The evolution of the earth observation system in India

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Abstract | The Indian Earth Observations Programme has been applications- driven and national development has been its prime motivation. From the experimental satellite Bhaskara-I launched in 1979 to the recent Cartosat-2B launched in July 2010, India's Earth Observations capability has increased manifold. The Enhancement in observation capabilities are not only in spatial, spectral, temporal and radiometric resolutions, but also in their coverage and value-added products. The sensors built over this period provide observations over land, atmosphere and oceans in visible, infrared, thermal and microwave regions of the electro magnetic spectrum. Earth Observation data has been extensively used in inventories, monitoring and conservation plans of various natural resources of the country for societal benefits. An institutional mechanism for the absorption of technology at different levels of governance in the country has been built through the concept of the National Natural Resources Management System. The Establishment of various centres/institutions in different states, central agencies as well as academic and research institutions has helped capacity building in the area of remote sensing technology and applications programmes. The paper reviews the evolution of the Earth Observation System in the country in the last three decades and briefly discusses future directions.

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Introduction

Earth Observation (EO) involves monitoring of earth surface features and estimating their geophysical properties using electromagnetic radiation as a medium of interaction. The EO system with its ability for a synoptic view, repetitive observations at different resolutions provides a better alternative for natural resource management when compared to traditional methods. Considering India's resource richness and the mounting problems ranging from demographic pressure to accelerated land degradation, the country needs a sustainable development plan [1]. The Indian Earth Observation Programme, with a beginning made in 1970 with an experiment on the detection of coconut root wilt disease has matured into a fully operational programme during the last three decades [2]. It is self-reliant in every aspect of the technology and applications programme. The major components of the programme are the space segment, ground segment, applications programme and capacity building. The space segment comprises the indigenous development of electro-optical and microwave sensors [3,4,5], spacecraft platforms for both low earth orbit and geo-synchronous orbits and satellite launch vehicles.

The ground segment is involved in setting up telemetry, tracking and command networks of stations, and data reception systems both within the country and outside. It also develops data processing software for the generation of data products and value-added services. The payload data reception

Table 1: Evolution of Indian Earth Observation Satellites.

Sl. No	Satellite	Sensors	Launch Date
1	Bhaskara-1	TV camera, SAMIR**	7 June, 1979
2	Bhaskara-2	TV camera, SAMIR**	20 Nov., 1981
3	IRS-1A	LISS-I, LISS-II	17 Mar.,1988
4	IRS-1B	LISS-I, LISS-II	29 Aug.,1991
5	IRS-P2	LISS-II	15 Oct.,1994
6	IRS-1C	LISS-III,PAN,WiFS	28 Dec.,1995
7	IRS-P3	MOS A,B,C, WiFS	21 Mar.,1996
8	IRS-1D	LISS-III,PAN,WiFS	29 Sep.,1997
9	INSAT-2E*	CCD, VHRR	03 Apr.,1999
10	IRS-P4 (Oceansat-1)	OCM, MSMR**	26 May, 1999
11	Kalpana-1*	VHRR	12 Sept, 2002
12	INSAT-3A*	CCD, VHRR	10 April, 2003
13	IRS-P6	LISS-III, LISS-IV, AWiFS	17 Oct., 2003
14	IRS-P5 (Cartosat-1)	PAN (Fore, Aft)	05 May, 2005
15	Cartosat-2	PAN	10 Jan. 2007
16	Cartosat-2A	PAN	28 April, 2008
17	IMS-1	Hysi, Mx	28 April, 2008
18	Oceansat-2	Scatterometer***, OCM, ROSA	23 Sept. 2009
19	Cartosat-2B	PAN	12 July 2010
20	RISAT	SAR***	Planned
21	Megha Tropiques	MADRAS**, SAPHIR**, ScaRaB, GPS Occ.	Planned
22	INSAT-3D*	Imager, Sounder	Planned
23	SARAL***	Altika. ARGOS	Planned

* INSAT-2E/3A/3D are geo-stationary satellites, the others are polar orbiting satellites.
** SAMIR, MSMR, MADRAS, SAPHIR are multifrequency passive microwave radiometers.
*** SAR, Altika and Scatterometer are active microwave sensors.

for IRS satellites is done at the National Remote Sensing Centre, Hyderabad. The data reception and archival for INSAT satellites is done at the India Meteorological Department (IMD), New Delhi. The applications programme has involved developing algorithms for parameter retrieval, carrying out demonstration experiments and operationalisation of the application packages among user agencies. The indigenous development of retrieval algorithm and data dissemination systems for the generation of meteorological data products from Kalpana and INSAT-3A for operational services at IMD, New Delhi, is a recent example. An institutional mechanism has been established in the country to ensure the use of remote sensing data by users through the National Natural Resources Management System.

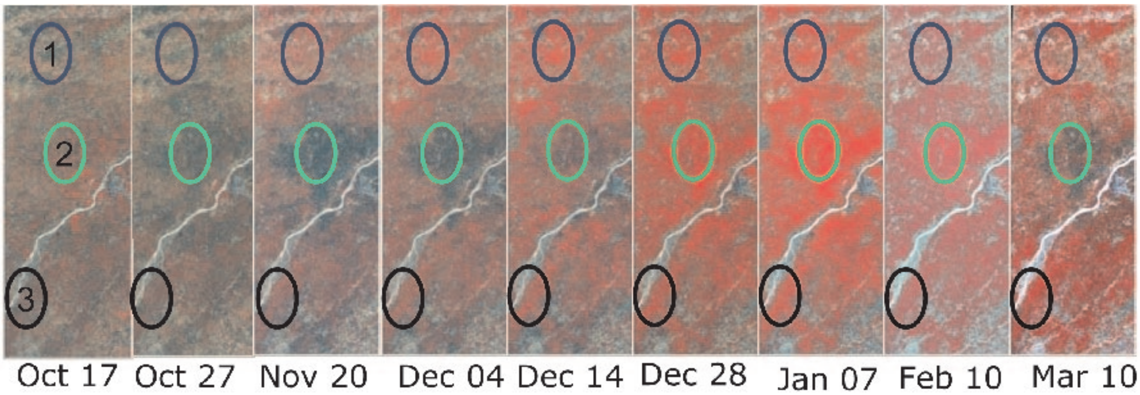
The Indian EO systems developed over the years is playing a significant role in the mapping and monitoring of natural resources and providing spatial information on different land, ocean, and atmospheric events during normal as well as disaster situations. These data are being used for a number of applications such as crop inventory and forecasts, drought and flood damage assessment, land use monitoring and management etc. Today, India is one of the major providers of earth observation data in the world (Table 1). This paper, briefly, presents the evolution of the sensor system, calibration and validation, application programmes, institutionalization and future perspectives.

Physical basis of earth observation

Earth Observation generally refers to the technology of acquiring information about the earth's surface (land and ocean) and atmosphere using sensors on board airborne (aircraft, balloons) or space borne (satellites, space shuttles) platforms. EO employs passive and/or active sensors, which detect electromagnetic (EM) radiation emitted/scattered from different targets in specific spectral band and spatial resolutions. Optical remote sensing is a widely used technique for high spatial resolution topographic mapping, geophysical parameter retrievals and global monitoring. Thermal remote sensing is used to estimate land or sea surface temperatures and thermal inertia properties. The cloud cover, particularly during the monsoon poses a challenge to optical as well as thermal sensing of the earth's surface. Microwave remote sensing is highly useful in such situations as it provides observation of the earth's surface regardless of the time of day and atmospheric conditions.

Different land cover features, such as water, soil, vegetation, cloud and snow reflect visible and infrared light in different ways. The interpretation of optical images requires a knowledge of the spectral reflectance signatures of various materials (natural or man-made) covering the surface of the earth. In the case of green vegetation, there is low reflectance in the blue and red region (due to chlorophyll absorption) and relatively high reflectance in green and a marked increase of leaf reflectance in the near-infrared region. Spectral, spatial, temporal and polarization variations are the four principal characteristics of signatures to identify an object. Figure 1 shows the temporal variation over different sites representing mustard, potato and wheat crops. We can see different growth patterns of mustard, potato and wheat (crop vigor represented by red in the image) in multi date observations. Figure 2 represents the vegetation growth characteristics over the forest-dominated region in Madhya Pradesh, India. The moist deciduous forest species remains greener for a longer duration as compared to dry deciduous forest species. Different nature of the growth profile forms the physical basis of vegetation differentiation. The atmospheric constituents cause wavelength-dependent absorption and a scattering of radiation. Remote sensing is done in atmospheric transmission windows where the atmospheric effects

Figure 1: Resourcesat-1 AWiFS data over agriculture dominated region of Gujarat, India. The circles (1), (2) and (3) indicate mustard, potato and wheat growing regions in different images starting from Oct. 2009 to March 2010. Early growth of mustard (more redness in images during Nov. Dec.) as compared to potato and wheat can be seen in false colour composite images where redness represents vegetation vigour.



are minimal for land and oceanic applications. The absorption property of the atmosphere is also used for the sounding of atmosphere and estimate trace gases concentration by probing the atmosphere in narrow spectral channels at specific wavelengths associated with gaseous absorption.

