Indian Earth Observation Programme towards Societal Benefits: GEOSS Perspective

Ranganath R. Navalgund
Space Applications Centre (ISRO)
Ahmedabad-380015, India

ABSTRACT

Indian Earth Observation (EO) programme, since its inception has been applications driven and national development has been its main motivation. In order to meet the observational requirements of many societal benefit areas, a series of EO systems have been launched in both polar and geo synchronous orbits. Starting from Bhaskara, the first experimental EO satellite in 1979 to Cartosat-1 successfully launched in May 2005, a large number of sensors operating in optical and microwave spectral regions, providing data at resolutions ranging from 1 km to a meter have been built and flown. Data reception and processing facilities have been established not only in the country but also at various international ground stations. Remotely sensed data and its derived information have become an integral component of the National Natural Resources Management System (NNRMS), a unique concept evolved and established in the country. The paper discusses the evolution of IRS satellite systems, application programmes in different societal benefit areas and the road ahead. How it complements and supplements the international efforts in the context of Global Earth Observation System of Systems has also been indicated.

Keywords : Earth Observation, Indian Remote Sensing Satellite, Agriculture, Biodiversity, Disaster Management, Capacity Building and GEOSS

1. INTRODUCTION

Human kind in pursuit of its needs has put natural resources of the earth to a severe strain. The rate of degradation and depletion of resources has accelerated tremendously in view of ever increasing demographic pressure. Deforestation, desertification, soil erosion and salinisation have degraded the environment, threatening the food security and economic development of many countries. Optimal management of natural resources is vital for the world in general and to the developing nations, in particular. The world population is expected to touch 11 billion by 2075 from 6.06 billion in 2000. Urban area, which amounts for 4% of the land area, inhabit around half of the global populance. As against the estimated minimum need of 0.5 ha per capita, over all arable land of 1500 Mha in the world presently available for agricultural activities amounts to only 0.3 ha per capita. The per capita arable land is expected to dwindle to 0.13 ha by 2075. About 65% of cropped land is having significant soil degradation. Forests occupy about 25% of the land area, from which about 50% world's forest cover has shrunk due to logging; the estimated annual loss of about 5.8 M ha. Besides, 12.5% of total biodiversity is threatened. Forests are responsible for 2 Gt of Carbon/year contributing to 30% of the total carbon cycle. To the global atmospheric carbon of 720-800 GtC, another 3.3 GtC is added each year. Water is another precious resource, whose value is undermined. About 1.6 billion (28%) people lack safe drinking water[1].

Although India is endowed with rich natural resources and is defined as one of the important biodiversity pools for genetic, economic and ecological prudence, it suffers from a variety of problems ranging from population explosion to accelerated land degradation. In India, agricultural resources alone sustain the livelihood of around 64% of the population and contribute nearly 26% of the gross domestic product. It homes over 16% of the world population in the area, which is only 2.42% of global spread. Per Capita arable

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land in India, which is around 0.15 ha at present, is expected to decrease to a meager 0.09 ha by 2075. About 175 M ha of vegetated area is degraded in some form or the other. Agricultural production, which stands at 205 M tons today needs to be increased to 325 M tons by 2050 to meet the needs of the increasing population. Despite an estimated availability of 3,000 cubic meter of water per person per year, uneven distribution on spatial and temporal dimensions is the root cause of water scarcity in many areas. Increasing use of ground water for irrigation, without implementing adequate recharging mechanism, has led to declining water tables and intrusion of seawater into aquifers. The country has about 17% of the world's cattle population, placing a heavy demand on fodder requirements and also resulting in overgrazing of grasslands and forest areas. Forest cover is only about 19 percent of geographical area of the country against 33 per cent prescribed. Area under closed forest category is half of what it was about fifty years ago. Increasing population and industrialization along the coastal areas are putting pressure on coastal wetlands, sea grass area, and coral reefs at an alarming rate. Glaciers in the Indian Himalaya are showing an alarming retreat. India is among the most vulnerable group of nations suffering from the damage due to natural disasters such as drought, floods, cyclone, landslides, forest fire, earthquakes, locust attacks etc. About 40 Mha areas are prone to floods. Many parts of the Himalayas and Western ghats are prone to land slides.

