limit their own thermal emissions. Thermal sensors essentially measure the surface temperature and thermal properties of targets.

Thermal Imagers are typically across-track scanners that detect emitted radiation in only the thermal portion of the spectrum. Thermal sensors employ one or more internal temperature references for comparison with the detected radiation, so they can be related to absolute radiant temperature. The data are generally recorded on film and/or magnetic tape and the temperature resolution of current sensors can reach 0.1 °C. For analysis, an image of relative radiant temperatures is depicted in grey levels, with warmer temperatures shown in light tones, and cooler temperatures in dark tones.

Table 1. Thermal Sensors

	HCMM	TM
Operational period	1978-1980	1982 to present
Orbital altitude	620 mm	705 km
Image coverage	700 by 700 km	185 by 170 km
Acquisition time, day	1:30 p.m.	10:30 a.m.
Acquisition time, night	2:30 a.m.	9:30 p.m.
Visible and reflected IR detectors		
Number of bands	1	6
Spectral range	0.5 0 - 1.1 µm	0.4 - 2.35 µm
Ground resolution cell	500 by 500 m	30 by 30 m
Thermal IR detector		
Spectral range	10.5 - 12.5 µm	10.5 - 12.5 µm
Ground resolution cell	600 by 600 m	120 by 120m 60 m by 60 m in Landsat 7

Microwave Sensing (RADAR)

Microwave data can be obtained by both active and passive systems. Passive system monitor natural radiation at a particular frequency or range of frequency. Data may be presented numerically as line trace data or as imagery. Active systems (like SLAR and SAR) transmit their own energy and monitor the returned signal.

Characteristics of such radar imagery both in SAR and SLAR and their resolution depends on various parameters like frequency of the signal, look direction, slant range, dielectric constant of the objects, phase, antenna length etc. Spatial resolution in range and azimuth direction varies in different manners.

RADAR (SAR) imageries have been obtained from satellite SEASAT, ERS and space shuttle missions SIR-A, SIR-B and SIR-C using synthatic aperture radar, which have all weather capability. Such data products are useful for studies in cloud-covered region of the earth and in oceanography.

Table 2. Microwave Sensors

	Seasat SAR	SIR-C/X-SAR	ESA SAR	RADARSAT SAR	ENVISAT ASAR	JERS-1
Frequency	1.275 GHz	5.3 GHz 1.275 GHz	5.3 GHz	5.33 GHz	5.33 GHz	1.275 GHz
Wave length	L band 23 cm	X band 3 cm C band 6 cm L band 23 cm	C band	C band	C band	L Band (23 cm)
Swath Width	100 km, centered 20° off nadir	15 to 90 km Depend on orientation is antenna	100 km	45-510 km Varies	5 km – 100 km Varies	75 km
Ground Resolution	25 x 25 m	10 to 200 m	30 m	100x100 m to 9x9 m Varies	Varies	30 m

LAND OBSERVATION SATELLITES

Today more than ten earth observation satellites provide imagery that can be used in various applications (Table-3). The list also includes some failed as well as future missions. Agencies responsible for the distribution and trading of data internationally are also listed.

Landsat Series of Satellites

NASA, with the co-operation of the U.S. Department of Interior, began a conceptual study of the feasibility of a series of Earth Resources Technology Satellites (ERTS). ERTS-1 was launched in July 23, 1972, and it operated until January 6, 1978. It represented the first unmanned satellite specifically designed to acquire data about earth resources on a systematic, repetitive, medium resolution, multispectral basis. It was primarily designed as an experimental system to test the feasibility of collecting earth resources data from unmanned satellites. About 300 individual ERTS-1 experiments were conducted in 43 US states and 36 nations. Just prior to the launch of ERTS-B on January 22nd 1975, NASA officially renamed the ERTS programme as the "LANDSAT" programme. All subsequent satellites in the series carried the Landsat designation. So far six Landsat satellites have been launched successfully, while Landsat-6 suffered launch failure. Table-4 highlights the characteristics of the Landsat series satellites. There have been four different types of sensors included in various combinations on these missions. These are Return Beam Vidicon camera (RBV) systems, Multispectral Scanner (MSS) systems, Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM).