Evolution of sensor system

The major specifications of Indian EO systems are given in table 1, table 2 and graphically represented in figure 3. The highlights of the development of different systems are as follows.

Developmental of Bhaskara-1/2 & IRS system

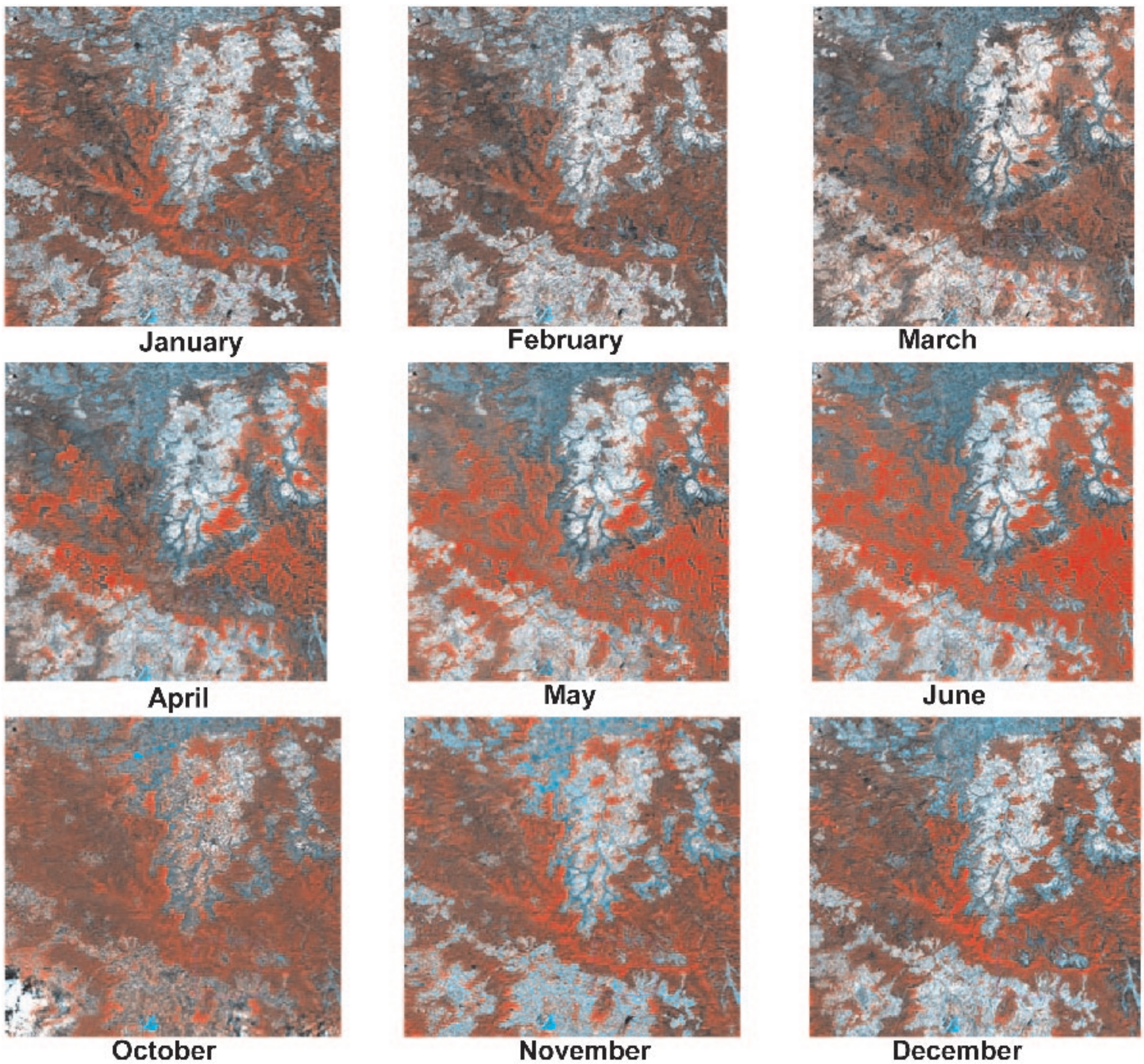
Bhaskara-1 was the first Indian EO satellite launched on June 7, 1979 by a Soviet Intercosmos rocket. It had two types of sensor systems viz. A television camera and a microwave radiometer. The spatial resolution of the images from the Bhaskara satellites was 1 km, and the data was used for applications related to forestry, land use and geology. A Satellite microwave radiometer (SAMIR) with a footprint of 125 km was developed to measure brightness temperature at 19 GHz and 22 GHz for the study of ocean-state, water vapor, liquid water content in the atmosphere, etc. Subsequently Bhaskara-2 was launched on Nov. 20, 1981. The Microwave radiometer SAMIR in Bhaskara-2 had a new channel at 31.4 GHz in addition to 19.24 GHz, 22.235 GHz for the improved estimation of atmospheric and ocean physical parameters. With the successful completion of the Bhaskara programme, the capability to build operational satellites for remote sensing applications was well established.

Following the successful operation of the Bhaskara-1 and Bhaskara-2 satellites respectively, an indigenous operational Indian Remote Sensing Satellite (IRS) programme was initiated to support national development in various areas of natural resources such as agriculture, water resources, forestry and ecology, geology, marine fisheries and coastal management. The first operational remote sensing satellite IRS-1A had two types of payloads employing Linear Imaging Self Scanning (LISS) system. The IRS-1A was followed by IRS-1B in 1991, an identical satellite with LISS-I and LISS-II cameras. An IRS-P2 satellite with only a LISS-II camera was added to this constellation in 1994. Both LISS-I and LISS-II systems were found useful in many national level natural resource management studies.

As a follow-on to the IRS-1A/1B satellites, IRS 1C/1D missions were planned with newer payloads such as a panchromatic (PAN) camera, LISS-III camera and a Wide Field Sensor (WiFS). The PAN camera was the highest spatial resolution (5.8 m) civilian system in the world at the time of the launch of the IRS-1C satellite in 1995. The four band multi-spectral camera LISS-I/LISS-II was modified into a four band multi-spectral LISS-III camera with the inclusion of a SWIR band in place of the blue band. The detection of moisture-stress in crops and snow-cloud discrimination were the driving forces for the inclusion of the SWIR band. The WiFS camera was conceptualized from the observation need for frequent monitoring of crops and vegetation on a national scale. The WiFS camera provided large area information on a temporal resolution of 5 days, which was found useful in national level wheat area and production forecasts. The WiFS data was used to generate a national level land use land cover map of India.

While the availability of data from the operational EO systems starting from IRS-1A to

Figure 2: Monthly variability in vegetation growth characteristics observed using IRS-LISS-III data in the forest dominated region of Kanha National Park region, Mandla, Madhya Pradesh, India. The moist deciduous forest species shows a consistent vegetation growth (represented as red in most of the images) as compared to dry deciduous forest, which has the highest foliage in the monsoon season and very low foliage during the summer season.



IRS-1C/1D facilitated applications in the fields of agriculture, forestry, land use, coastal zone and cartography from the regional scale to the national scale, there was a strong need felt to design sensors for ocean observations, cartography and improved land applications. The Launch of IRS-P3, an experimental satellite, in 1996 brought in a new era of oceanic applications. The IRS-P3 carried a WiFS sensor similar to IRS-1C with an additional spectral band in SWIR and a modular opto-electronic scanner (MOS) sensor developed by the German space agency, DLR. MOS-A, B, & C sensors provided quantitative modeling for the retrieval of ocean colour and aerosol characteristics. The Experience gained in the ocean colour studies from MOS data helped to formulate the sensor specifications for IRS-P4, also known as Oceansat-1. IRS-P4 (Oceansat-1) became the first Indian satellite primarily built for ocean applications [8]. The satellite carried on board an Ocean Colour Monitor (OCM) and a Multi-frequency Scanning Microwave Radiometer (MSMR). The OCM is a solid-state camera operating in eight narrow spectral bands. The MSMR, which is a dual polarization passive microwave radiometer, operates in four microwave frequencies (6.6, 10.65, 18 and 21 GHz) both in vertical and horizontal polarizations. The MSMR-derived geophysical parameters were found useful in the prediction of atmospheric and sea state variables.