In this context, the Earth Observation (EO) satellites play a significant role in providing information in a spatial format and in determining, enhancing and monitoring the over all capacity of the earth. Satellite Observations over land, oceans, atmosphere, and during natural and human-induced hazards have become crucial for protecting the global environment, reducing disaster losses, and achieving sustainable development. Today, India has the world's largest constellation of remote sensing satellites in operation. It provides space-based remote sensing data in a variety of spatial, spectral and temporal resolution meeting the needs of many applications of relevance to national development. The Indian earth observation satellites specifically designed to meet country's needs can ideally meet the global needs as well, in view of the similarity of situations in India and most parts of the developing world.

2. INDIAN EARTH OBSERVATION PROGRAMME

2.1 Earth Observation Infrastructure

The Indian Earth Observation Programme, with a beginning made in 1970 with the experiment on detection of coconut root wilt disease from a helicopter-mounted multi-spectral camera system 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 indigenous development of electro-optical and microwave sensors[3,4], spacecraft platforms for both low earth orbit and geo-synchronous orbits and satellite launch vehicles (Table 1). The ground segment has involved setting up telemetry, tracking and command network of stations, data reception systems both within the country and outside, and development of data processing software for generation of data products and value added services. The payload data reception for IRS satellites is done at the National Remote Sensing Agency, Hyderabad. The applications programme has involved developing algorithms for parameter retrieval, carrying out demonstration experiments and operationalisation of the application packages among the user agencies. An institutional mechanism has been established in the country to ensure use of RS data by the users through the National Natural Resources Management System.

2.2 National Natural Resources Management System : Institutional Framework.

In the early 1980s, 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 optimum utilisation of country's natural resources by a proper and systematic inventory of resources availability using EO data in conjunction with conventional techniques. The NNRMS concept has arisen from the overall concept of resource management and is envisaged to be a management system for the natural resources, addressing issues related to (a) systematic inventory of the country's natural resources for their optimal utilization, (b) reducing regional imbalances by effective planning in line with the developmental efforts, (c) maintain the ecological balance with a view to evolve and implement the environmental guidelines[5]. The NNRMS emphasizes to bring operational observing systems in accordance with the requirements for addressing a range of issues of concern, which include food security[6], water, energy, disaster management and weather forecasting etc. The major functions of NNRMS encompass application studies, 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 Service Centres (RRSSCs) 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 cover the following themes: Agriculture & Soils, Bio-resources and Environment, Geology & Mineral Resources, Ocean Resources, Water Resources and Remote Sensing Training & Technology. The Planning Committee, NNRMS meets once or twice every year and provides policy guidelines for the Earth Observation Programme of the country.

2.3 Capacity Building

Training and manpower development in the field of remote sensing applications to various natural resource management areas is one of major emphasis of NNRMS. One of the NNRMS Standing Committee deals with Technology promotion, education and Training (SC-T). Indian Institute of Remote Sensing (IIRS), Space Applications Centre (SAC) and Regional Remote Sensing Service Centres (RRSSC's) are the major DOS centres engaged in capacity building. Remote Sensing has been introduced as part of Science/Engineering/ Agriculture Curriculum in different Departments of many Indian Universities. One of the major capacity building contribution of Indian EO progarmme towards global education in the field of space sciences and applications is establishment of the Centre for Space Science and Technology Education for the Asia Pacific region (CSSTE- AP), affiliated to United Nations established 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. Indian Institute of Remote Sensing (IIRS) also conducts short-term courses for decision makers and administrators. This has helped in the absorption of technology at the user level.

3. INDIAN REMOTE SENSING SATELLITES

3.1 The Early Experimental Era

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. television camera and microwave radiometer. The two-band television camera operated in visible (0.54 – 0.66 micrometer) and near infrared (NIR) (0.75-0.85 micrometer) to collect data for land applications. The spatial resolution of the imageries from the Bhaskara satellites was 1 km and data was used for applications related to forestry, land use and geology. Satellite microwave radiometer (SAMIR) with footprint of 125 km was developed to measure brightness temperature at 19 GHz and 22 GHz for study of ocean-state, water vapor, liquid water content in the atmosphere, etc. Subsequently Bhaskara-2 was launched on Nov. 20, 1981. Microwave radiometer SAMIR in Bhaskara-2 had a new channel at 31.4 GHz in addition to 19.24 GHz, 22.235 GHz for improved estimation of atmospheric and ocean physical parameters. With successful completion of Bhaskara programme, the capability to build operational satellites for remote sensing applications was well established.