After more than two decades of success, the Landsat program realised its first unsuccessful mission with the launch failure of Landsat-6 on October 5, 1993. The sensor included on-board was the Enhanced Thematic Mapper (ETM). To provide continuity with Landsat -4 and -5 the ETM incorporated the same seven spectral bands and the same spatial resolutions as the TM. The ETM's major improvement over the TM was addition of an eighth panchromatic band operating in 0.50 to 0.90-µm range and spatial resolution of 15m. Landsat-7 includes two sensors: the Enhanced Thematic Mapper plus (ETM+) and the High Resolution Multispectral Stereo Imager (HRMSI).

Spot Series of Satellite

French Government in joint programme with Sweden and Belgium undertook the development of Systeme Pour l'Observation de la Terre (SPOT) program. Conceived and designed by the French Center National d'Etudes Spatiales (CNES), SPOT has developed into a large-scale international programme with ground receiving stations and data distribution outlets located in more than 30 countries. It is also the first system to have pointable optics. This enables side-to-side off-nadir viewing capabilities, and it affords full scene stereoscopic imaging from two different satellite tracks permitting coverage of the same area. SPOT-1 was retired from full-time services on December 31, 1990. The SPOT-2 satellite was launched on January 21, 1990, and SPOT-3 was launched on September 25, 1993. SPOT-4 was launched on 26 March, 1998. Characteristics of SPOT Satellites are presented in Table 5.

Table 3. Operational Earth Observation Satellites

EUROPE		MIDDLE EAST	NORTH AMERICA			ASIA	
France	ESA	Israel	USA		Canada	India	Japan
SPOT1-1986 10m			LANDSAT5 -85, 30m				
SPOT2-90 10m	ERS1-92/00 Radar		LANDSAT6-93				
SPOT3-93/96	ERS2-95 Radar		EARLYBIRD -98	IKONOS1-99, 1m	RADARSAT-95	IRS1C-95 6m	
SPOT4-98 10m	ENVISAT-2001Radar		LANDSAT7-99, 15m	IKONOS2 -99, 1m		IRS1D-97 6m	
		EROS A/ 1-00 2m	QUICKBIRD-01, 0.6m	ORBVIEW-01, 1m			
SPOT5-02 3m+ HRS10		EROS B/ 1-02, 1m		ORBVIEW -02, 1m	RADARSAT -03	IRS-P6-03, 6MMSS	ALOS-03, 2.5m
Distribution							
SPOT IMAGING	Miscellaneous	Imagesat	SI-EOSAT, Earthwatch, Orbimage, USGS		RADARSAT	NRSA-EOSAT	JSI

Table 4. Characteristics of Landsat-1 to -7 Missions

Sensor-system	Spectral resolution (µm)	Spatial resolution (m)	Scan-width (km)	Time interval Equator	Orbital altitude	Operation period
MSS	Band 4: 0.5 - 0.6	79×79	185	18 days	918 km	Landsat 1 23/07/1972-06/01/1978 Landsat 2 22/01/1975 -25/02/1982 Landsat 3 05/03/1978 - 30/11/1982
	Band 5: 0.6 - 0.7	79×79				
	Band 6: 0.7 - 0.8	79×79				
	Band 7: 0.8 - 1.1	79×79				
MSS	As Landsat 3		185	16 days	710 km	Landsat 4 16/07/1982 - 02/1983 Landsat 5 01/03/1984 -
TM	Band 1:0.45- 0.52	30×30				
	Band 2: 0.52 - 0.60	30×30				
	Band 3:0.63 - 0.69	30×30				
	Band 4:0.76 - 0.90	30×30				
	Band 5:1.55 -1.75	30×30				
	Band 6:10.40-12.50	120×120				
	Band 7:2.08 - 2.35	30×30				
TM	As Landsat 4-5	30x30	185	16 days	705 km	Landsat 7 15/04/1999 -
	Band 6:10.40 - 12.50	60×60				
	Panchromatic: 0.50 - 0.90	15×15				