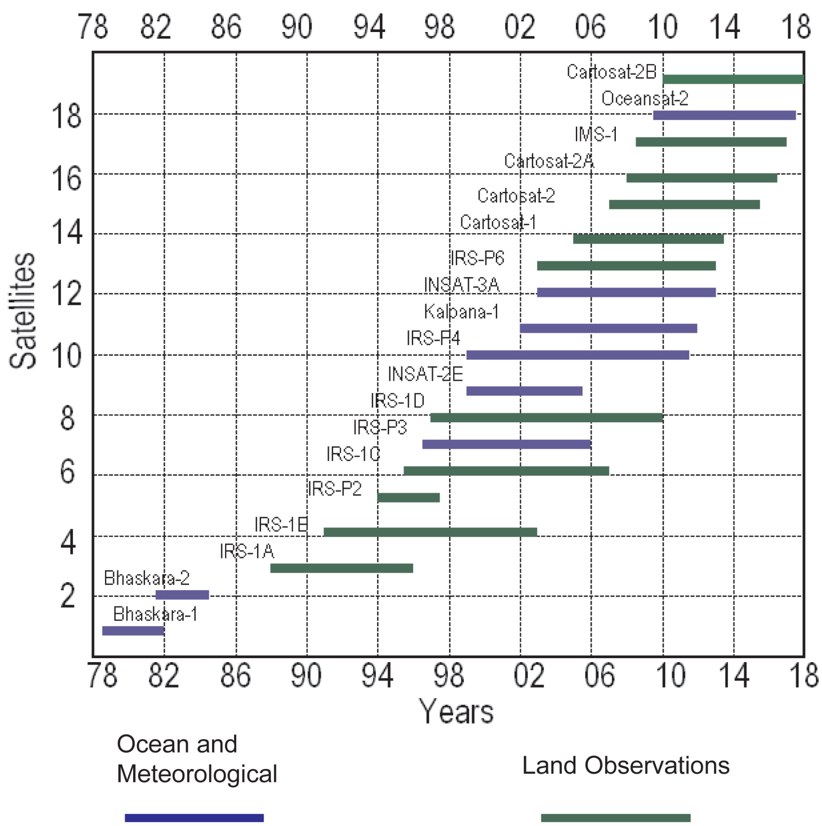
Table 2: Major specifications of sensors in the IRS series of satellites.

Sensor	Spectral Bands (μm)	Spatial Res. (m)	Swath (km)	Radiometric Res. (Bits)	Repeat Cycle (days)
LISS I	0.45–0.52 (B) 0.52–0.59 (G) 0.62–0.68 (R) 0.77–0.86 (NIR)	72.5	148	7	22
LISS–II	Same as LISS–I	36.25	74	7	22
LISS–III	0.52–0.59 (G), 0.62–0.68 (R) 0.77–0.86 (NIR) 1.55– 1.70 (SWIR)	23.5 70.5 (SWIR)	141 148	7	24
IRS–1C/1D WiFS	0.62–0.68 (R) 0.77–0.86 (NIR)	188	810	7	24(5)
IRS–1C/1D PAN	0.50–0.75	5.8	70	6	24(5)
MOS–A	0.755–0.768(4 bands)	1570×1400	195	16	24
MOS–B	0.408–1.010(13 bands)	520×520	200	16	24
MOS–C	1.6 (1 band)	520×640	192	16	24
IRS–P3 WiFS	0.62–0.68 (R) 0.77–0.86 (NIR) 1.55–1.70 (SWIR)	188	810	7	5
IRS–P4 OCM	8 bands (0.412, 0.443, 0.490, 0.510, 0.550, 0.670, 0.765, 0.865)	360×236	1420	12	2
MSMR	6.6,10.65,18,21 GHz (V & H)	150,75,50 & 50 km respectively	1360	–	2
LISS–IV	0.52–0.59 (G) 0.62–0.68 (R) 0.77–0.86 (NIR)	5.8	70	10(7)	24(5)
AWiFS	0.52–0.59 (G), 0.62–0.68 (R) 0.77–0.86 (NIR) 1.55– 1.70 (SWIR)	56	737	10	24(5)
Cartosat–1 PAN	0.50–0.85 (Fore (+26°)& Aft (−5°)	2.5	30	10	5
Cartosat–2 PAN	0.50–0.85	0.8	9.6	10	5
IMS–1 MX	0.45–0.52 (B) 0.52–0.59 (G) 0.62–0.68 (R) 0.77–0.86 (NIR)	37	151	10	24
IMS–1 HySi	64 bands 400–950 nm range	505.6	129.5	11	24
Oceansat–2 Scatterometer	13.4 GHz	50000	1840	–	2
Oceansat–2 OCM	8 bands (0.412, 0.443, 0.490, 0.510, 0.550, 0.620, 0.740, 0.865)	360×236	1420	12	2

Present theme specific EO systems

Presently, many theme-specific satellites such as Resourcesat-1, Cartosat-1/2/2a/2b, Indian Mini Satellite (IMS), Oceansat-2, Kalpana and INSAT-3A are operationally providing data for Land, Ocean and Atmospheric applications. IRS-P6 Resourcesat-1 is a mission primarily dedicated to agricultural applications in India. The Resoursesat-1 satellite is equipped with three cameras viz. LISS-IV, LISS-III and an Advanced WiFS (AWiFS). A high resolution LISS-IV camera operates in three spectral bands in the Visible and Near Infrared Region (VNIR) with a 5.8 m spatial resolution. Medium resolution LISS-III operates in three spectral bands in VNIR

Figure 3: Evolution of different Indian earth observation systems.



and one in the SWIR band with a 23.5 m spatial resolution. An Advanced Wide Field Sensor (AWiFS) has three spectral bands in VNIR and one band in the SWIR region with a 56 m nominal spatial resolution.

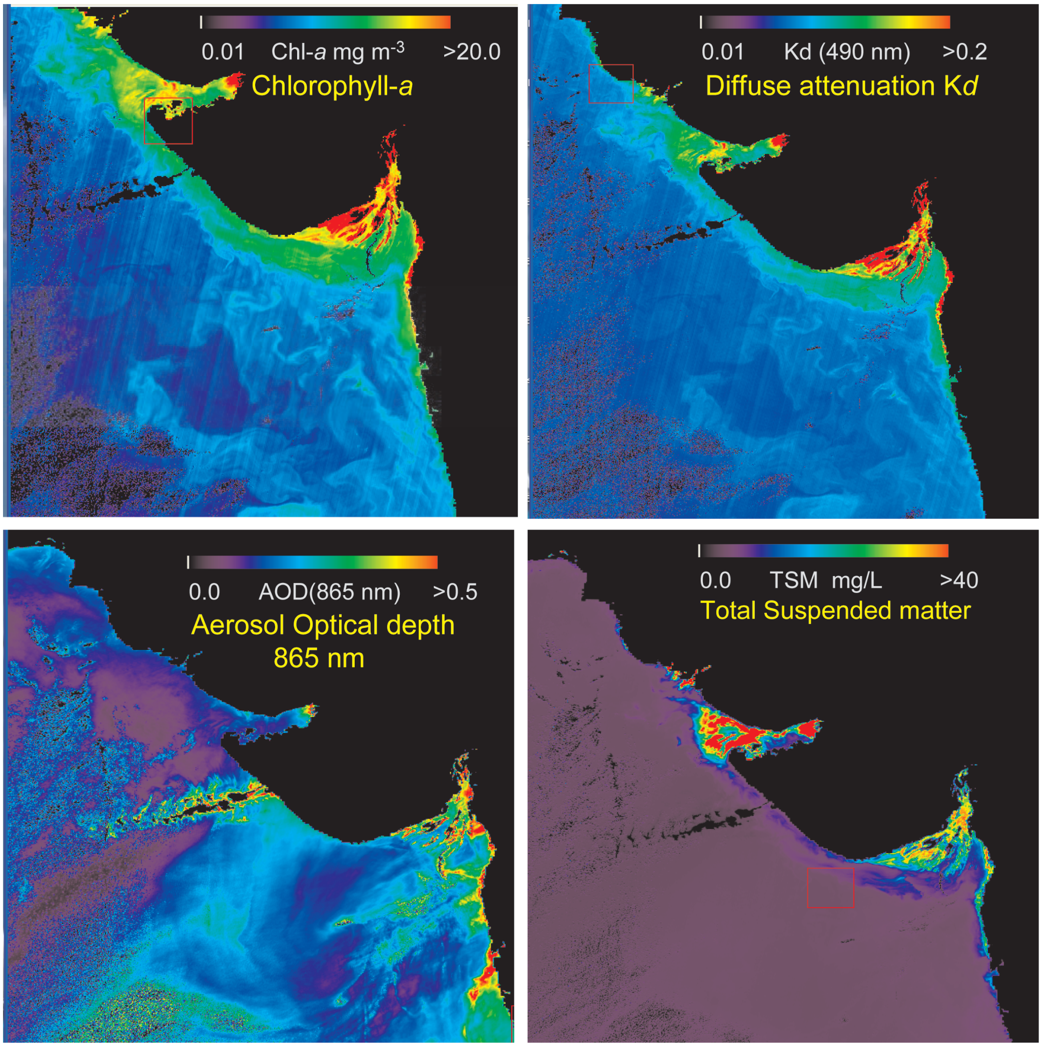
Cartosat-1 carries two state-of-the-art panchromatic cameras that take stereoscopic pictures of the earth in the visible region of the electromagnetic spectrum for cartographic applications. The cameras are mounted on the satellite in such a way that near simultaneous imaging of the same area from two different angles is possible. This facilitates the generation of accurate three-dimensional maps. Cartosat-1 is followed by Cartosat-2/2a/2b, which have been better than 1m spatial resolutions. The satellites provide cadastral level information up to 1:5000 scales and are useful for making 5 m contour maps.