3.2 Operational EO Satellites

Following the successful operation of Bhaskara-1 and Bhaskara-2 satellites respectively, India embarked upon an indigenous Indian Remote Sensing Satellite programme to support the 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 was launched on March 17, 1988 from Vostok boosters from the Baikonur Cosmodrome, USSR. The IRS-1A had two types of payloads employing Linear Imaging Self Scanning (LISS) sensors. The first camera LISS-I operated in blue, green, red and NIR region with geometric resolution of 72.5 m and swath of 148.48 km. The second payload LISS-II had two cameras operating in similar LISS-I four spectral bands with improved geometric resolution of 36.25 m, each with a swath of 74.24 km. The IRS-1A was followed by the IRS-1B, an identical satellite with LISS-I and LISS-II cameras in 1991. IRS-P2 satellite with only LISS-II camera was added to this constellation by indigenous launch from PSLV-D2 rocket in 1994. Both the LISS-I and LISS-II systems were found useful in many national level natural resource management studies[7].

With many field based studies and accuracy assessment campaigns carried out over agricultural regions, a need was felt to have further improvement in spatial resolution. As a follow on to 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 panchromatic camera operated in the 0.50 to 0.75 micrometer range with geometric resolution of about 5.8 m and a swath of about 70 km. The PAN camera was the highest spatial resolution civilian system in the world at the time of the launch of 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 inclusion of SWIR band in place of blue band. Need for detection of moisture-stress in crops and snow-cloud discrimination were the driving forces for inclusion of SWIR band. The geometric resolution of LISS-III is 23.5 m in green, red and NIR band and 70 m in SWIR band.

Table 1. Indian Earth resources remote sensing satellite payloads

Satellite	Sensors	Launch Date
Bhaskara-1	TV camera, SAMIR**	7 June, 1979
Bhaskara-2	TV camera, SAMIR**	20 Nov., 1981
IRS-1A	LISS-I, LISS-II	17 Mar.,1988
IRS-1B	LISS-I, LISS-II	29 Aug.,1991
IRS-P2	LISS-II	15 OCT.,1994
IRS-1C	LISS-III,PAN,WiFS	28 Dec.,1995
IRS-P3	MOS A,B,C, WiFS	21 Mar.,1996
IRS-1D	LISS-III,PAN,WiFS	29 Sep.,1997
INSAT-2E*	CCD, VHRR	03 Apr.,1999
IRS-P4 (Oceansat-1)	OCM, MSMR**	26 May, 1999
Kalpana-1*	VHRR	12 Sept, 2002
INSAT-3A*	CCD, VHRR	10 April, 2003
IRS-P6 (Resourcesat-1)	LISS-III, LISS-IV, AWiFS	17 Oct., 2003
IRS-P5 (Cartosat-1)	PAN (Fore, Aft)	05 May, 2005
Cartosat-2	PAN	Planned
RISAT	SAR***	Planned
Megha Tropiques	MADRAS**, SAPHIR**, ScaRaB	Planned
Oceansat-2	Scatterometer***, OCM	Planned
INSAT-3D*	Imager, Sounder	Planned
TWSAT	Multi-Spectral	Planned

* INSAT-2E/3A/3D are geo-stationary satellites, others are polar orbiting satellites

** SAMIR, MSMR, MADRAS, SAPHIR are multifrequency passive microwave radiometers
*** SAR and Scatterometer are active microwave sensors

The WiFS camera was conceptualized from the observational need of frequent monitoring of crops and vegetation at national scale. Both IRS 1C/1D satellites were equipped with WiFS sensor operating in two spectral bands (red and NIR) with geometric resolution of 188 m and swath of 770 km. The WiFS camera provided large area information on temporal resolution of 5 days, which was found useful in national level wheat area and production forecast[8].

3.3 Present Theme-Specific EO Satellites

While the availability of data from the operational EO systems starting from IRS-1A to IRS-1C/1D facilitated applications in field of agriculture, forestry, land use, coastal zone and cartography from regional scale to national scale, there was strong need felt to design sensors for ocean observations, cartography and improved land applications. Data from IRS series of satellites from IRS-1A to IRS-1D was used by remote sensing community from all disciplines but there were a lot of pressing requirements from the users to have satellites especially optimized for theme specific applications like ocean, land resources and cartography. The presently available Oceansat-1, Resourcesat-1 and Cartosat-1 are mission-specific satellites.

Launch of IRS-P3, an experimental satellite in 1996 brought a new era of oceanic applications. The IRS-P3 carried WiFS sensor similar to IRS-1C with additional spectral band in SWIR and Modular opto-electronic scanner (MOS) sensor developed by German space agency, DLR. MOS-A, B, & C sensors gave opportunity of improved quantitative modeling for retrieval of ocean colour and aerosol characteristics. Experiences 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[9]. It was launched from PSLV-C2 rocket on May, 26, 1999 from Sriharikota, India. The satellite carried on board an Ocean Colour Monitor (OCM) and a Multi-frequency Scanning Microwave Radiometer (MSMR). OCM is a solid-state camera operating in eight narrow spectral bands. 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 polarization. The MSMR-derived geophysical parameters were found useful in prediction of atmospheric and sea state variables.