SPOT-4 includes the additional 20m-resolution band in the mid-infrared portion of the spectrum (between 1.58 and 1.75 μm). This band is intended to improve vegetation monitoring and mineral discriminating capabilities of the data. Furthermore, mixed 20m and 10m data sets will be co-registered on-board instead of during ground processing. This will be accomplished by replacing the panchromatic band of SPOT-1, -2 and -3 (0.49 to 0.73 μm) with red band from these systems (0.61 to 0.68 μm). This band will be used to produce both 10m black and white images and 20m multispectral data. Another change in SPOT-4 is the addition of a separate wide-field-of-view, sensor called the Vegetation Monitoring Instrument (VMI).

IRS Satellite Series

The Indian Space programme has the goal of harnessing space technology for application in the areas of communications, broadcasting, meteorology and remote sensing. The important milestones crossed so far are Bhaskara-1 and 2 (1979) the experimental satellites, which carried TV Cameras and Microwave Radiometers. The Indian Remote Sensing (IRS) Satellite was the next logical step towards the National operational satellites, which directly generates resources information in a variety of application areas such as forestry, geology, agriculture and hydrology. IRS -1A/1B, carried Linear Imaging Self Scanning sensors LISS-I & LISS-II (Table 6). IRS-P2 was launched in October 1994 on PSLV-D2, an indigenous launch vehicle. IRS-1C, was launched on December 28, 1995, which carried improved sensors like LISS-III, WiFS, PAN Camera, etc. Details of IRS series platforms are given in the following section. IRS-P3 was launched into the sun synchronous orbit by another indigenous launch vehicle PSLV - D3 on 21.3.1996 from Indian launching station Sriharikota (SHAR). IRS-1D was launched on 29 September 1997 and IRS-P4 was launched on 26 – 5-1999 on-board PSLV from Sriharikota.

IRS-P4 carrying an Ocean Colour Monitor (OCM) and a Multi-frequency Scanning Microwave Radiometer (MSMR) was launched on May 26, 1999. OCM has 8 narrow spectral bands operating in visible and near-infrared bands (402-885 nm) with a spatial resolution of 360 m and swath of 1420 km. IRS-P4 OCM thus provides highest spatial resolution compared to any other contemporary satellites in the international arena during this time frame. The MSMR with its all weather capability is configured to have measurements at 4 frequencies (6.6, 10.6, 18 & 26 GHZ) with an overall swath of 1360 km. The spatial resolution is 120, 80, 40 and 40 km for the frequency bands of

Table 5. Characteristics of SPOT Satellites

Satellite Name	Launch	Sensors	Types	No. of Channels	Spectral Range (microns)	Resolution (metres)	Swath Width (km)	Revisit Time
SPOT -5	May 2002	VMI	Multi-spectral	4	0.43-0.47 (blue) 0.61-0.68(red) 0.78-0.89(NIR) 1.58-1.75(SWIR)	1000	600 x 120	1 day
		HRS	Multi-spectral	4	0.5-0.59 (green) 0.61-0.68 (red) 0.79-0.89 (NIR) 1.58-1.75 (SWIR)	10 10 10 20	60	26 days
		HRG	Pan	1	0.61-0.68	5 m, combined to generate a 2.5 metre product.	60	
			Pan	1	0.61-0.68	10 m (re-sampled at every 5 m along track)	60	
SPOT-4	March 24, 1998	VMI	Multi-spectral	4	4	Same as SPOT 4	I000	26 days
		HRV	Multi-spectral	4	0.5-0.59 (green) 0.61-0.68 (red) 0.79-0.89 (NIR) 1.58-1.75 (SWIR)	20	60	
			Pan	1	0.61-0.68	10	60	

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Satellite Name	Launch	Sensors	Types	No. of Channels	Spectral Range (microns)	Resolution (metres)	Swath Width (km)	Revisit Time
SPOT-2 & 3	1990 & March 1998	HRV	Multi-spectral	3	0.5-0.59 0.61-0.68 0.79-0.89	20	60	26 days
			Pan	1	0.51-0.73	10	60	
SPOT-1	1986	HRV	Multi-spectral	3	Same as SPOT 2	20	-do-	26 days
			Pan	1	-do-	10	-do-	