As a continuity of Oceansat-1, Oceansat-2 with an OCM, Ku band Scatterometer and Radio Occultation for Sounding of Atmosphere (ROSA) provides valuable data for Indian as well as global applications (figure 4). The Scatterometer operates at 13.515 GHz with a resolution of 50 km and measures ocean surface wind vectors (Figure 5). The OCM sensor is configured in terms of replacement of earlier 765 nm channel into 740 nm to avoid O_2 absorption and the replacement of the 670 nm channel into a 620 nm channel for better quantification of suspended sediments. A Geostationary orbit is providing constant surveillance, and a 1 km imaging capability is present in visible and Near-Infra red regions (CCD) on INSAT 3A. Meteorological observations from Very High Resolution Radiometer (VHRR) sensors onboard in Kalpana and INSAT-3A satellites are providing real time observations of meteorology.

Ground based measurements, calibration and validation

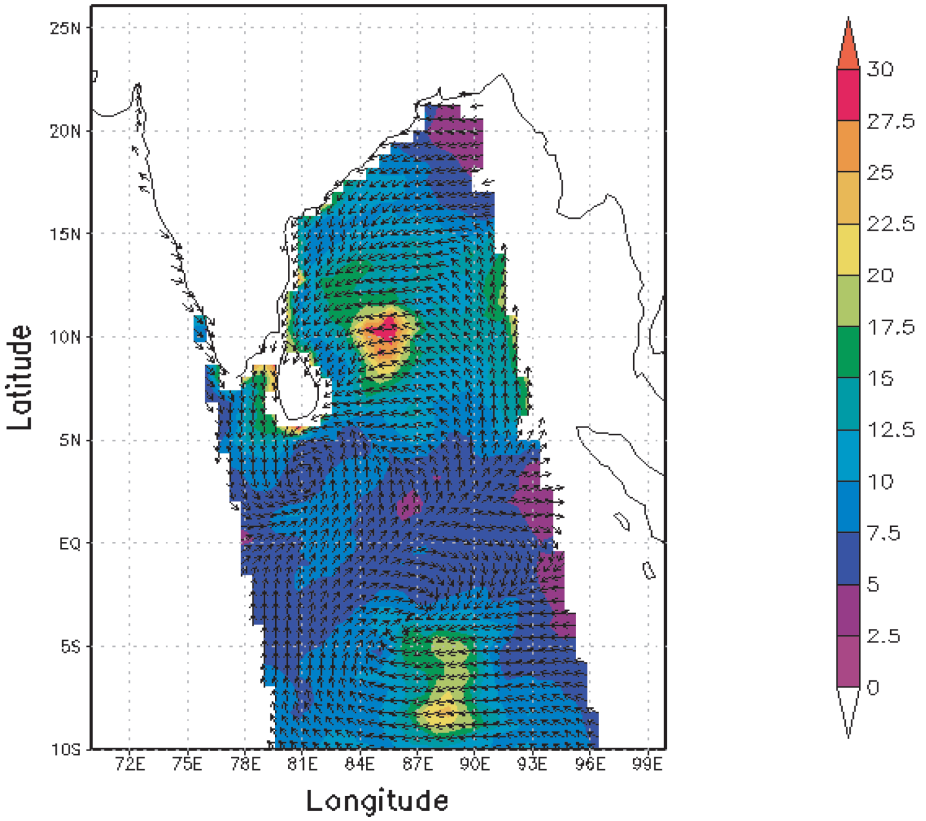
The Indian EO space programme has emerged as a global player in delivering satellite based remote sensing data at various resolutions and spectral bands on a sustainable basis. Many users in India as well as abroad are using the measurements from the Indian satellite for terrestrial, ocean and meteorological applications in conjunction with data available from the satellites of other countries. The Calibration and validation of the satellite data/products is very important for meaningful

Figure 4: OCENASAT-2 OCM derived Geophysical products (25 Nov 2009).



scientific investigations [8,9]. Calibration is the process of quantitatively defining the system response to known, controlled signal inputs. The Importance of calibration/validation arises due to the fact that sensor response depends not only on surface conditions but is also a function of relative spectral response, viewing geometry and atmospheric conditions. Looking into the specific need for ground verification of satellite products, all Indian missions have inbuilt mechanisms of calibration/validation under the specific satellite data utilization programme. This includes pre-launch laboratory calibration, onboard calibration and vicarious post-launch calibration. Different measurements such as minimum and saturation radiance (Lmin, Lmax), light transfer characteristics and the relative spectral response of the sensor are carried out in the laboratory before the launch of the satellite. The System level relative spectral response (RSR) of electro-optical payloads is measured using an Optronic Spectroradiometer system. It consists of a lamp source (tungsten halogen), a double monochromator, a collimator and a standard detector whose spectral responsivity data is available. RSR characterization is a two-step process where the, monochromator beam is allowed to fall on the standard detector. The Corresponding signal output (100% signal) and standard responsivity of the detector is used to estimate the monochromatic flux in the entire spectral range. The sensor system under test is then placed in the beam path and RSR data is generated in terms of the responsivity of the sensor system to incident monochromatic wavelengths in the desired spectral range. A Blackbody is used to calibrate thermal and passive microwave sensors. Provisions are also made for onboard calibration

Figure 5: Oceansat-2 Scatterometer derived winds (Dec, 11, 2009).



of the system to check out sensor degradation with time. Standard lamps (LEDs) and/or solar diffuser reflectance panels are used for onboard calibrations. External space objects such as the moon and deep space are also used to assess on-board sensor calibration. Natural or artificial sites on the surface of the earth are used for the post-launch calibration of sensors (vicarious calibration). In-synchronous satellite passes over natural (*viz.* Thar desert) or artificial sites (near SAC Ahmedabad) are used for inter-sensor vicarious calibration with the help of field based measurements of spectral reflectance, atmospheric properties and radiative transfer modeling. Corner reflectors are deployed to calibrate microwave Synthetic Aperture Radar (SAR) data. Uniform and temporally invariant earth surfaces such as deserts, forests and ice in Antarctica are generally preferred targets of vicarious calibration.

Validation is the process of assessing by independent means the quality of the data products derived from system outputs. Validation in the EO programme means the validation of geophysical parameters derived from a sensor as well as accuracy assessments of application outputs such as crop areas, assessment of cyclone trajectories and modeling net primary productivity etc. Field based measurements are carried out for the development of the model and the validation of the accuracy of remote sensing derived products such as leaf area index, ocean chlorophyll, sea surface temperature etc. Sites are selected based upon the minimum area compatible with the resolution of the satellite data/product to be validated. The number and size of sites are chosen based on the homogeneity/heterogeneity of the target so as to capture the spatial variability of the biophysical parameter of interest. The location of the site is recorded with the help of the global positioning system (GPS). The statistical aggregation of field-measured geophysical parameters collected within the footprint of satellite observations is carried to validate the satellite product. The Up-scaling of field measurements and high-resolution aerial/satellite measurements are needed to validate the geophysical products available at very coarse resolutions.

Application programmes related to inventory/mapping and modeling use extensive field surveys which involve the collection of terrain information in designated samples derived from appropriate

Figure 6: Proposed network of ISRO developed Agro Meteorological Station (AMS) for studying the micrometeorology of agriculture and the natural vegetation ecosystem.