Table 6. Characteristics of IRS series Satellites

Satellite Name	Launch	Sensors	Types	No. of Bands	Spectral Range (microns)	Resolution (metres)	Swath Width (km)	Revisit Time
IRS-P4 (Oceansat)	May 26, 1999	OCM	Multi-spectral	8	0.4 - 0.885	360 m	1420 km	2 days
		MSMR	RADAR	4	6.6,10.65, 18, 21 GHz	120, 80, 40 and 40 kms	1360 km	
IRS-1D	September, 1997	WiFS	Multispectral	2	0.62-0.68 (red)	189	774	5 day
					0.77-0.86 (NIR)			
		LISS-III	Multispectral	3	0.52-0.59 (green)	23	142	24-25 days
					0.62-0.68 (red)			
					0.77-0.86 (NIR)			
				1	1.55-1.70 (SWIR)	70	148	
		PAN	PAN	1		6	70	
IRS-1C	1995	WiFS	Multispectral	2	0.62-0.68 (red)	189	810	5 day
					0.77-0.86 (NIR)			
		LISS-III	Multispectral	3	0.52-0.59 (green)	23.6	142	24-25 days
					0.62-0.68 (red)			
					0.77-0.86 (NIR)			
				1	1.55-1.70 (SWIR)	70.8	148	
		PAN	PAN	1		5.8	70	

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Satellite Name	Launch	Sensors	Types	No. of Bands	Spectral Range (microns)	Resolution (metres)	Swath Width (km)	Revisit Time
IRS-1B	1991	LISS-I	Multispectral	4	450-520	72.5	148	22 days
					0.52-0.59			
					0.62-0.68			
					0.77-0.86 (NIR)			
IRS-1A	1988	LISS-II	Multispectral	4	(same as LISS I)	36.25	74	
		LISS-I	Multispectral	4	Same as above	72.5	148	
		LISS-II	Multispectral	4	Same as above	36.25	74	22 days

6.6., 10.6, 18 and 21 GHz. MSMR will also be in a way a unique sensor as no other passive microwave radiometer is operational in the civilian domain today and will be useful for study of both physical oceanographic and meteorological parameters.

FUTURE INDIAN SATELLITE MISSIONS

Encouraged by the successful operation of the present IRS missions, many more missions have been planned for realization in the next few years. These missions will have suitable sensors for applications in cartography, crop and vegetation monitoring, oceanography and atmospheric studies.

CARTOSAT-1:

It will have a cutting-edge technology in terms of sensor systems and will provide state-of-art capabilities for cartographic applications. The satellite will have only a PAN camera with 2.5 m resolution and 30 km swath and Fore-Aft stereo capability. The 2.5 m resolution data will cater to the specific needs of cartography and terrain modeling applications.

RESOURCESAT-1:

Launched on 17^{th} October, 2003, it is designed mainly for resources applications and having 3-band multi-spectral LISS-4 camera with a spatial resolution 5.8m and a swath of around 24 km with across – track steerability for selected area monitoring. An improved version of LISS-III, with 4 bands (green, red, near—IR and SWIR), all at 23.5 meters resolution and 140 km swath will also provide the much essential continuity to LISS-III. These payloads will provide enhanced data for vegetation applications and will allow multiple crop discrimination; species level discrimination and so on. Together with an advanced wide-field sensor, WiFS with ~ 60 m resolution and ~ 740 km swath, the payloads will aid greatly for crop and vegetation applications and integrated land and water applications. The data will also be useful for high accuracy resources management applications, where the emphasis is on multi crop mapping studies, vegetation species identification and utilities mapping.