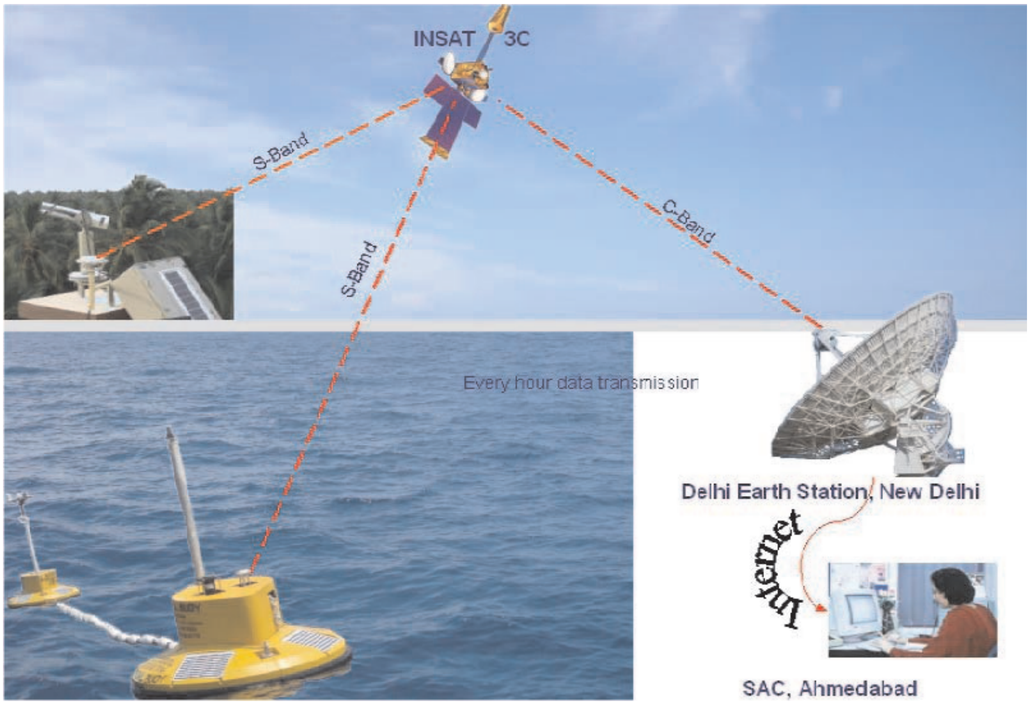
sampling plans. The Crop Area and Production Estimation (CAPE) project uses a stratified random sampling approach with 90/90 accuracy goals where 10 percent of the samples (of 5×5 km) are analyzed to estimate district level crop areas. The accuracy of the application programmes is judged by knowing the bias (closeness of the result from the true value) and precision (repeatability of results) of the estimate from the reference value. The Classification accuracy assessment approach is used to quantify the errors associated with mapping. Wall to wall field survey data and remotely sensed maps are statistically analyzed to compute the percentage agreement in the two estimates. Overall accuracy, mapping accuracy, and the kappa coefficient are some of the statistical measures used to assign the value of remote sensing assessment.

The ISRO Geosphere Biosphere Programme, which deals with scientific issues of land, ocean and atmospheric interaction, conduct specific measurement campaigns related to aerosol optical characterization, trace gases, carbon fluxes and important oceanic parameters. There is a further need to establish long-term regular measurement sites, which can be used for different satellite product validation. The Installation of the network of Automatic Weather Stations (AWS) and Agro-Meteorological Stations (AMS) (Figure 6) is one of ISRO's recent steps in the development of satellite based in-situ measurement systems. The Calibration and validation site developed at Kavaratti (Lakshadweep) is being regularly used to monitor OCM sensor spectral radiance for cross comparison of OCM with other satellite sensors (Figure 7).

Applications towards societal benefits

Under the umbrella of the NNRMS, a large number of applications at the national and regional level have been formulated and carried out to meet the specific needs of users in the country. The Major areas of applications include agriculture [7], forestry, water resources, snow and glaciers, geology, cartography, coastal zones, marine fisheries, ocean colour [8], weather forecasting, ocean state forecasting, besides disaster monitoring and mitigation. The Work carried out in a few of these areas is described in the following sections.

Figure 7: Calibration and validation site at Kavaratti (Lakshadweep) for the monitoring of aerosol optical thickness, OCM sensor spectral radiance, and cross comparison of OCM with other satellite sensors.



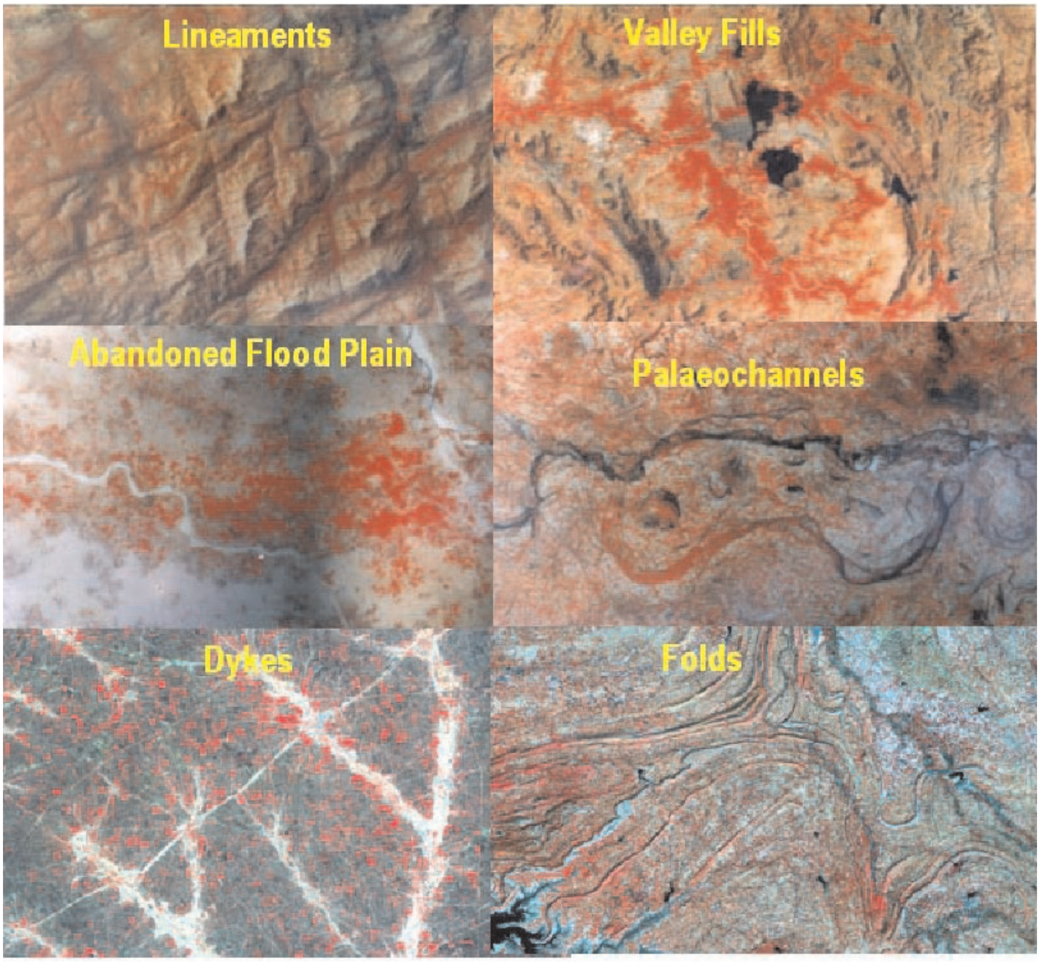
Food security

Agriculture is the world's major user of land, water and biological resources. Data from EO satellites enable estimations of pre-harvest acreage and production, besides assessment of conditions. Procedures have been developed to make production forecasts at the national level to help in planning and formulating policy decisions. Figure 1 shows the pictorial representation of the IRS-AWiFS data used for making national estimates of wheat, mustard and potato. The differential growth pattern of these crops forms the scientific basis of the hierarchical rule-based classification scheme used for crop assessment. Currently, multi temporal IRS-AWiFS data are regularly used to make national and state level wheat production estimates. As most of the rice crop is grown in the kharif season (monsoon) coinciding with overcast cloudy conditions of the sky most of the time, Radarsat microwave data is used to generate national level rice estimates. Recognising that remote sensing data can not provide a stand alone system for making multiple and reliable forecasts, a programme viz. Forecasting Agricultural Output using Space Agro-meteorology and Land based observations (FASAL) has been conceptualized and is being institutionalized. Studying crop rotation patterns and adopting a cropping system approach towards sustainable agriculture has been another important area of application [10]. Mapping salt-affected soils, monitoring their reclamation, inventorizing and categorizing waste lands, identifying post-kharif fallow lands, and suitable sites for horticulture cultivation, and evaluating of the irrigation performance of command areas are some of the other applications being carried out towards the sustainable development of the food security situation. Ocean Colour data are used in conjunction with sea surface temperature to prepare fishery prospect charts to facilitate marginal fishermen.

Water resources

Providing safe drinking water to lakhs of villages is a priority. Towards this ground water prospect maps showing probable regions where wells can be drilled have been generated using satellite data in conjunction with ground information (Figure 8 and Figure 9). These maps show the yield range at different depths besides indicating sites for recharging aquifers and water harvesting structures. Such work has facilitated identifying sources of drinking water for deprived villages. The synoptic and repetitive information provided

Figure 8: Satellite based synoptic observations of different land features such as lineaments, valley fills, abandoned flood plains, palaeochannels, dykes and folds. These features are used indicators for the generation of ground water prospect maps.

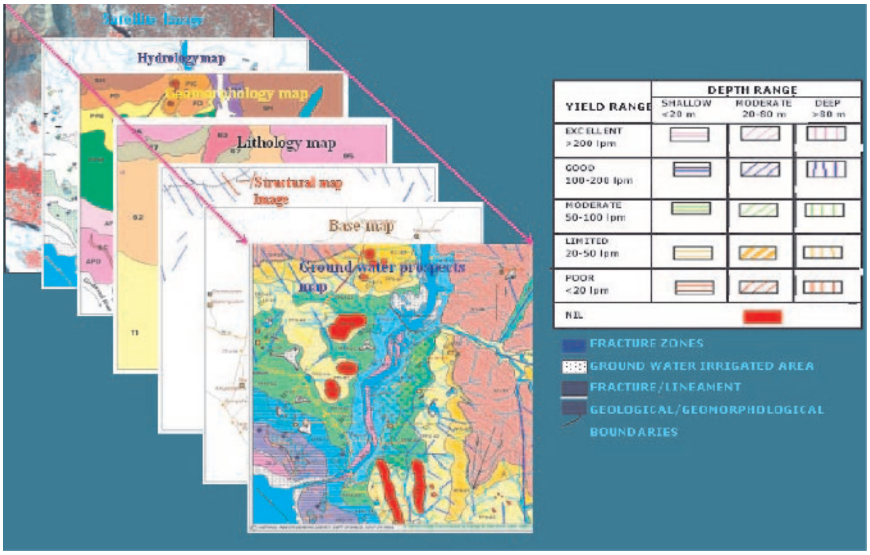


by EO satellite data have been extensively used to map surface water bodies, monitor their spread and empirically estimate the volume of water. National level wetland maps have been prepared at 1:250000 scale and currently work is going on to generate maps at 1:50000 scale for different states. Monitoring reservoir spread through the seasons has helped irrigation scheduling. Snowmelt runoff forecasts are being made using IRS-AWiFS and National Oceanic and Atmospheric Administration (NOAA)- Advanced Very High Resolution Radiometer (AVHRR) data. These forecasts have enabled better planning of water resources by the respective water management boards. Inventorizing the Himalayan glaciers and monitoring their retreat is another important area of study. Remote sensing data along with GIS tools are being used towards national river-linking programmes aimed at reducing the unevenness in water availability.

Biodiversity and ecosystem sustainability

Forests have a profound effect on the global carbon cycle. Satellite remote sensing has enabled the generation of biennial forest cover maps and monitoring changes therein at an operational level by the Forest Survey of India. The advent of high resolution IRS-P6 Resourcesat has enhanced the capacity to prepare forest type and density maps and generate forest-working plans. Figure 2 shows the multi-temporal observations from IRS-P6-LISS-III data showing phenological variations in the forest ecosystem of the Kanha Tiger Reserve, Mandla, Madhya Pradesh, India. Afforestation and deforestation can also be assessed using multi temporal satellite data. The Conservation of biodiversity can only be achieved through the conservation of biological habitats, which require detailed surveys and inventories of the existing bio-resources. Remote sensing techniques

Figure 9: Representative examples of the generation of ground water prospect maps using geo-spatial analysis of satellite data, hydrology maps, geomorphological map, lithology maps and structural maps etc. The prospect of ground water is shown in VIBGYOR, indicating the range from very good conditions (in violet) to very poor conditions (in red).



have been useful in locating different types of bio-resources, identifying appropriate corridors surrounding natural habitats and protecting them from human intervention. Biological richness, disturbance index and habitat suitability index maps have been prepared for different ecologically important sites. Mangrove forests, coral reefs and wetlands are the critical habitats of the coastal zone. The information required for coral reefs includes the spatial distribution of the reefs, vegetation cover, reef zones and reef morphology, biodiversity of fauna and condition assessment. The Satellite data from IRS, SPOT and Landsat have been used to prepare maps showing the extent and condition of coral reefs and the extent, density, condition and diversity of mangroves. Marine National Parks are monitored using EO data regularly. Inland and coastal wetlands of the country have been mapped and reliable databases on the wetlands of the country have been generated.

Disaster monitoring and mitigation

Disaster management support services are mainly directed towards the creation of a digital database for facilitating hazard zonation, damage assessment, monitoring of major natural disasters using satellite and aerial data, the development of appropriate techniques/tools, and the acquisition of close contour data for hazard prone areas using an air-borne Laser Terrain Mapper. It also involves strengthening communication for the timely dissemination of information and emergency support, development of air-borne Synthetic Aperture Radar (DMSAR) towards all-weather monitoring capability, establishment of a Decision Support Centre at NRSC as a single-window service provider and support for the International Charter on Space and Major Disasters, as a signatory. The important components of the Decision Support Centre (DSC) established at NRSC include satellite/aerial data acquisition strategy, turn-around-time for data analysis and output generation, user-required information and formats, dissemination to users and networking and support facilities such as digital database creation, hazard zonation, modeling, query-shell and others.

Near-real time flood monitoring is being done, wherein administrative (village) and current land use layers are being overlaid in GIS on top of satellite-based inundation layers to identify affected settlements for damage assessment and relief purposes. Drought is another important weather-related natural disaster. Being a semi-arid tropical country, India faces severe agricultural drought periodically due to erratic rainfall. A National Agricultural Drought Monitoring Systems (NADAMS) project gives fortnightly information during the monsoon season at the district level using satellite-derived NDVI information as input. EO data has helped in the preparation of landslide hazard zonation maps using databases on lithology, geological structures, slope, vegetation and land use. For earthquakes, seismic hazard zonation is an important step. Space data provide critical spatial inputs like geological structure, lithology, geomorphology etc for integrating with other databases for hazard zonation. The availability of high-resolution data provides the necessary inputs for micro-seismic hazard zonation.

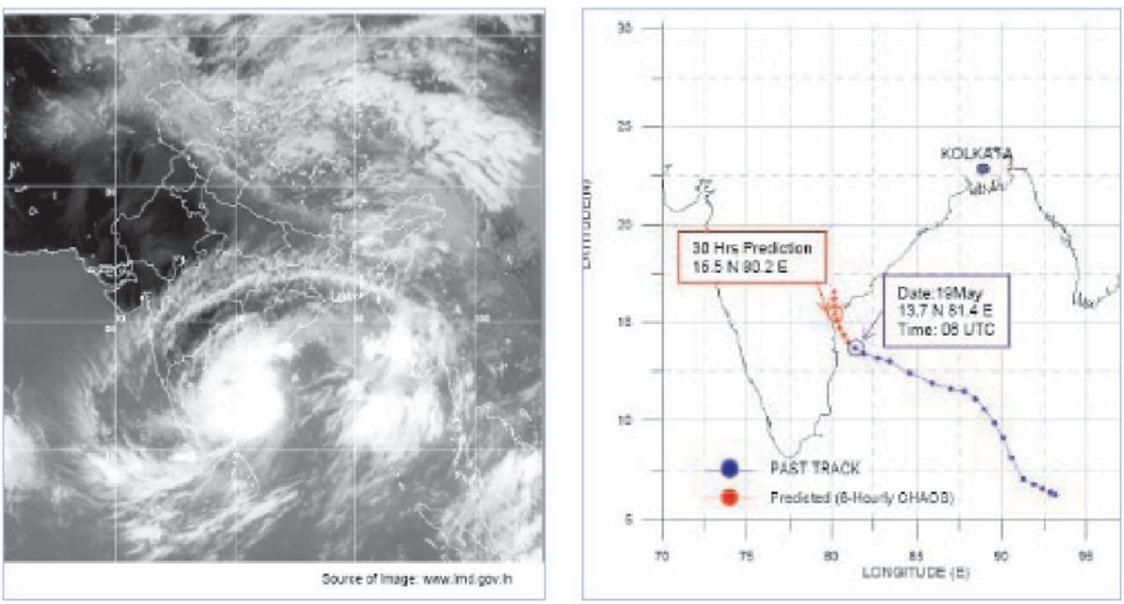
Weather and climate

Using remote-sensing data, wetlands and rice growing regions have been stratified to make methane emission estimates at the national level [11]. The major application in the field of satellite meteorology has been the monitoring of synoptic weather systems ranging from thunderstorms to cyclones (figure 10) and planetary scale phenomena such as the monsoon. The dynamic nature of weather systems can be captured through a time series of satellite observations leading to a better understanding of the process of genesis, growth and decay. This has helped to develop a satellite-based technique to assess the intensity of tropical cyclones accurately and estimate their growth potential. Specific applications include identification of primary weather systems such as low pressure, depression, troughs/ridges, jet streams, regions of intensive convection and inter-tropical convergence zones. One of the major applications of satellite data has been for the study of the monsoon in terms of onset, dynamics and intra-seasonal variability. A Detailed characterization of inter tropical convergence zones has been carried out using satellite data. The Indian National SATellite (INSAT) and National Oceanic and Atmospheric Administration (NOAA) data have brought out the unique nature of the outset of the monsoon with large-scale changes in wind and moisture profiles in the lower troposphere prior to the monsoon. [12, 13]. The critical role played by sea surface temperature in the Indian Ocean and Pacific Ocean regions were clearly brought out by several studies.