CLIMATSAT/OCEANSAT-2:

In order to meet the information requirements to study the Planet Earth as an integrated system, satellite missions are planned which would enable global observations of climate, ocean and the atmosphere, particularly covering the tropical regions, where sufficient data sets are not available. The instruments like radiometers, sounders, spectrometers etc. for studying the land, ocean and atmospheric interactions are being planned for these missions.

OTHER COMMERCIALLY AVAILABLE SATELLITES

IKONOS:

The IKONOS-2 satellite was launched in September 1999 and has been delivering commercial data since early 2000. IKONOS is the first of the next generation of high spatial resolution satellites. IKONOS data records 4 channels of multispectral data at 4 m resolution and one panchromatic channel with 1 m resolution (Table 7). This means that IKONOS is first commercial satellite to deliver near photographic quality imagery of anywhere in the world from space. Radiometric Resolution: Data is collected as 11 bits per pixel (2048 gray tones).

The applications for this data are boundless: in particular, it will be used for large scale mapping, creating precise height models for e.g. micro-cellular radio, and for every application requiring the utmost detail from areas which are inaccessible for aerial photography.

ENVISAT:

Envisat launched on 1st March 2002 is the most powerful European Earth-observation satellite. Envisat is a key element of the European Space Agency's plans for the next decade to monitor Earth's environment. It carries instruments to collect information that will help scientists to understand each part of the Earth system and to predict how changes in one part will affect others (Table 8). It is in a Sun synchronous orbit at an altitude of 800 km and carrying 10 instruments onboard.

Variety of earth resources satellites are currently commercially available for inventorying and monitoring earth resources. These satellites are characterised by varying spatial, spectral, radiometric and temporal resolutions (Table 9).

Table 7. Characteristic of IKONOS Satellite

Satellite Name	Launch	Sensors	Types	No. of Bands	Spectral Range (microns)	Resolution (metres)	Swath Width (km)	Revisit Time
IKONOS-2	September 24, 1999	IKONOS	Multi-spectral	4	0.45-0.52 (blue)	4		11 days
					0.52-0.60 (green)			
					0.63-0.69 (red)			
					0.76-0.90 (NIR)			
			PAN	1		1		

Table 8. Envisat's Instrument
(source: www.esa.int/export/esasa/ESADTOMBAMC_earth_O.html)

Instrument	Main purpose
Global ozone monitoring by occultation of stars (GOMOS)	To observe the concentration of ozone in the stratosphere.
Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY)	To measure trace gases and aerosol concentrations in the atmosphere.
Michelson interferometer for passive atmospheric sounding (MIPAS)	To collect information about chemical and physical processes in the stratosphere, such as those that will affect ozone concentration in future.
Medium resolution imaging Spectrometer (MERIS)	Measures radiation in 15 frequency bands that give information about ocean biology, marine water quality, and vegetation on land, cloud and water vapor.
Advanced synthetic aperture Radar (ASAR)	All weather, day or night radar imaging.
Advanced along track scanning radiometer (AATSR)	To measure sea-surface temperature, a key parameter in determining the existence and/or extent of global warming.
Radar Altimeter (RA-2)	Measures distance from satellite to Earth. So can measure sea-surface height, an important measurement for monitoring El Nino, for example.
Microwave radiometer (MWR)	Allows corrections to be made to radar altimeter data.
Doppler Orbitography and Radio positioning integrated by satellite (DORIS)	Gives the position of Envisat in its orbit to within a few centimeters. This is crucial to understanding the measurements all the instruments make.
Laser retro-reflector (LRR)	Reflects pulsed laser to ground stations to help determine the satellite's exact position in its orbit.

Table 9. Characteristics of some more commercially available satellites

Satellite Name	Launch	Sensors	Types	No. of Bands	Spectral Range (microns)	Resolution (metres)	Swath Width (km)	Revisit Time
QuickBird-2	Oct. 18, 2001		Multi-spectral	4	blue (0.45-0.52)	2.5	17	
					green (0.52-0.6)			
					red (0.63-0.69)			
					NIR.(76-0.89)			
			Pan	1	0.45-0.9	0.61		
EROS 1	Dec. 5, 2000		Pan	1	0.5-0.9	1.8	12.5	1-4 days
EO 1	Nov. 21, 2000	ALI	Multi	9	0.433-0.453			
					0.45-0.515			
					0.525-0.605			
					0.63-0.69			
					0.775-0.805			
					0.845-0.89			
					1.2-1.3			
					1.55-1.75			
					2.08-2.35	30	37	16 days
			Pan	1	0.48-0.69	10		
		Hyperion	Hyper	220	0.4 to 2.5 (10nm sampling interval)	30	7.5 km x 100 km	

contd...