Development of Institutional Framework: National Natural Resources Management System

In the early 1980s, The Planning Commission, Government of India recognized the need and importance of setting up a National Natural Resources Management System (NNRMS). The NNRMS is an integrated resource management system aimed at the optimum utilisation of the country's natural resources by a proper and systematic inventory of resources using EO data in conjunction with conventional techniques. The NNRMS concept has arisen from the overall concept of resource management and is envisaged as a management system for natural resources, addressing issues related to (a) making systematic inventories of the country's natural resources for their optimal utilization, (b) reducing regional imbalances by effective planning in line with developmental efforts, (c) maintaining the ecological balance with a view to evolving and implementing environmental guidelines. The

Figure 10: Tropical Cyclone (Laila) and its predicted track using observations from the Kalpana satellite (19 May 2010).



NNRMS emphasizes the bringing together of operational observing systems in accordance with the requirements for addressing a range of issues which include food security, water, energy, disaster management, weather forecasting and others. The major functions of the NNRMS encompass application studies. The establishment of necessary infrastructure for remote sensing at various levels, technology development, generation of trained manpower etc. Towards this, extensive infrastructural facilities have been established which include five Regional Remote Sensing Centres (RRSCs) and a number of State Remote Sensing Application Centres. It is essential to have an efficient and coordinated functioning of different elements, consisting of the space segment and associated ground segment for data acquisition, processing and dissemination, and the user segment which consists of users at the Centre, regions, States, districts and taluks. To take care of this coordination, the Planning Commission formed Standing Committees on various themes in 1984. Currently, the Standing Committees span the following themes: Agriculture & Soils, Bio-resources and Environment, Geology & Mineral Resources, Ocean Resources, Water Resources and Remote Sensing Training & Technology. The Planning Committee, and the NNRMS meet once or twice every year and provide policy guidelines for the Earth Observation Programme of the country.

Training and manpower development in the field of remote sensing applications to various natural resource management areas is one of the major emphases of the NNRMS. One of the NNRMS Standing Committees deals with technology promotion, education and training (SC-T). The Indian Institute of Remote Sensing (IIRS), Space Applications Centre (SAC) and Regional Remote Sensing Centres (RRSC's) are the major DOS centres engaged in capacity building. Remote Sensing has been introduced as part of the Science/Engineering/ Agriculture curriculum in different departments of many Indian universities. One of the major capacity building contributions of the Indian EO programme in global education in the field of space sciences and applications is the establishment of the Centre for Space Science and Technology Education for the Asia Pacific region (CSSTE- AP), affiliated to the United Nations at Dehradun. The CSSTE-AP conducts courses on remote sensing and GIS, satellite meteorology and global climate, atmospheric sciences, satellite communication and space sciences for students from many countries. The Indian Institute of Remote Sensing (IIRS) also conducts short-term courses for decision makers and administrators. This has helped in providing technology to the user.

Future direction

A Knowledge of the current state of the land, ocean and atmosphere is needed in various EO applications. A series of advanced theme-specific sensors are planned to provide some additional observational needs. A Brief summary of the planned missions for different applications follows.

Terrestrial missions

The Major thrust in future terrestrial applications is the consolidation of natural inventories and mapping efforts in diverse areas (land cover, wasteland, forest cover etc) by storing and providing access through geo-spatial databases. This includes continuing major resource management applications related to food security (FASAL, horticulture, fishery prospect), water security (snow, glacier and ground water), and environmental security (coastal, marine etc.). The EO missions related to terrestrial applications, to be launched in the next 2–3 years, include Radar Imaging Satellite (RISAT) and Resourcesat-2. It is proposed that the Cartosat-1/2 series be continued with the launch of a very high spatial resolution (0.3 m) camera on board Cartosat-3. Future terrestrial missions have been planned not only for resource mapping but also parameter retrieval to model crop/forest growth and other terrestrial processes such as energy and mass exchange.

Considering that a national agricultural programme such as FASAL requires multi resolution imaging at frequent intervals for multi crop assessment, the Resourcesat –2 satellite will be launched as a sequel to Resourcesat-1 and these two missions will provide the service of AWiFS, LISS-III and LISS-IV for more than a decade. In Resourcesat-3, LISS-III, which is currently the workhorse sensor, will be modified to LISS-III-WS (Wide Swath) having a swath around 700 km and revisit capability similar to AWiFS (5 days), thus overcoming any spatial resolution limitation of AWiFS. It was observed that the large tilt of the LISS-IV camera creates a difficulty in terms of geometry and radiometry as well as terrain related issues. The swath of LISS-IV is to be increased to 70 km with associated innovative methods for full swath transmission. The payload tilt of LISS-IV should be minimized to fewer than 5 degrees. Resourcesat-3 will also carry an Atmospheric corrector (ATCOR) sensor for the characterization of atmospheric properties (Aerosol, water vapour).

Cloud cover remains a major hurdle in optical remote sensing in India during the monsoon season. Imaging RADAR applications will be served through the RISAT-1 satellite. The C- band Synthetic Aperture Radar (SAR) sensor would be flown on the RISAT-1 satellite for resource monitoring and disaster monitoring. In order to develop a large user community and provide continuing service, it has been suggested that a follow on mission should have features similar to RISAT-1 (C-band and multi-polarization) with multi resolution capability. The L-band SAR has been suggested on the RISAT-3 mission for applications supporting soil moisture, crop and forest type discrimination. In addition, it is desirable to design, develop and launch an agile SAR mission (DMSAR C/X) to meet the needs of monitoring disaster situations.

Beyond Resourcesat-2, a high repetitive sensor will be continued on a geostationaty platform as a Geostationary High Resolution Imager (Geo-HR-Imager). This will provide multiple/day acquisition capability and will overcome all limitations posed on AWiFS availability. Since geostationary satellites have a longer life, the GEO-HR Imager will assure a moderately high spatial resolution (50 m VNIR, 250 m SWIR and 1 km TIR) coverage over India every half an hour for more than a decade.

Vegetation stress, disease and pest detection using hyper spectral techniques such as red edge shift and mineral targeting are some of the important applications which would require a hyperspectral spectrometer on board IRS satellites. This is proposed as an EO Technology Experimental Satellite (TES). The Hyperspectral spectrometer may have 200 channels with a 30 m spatial resolution. The TES can be optimized for a number of spectral bands and have finer spectral bands in specific regions of the EM spectrum to address specific applications. Along with the improvements in sensor systems, efforts are being made to retrieve geophysical products. The important products to be generated from Indian missions are land surface temperature, insolation, albedo, soil moisture, leaf area index, fraction of absorbed photosynthetically active radiation (fAPAR), snow type, snow water equivalent and other. It has been suggested that real time dissemination of remote sensing derived information be provided to the user. There is a need to strengthen process modeling (crop growth, hydrology), which can be used for simulation and forecasting using satellite- derived inputs.

Meteorology & oceanography missions

Numerical weather prediction involves solving the interaction of land, ocean and atmospheric processes. Conventional surface-based observations are sparse in both space and time, whereas satellite-based observations can provide near-global coverage at regular time intervals. The observational need for weather prediction includes 3–6 hourly profiles of temperature, wind, humidity as well as surface pressure, sea surface temperature, rainfall, out going long wave radiation (OLR), cloud cover, ocean wave height, ocean wave vector etc. The Placement of more channels on the INSAT system as well the development of other sensors (microwave sounder, altimeter, GPS occultation) has been planned to resolve some of these observation needs. The two future satellites planned for atmospheric sounding, studying the water vapour and radiation balance and ocean surface wind vectors are INSAT-3D and Megha Tropiques respectively.

The INSAT-3D is to carry a six-channel imager and 19 channel sounders and also provide profiles of atmospheric temperature (50×50 km grid with accuracy 1–2 °C) and water vapour (50×50 km grid). The other geophysical products planned from INSAT-3D data are total ozone content, Outgoing Longwave Radiation (OLR), Quantitative Precipitation Estimation (QPE), Sea Surface Temperature (SST), snow cover, snow depth, fire, smoke, aerosol, cloud motion vector and Upper Tropospheric Humidity (UTH) etc. The Megha Tropiques, a collaborative endeavor with French CNES with three sensors viz. MADRAS, SAPHIR and ScaRab for the estimation of rainfall, atmospheric and cloud water vapour and radiation balance, will be launched in a low inclination angle orbit (20°) covering the tropical region. MADRAS, which is a passive microwave radiometer, has an 89 &157 GHz channel for the estimation of ice particles in cloud tops, 18 & 37 GHz channels for the estimation of cloud liquid water and precipitation and a 23 GHz channel for integrated water vapour estimation. SAPHIR which is a microwave sounder with multiple channels in water absorption bands at 183.31 ± 2, 1.1, 2.7, 4.2, 6.6, 11.0 GHz frequency for the estimation of the water vapour profile in six atmospheric layers up to 12 km height at 10 km Horizontal Resolution, is also be used. The Megha Tropique mission will also carry a GPS occultation system.

The availability of data from INSAT-3D and Megha Tropiques will fill some of the gap areas of meteorological applications but the technology for more advanced sensor systems such as hyperspectral sounders (Michelson interferometer), rain radar and millimeter wave sounders is currently being explored and developed. It is proposed to include a thermal channel of 1 km spatial resolution to go along with OCM in the presence of a Scatterometer on the same platform in future Oceansat missions. The Thermal Infra red combination with OCM will support joint analysis for the generation of potential fishery zones. It is also planned to have a Ka band radio altimeter in a joint Indian Space Research Organization (ISRO)-CNES mission of Satellite for Argos and altimeter (SARAL). Technology development towards an L-band synthetic aperture microwave radiometer is needed for the estimation of ocean salinity.

Planetary Sciences and issues related with climate change studies

The evolution of sensor system design in terms of achieving higher spatial, spectral, and radiometric resolutions with a miniaturized system led to the development of instruments for planetary exploration. Technology demonstrated for national development and societal benefit now addresses global concerns related to climate change [14] and the planetary sciences. The indigenous payloads on Chandrayan-I (Hyperspectral Imager (HySi), Terrain Mapping Camera (TMC), Moon Impact Probe (MIP), Lunar Laser Ranging Instrument (LLRI) etc.) have provided extremely important experiences in lunar exploration. Feasibility studies are being carried out to develop a sensor for the Chandrayan-II mission and the future Indian Mars Orbiter mission.

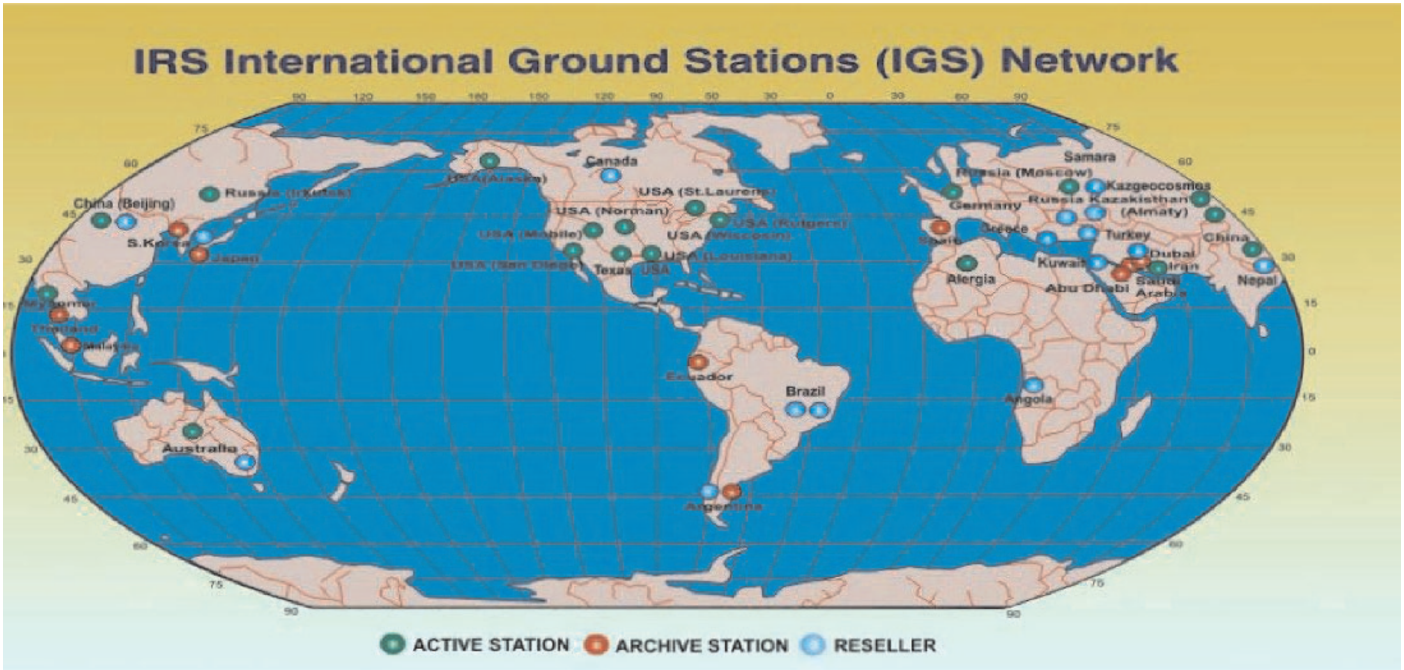
One of the recent advancements in the field of EO is to develop high precision instruments to characterize the composition of the atmosphere. The most important global concern related to climate change is the monitoring of aerosols (known for light scattering and associated global dimming/cooling) and green house gases (responsible for global warming). Technology development is being initiated for aerosol monitoring and the estimation of atmospheric gaseous concentration. The I-STAG (Indian SaTellite for Aerosols and trace Gases) has been planned under ISRO's Small Satellite Programme, and will carry three payloads viz., MAPI (Multi-Angle Polarisation Imager); MAVELI (Measurement of Aerosols by Viewing Earth's LImb; and MAGIS (Measurement of Atmospheric Gases using Infrared Spectrometer). Aerosol detection involves multi angular probing of the atmosphere and includes the detection of the polarized components of light scattering. A Nano satellite for Earth Monitoring and Observation (NEMO) for Aerosol Monitoring (AM) is to be launched in cooperation with the Space Flight Laboratory, University of Toronto, Canada. The NEMO-AM is an experimental satellite designed to observe the polarized sunlight that is scattered from aerosol particles in the atmosphere from different angles. Space-borne atmospheric LIDAR becomes essential to characterize the altitudinal distribution of aerosols optical properties. The space-based precise detection of green house gases up to the level of the requirements for climate change is a scientific challenge. It would involve the development of hyperfine spectral resolution spectrometers designed to measure at specific spectral absorption lines of green house gases in nadir as well as limb observational geometry.

One of the important areas for the development of improved space-based services is to design specific micro-satellites and launch them into a constellation of satellites and formation flying for different applications. This constellation of micro- satellites would achieve superior sampling in space/time and will also be useful in the generation of multi-layer information about a process through a variety of sensors. The availability of inter-sensor calibrated data for long periods is an important concern for the user who has an understanding of long-term changes in ecosystem processes. It is suggested that integrated system of data dissemination be created where merged fields and geophysical products are generated using satellite data, field measurements and associated process-based model outputs. Data archival and dissemination through web-based services on the Internet form important elements of the EO program.

Global participation and international cooperation

The Indian space programme interfaces with all the major space agencies in the world. This includes both bilateral and multi-lateral cooperation on different aspects of space technology including the launching of satellites, development of sensor systems, participation in strengthening constellations of satellites for specific applications and training and education. India has an important role in conducting activities of global concern as a member of various international space agencies such as the Committee on Earth Observation Satellites (CEOS), Global Earth Observation System of Systems (GEOSS), Committee on Space Research (COSPAR), International Astronautical Federation (IAF), International Academy of Astronautics (IAA), UN Office for Outer Space Affairs (UNOOSA) etc. The Indian Space Research Organization interacts closely with the European Space Agency (ESA), National Aeronautics and Space Administration (NASA), The Japan Aerospace Exploration Agency (JAXA) and the space agencies of other countries (France, Germany, Italy, Bulgaria etc) in formulating programmes for global monitoring. India is an important member of the Global Precipitation Measurements (GPM) mission, which is being conducted in cooperation with JAXA, NASA, NOAA, CNES and China. GPM is a cooperative constellation of precipitation measurement instruments . Important discoveries made by the Indian mission to the Moon (Chandrayan-1) are an example of international cooperation in which instruments such as the Moon Mineralogy Mapper, Miniature SAR (USA), Low Energy X-Ray Spect. (UK), SIR-2 Infrared Spect. (Germany), Sub KeV Atom reflect. Analyser (Sweden) and Radiation Dose Monitor (Bulgaria)

Figure 11: Network of IRS international ground stations located in different parts of the world.



from different countries were incorporated for scientific purposes. India has emerged as a centre of excellence in providing training in space technology (satellite communication, earth observation and planetary sciences) to the global community, particularly to the Asia Pacific region. The Institutionalization of the Indian Institute of Space Science and Technology (IIST), Centre for Space Science and Technology Education for the Asia Pacific region (CSSTE- AP), which are affiliated to the United Nations and the Indian Institute of Remote Sensing is an important step towards capacity building.

Conclusions

The Indian Remote Sensing satellite series from IRS-1A to the recently launched Cartosat-2B and sensors onboard-the INSAT series of satellites have established space technology for operational applications related to areas of societal benefits. The missions planned in the near future viz., RISAT, Megha Tropiques, INSAT-3D, SARAL-Altika seek to enhance utility of EO data in meeting the needs of societal benefit areas. An Institutional framework for ensuring the utilization of EO data is in place. Capacity building at different levels including decision making has been organized. Indian EO data is available to global users through international ground stations (Figure 11), and Internet-based data archival systems (MOSDAC) and capacity building has been extended to countries in the Asia-Pacific region. The Continuity of EO missions with enhanced capability has been ensured, and the road ahead has been visualized. Thus, The Indian Earth Observation Programme is complementing GEOSS and adding to the remote-sensing infrastructure in the world.

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