Satellite Name	Launch	Sensors	Types	No. of Bands	Spectral Range (microns)	Resolution (metres)	Swath Width (km)	Revisit Time
		LAC	Hyper	256	0.9-1.6 (2-6nm sampling interval)	250	185 km	
Terra (EOS AM-1)	Dec. 18, 1999	ASTER	Multi	3	VNIR - stereo (0.5-0.9)	15	60	16 days
				6	SWIR (1.6-2.5)	30		
				5	TIR (8-12)	90		
		CERES	Multi	3	SWIR, TIR, Total	20 km		
		MISR	Multi	4		250-275	360	
		MODIS	Multi	2	0.4-14.4	250	2330	
				5		500		
				29		1000		
		MOPITT	Multi	3	2.3 (CH4)	22 km	640	
					2.4 (CO)			
					4.7 (CO)			
CBERS	October 14, 1999	WFI	Multi	2	0.66 (green)	260	890	5 days
					0.83 (NIR)			
		CCD (stereo)	Multi	5	0.51-0.73 (pan)	20	113	26 days
					0.45-0.52 (blue)			
					0.52-0.59 (green)			
					0.63-0.69 (red)			
					0.7-0.89 (NIR)			

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Satellite Name	Launch	Sensors	Types	No. of Bands	Spectral Range (microns)	Resolution (metres)	Swath Width (km)	Revisit Time
		IR-MSS	Multi	4	0.5-1.1 (pan)	80	120	
					1.55-1.75 (IR)			
					2.08-2.35 (IR)			
					10.4-12.5 (TIR)	160		
KITSAT-3	May 26, 1999	CCD	Multi	3	red, green, NIR	15		
			Pan	1		15		
NOAA-K	May - 1998	AVHRR	Multi	5		1100		
OrbView-2	August, 1997	SeaWiFS	Multi	8	0.402-0.422	1130	2,800	1 day
					0.433-0.453			
					0.48-0.5			
					0.50-0.52			
					0.545-0.565			
					0.66-0.68			
					0.745-0.785			
					0.845-0.885			
RADARSAT	November, 1995	SAR	Radar	1	C-band (HH polarization)	8-120		24 days
ERS-2	1995	AMI	Radar	1	5.3 GHz(C-band)	26	99	35 days
		ATSR	Multi	4		1000		

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Satellite Name	Launch	Sensors	Types	No. of Bands	Spectral Range (microns)	Resolution (metres)	Swath Width (km)	Revisit Time
NOAA-14	1994	AVHRR	Multi	5		1100		
RESURS-O1-3	1994	MSU-SK	Multi	4	0.5-0.6 (green)	170	600	21 days
					0.6-0.7 (red)			
					0.7-0.8 (NIR)			
					0.8-1.1 (NIR)			
				1	10.4-12.6 (Thermal IR)	600		
JERS-1	February, 1992	SAR	Radar	1	1275 MHz (L-band, HH polarization)	18	75	44 days
		OPS	Multi	3	Visible NIR	18 x 24	75	
				4	SWIR			
ERS-1	1991	AMI	Radar	1	C band (VV polarization)	26		35 days
		ATSR	Multi	4		1000		
NOAA-12	1991	AVHRR	Multi	5		1100		

CONCLUSIONS

Since the launch of first earth resource satellite in 1972, various satellite platforms with a variety of remote sensing sensors have been launched to study the earth, the ocean, the atmosphere and the environment. These earth resources satellites data are very useful for mapping and monitoring natural resources and environment at various levels, such as global, regional, local and micro level.

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