IRS-P6 Resourcesat-1 (Table 2) is a mission primarily dedicated for agricultural applications in India. The Resoursesat-1 satellite was launched by PSLV-C5 rocket on Oct. 17, 2003 and is equipped with three cameras viz. LISS-IV, LISS-III and Advanced WiFS (AWiFS). A high resolution LISS-IV camera works in three spectral bands in the Visible and Near Infrared Region (VNIR) with 5.8-m spatial resolution. The LISS-IV camera is steerable up to plus/minus 26 deg across track to obtain stereoscopic imagery and achieve five-day revisit capability. Medium resolution LISS-III works in three spectral bands in VNIR and one in SWIR band with 23.5 m spatial resolution. An Advanced Wide Field Sensor (AWiFS) has three spectral bands in VNIR and one band in SWIR region with 56 m spatial resolution.

Cartosat-1 is a state-of-the-art remote sensing satellite, which is mainly intended for cartographic applications. It was launched into a 618 km high polar Sun Synchronous Orbit by PSLV-C6 on May 05, 2005. 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. The swath covered by these high-resolution PAN cameras is 30 km and their spatial resolution is 2.5 meters. 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. The cameras are steerable across the direction of the satellite's movement to facilitate the imaging of an area more frequently. The satellite provides cadastral level information up to 1:5000 scales and is useful for making 5 m contour maps. Measurements from these instruments are expected to enhance large-scale mapping.

Table 2. Specifications of Resourcesat-1 sensors

Specification	LISS-IV	LISS-III	AWiFS
Instantaneous Geometric Field of View (m)	5.8 at nadir (Across Track)	23.5	56 at nadir (Across Track)
Spectral Bands (micrometer)	B2: 0.52-0.59 B3: 0.62-0.68 B4: 0.77-0.86	B2: 0.52-0.59 B3: 0.62-0.68 B4: 0.77-0.86 B5: 1.55 – 1.70	B2: 0.52-0.59 B3: 0.62-0.68 B4: 0.77-0.86 B5: 1.55 – 1.70
Swath (km)	23.9 (MX) 70 (mono)	141	740 (combined) 370 (each head)
Integration time (msec)	0.87	3.32	9.96
Quantization (bits)	10 selected 7 bits transmitted by data handling system	7 MIR band has 10 bits quantization. Selected 7 bits out of 10 bit transmitted by data handling system	10
No. of gains	Single gain (Dynamic range obtained by sliding 7 bits out of 10 bits)	4 for B2, B3 and B4 For B5 dynamic range obtained by sliding 7 bits out of 10 bits	1

4. APPLICATIONS TOWARDS SOCIETAL BENEFITS

Under the overall umbrella of the NNRMS, a large number of applications at national and regional level have been formulated and carried out meeting the specific needs of users in the country. Major areas of applications include agriculture, forestry, water resources, snow and glaciers, geology, cartography, coastal zone, marine fisheries, weather forecasting, ocean state forecasting, besides disaster monitoring and mitigation[10]. Work carried out in a few of these is described in the following sections

4.1 Food Security

Agriculture is the world's major user of land, water and biological resources. EO satellites data enable estimation of the pre-harvest acreage and production, besides assessment of condition. Procedures have been developed to make production forecasts at national level to help in planning and formulating policy decisions. 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 kharif season (monsoon), coinciding with the over cast cloudy conditions of the sky most of the time; Radarsat microwave data is being used to generate national level rise estimates. Realizing the remote sensing data can not provide a stand alone system for making multiple and reliable forecasts, a new programme viz. Forecasting Agricultural Output using Space Agro-meteorology and Land based observations (FASAL) has been conceptualized and being institutionalized. Studying crop rotation patterns and adopting cropping system approach towards sustainable agriculture has been another important area of application[11]. Mapping salt-affected soils, monitoring their reclamation, inventorying and categorization of waste lands, identification of post-kharif fallow lands, identification of suitable sites for horticulture cultivation, evaluation of irrigation performance of command areas are some of the other applications carried out which aim towards sustainable development of the food security situation. Ocean Colour data conjuctively with sea surface temperature are operationally used to prepare fishery prospect charts to facilitate marginal fishermen.

4.2 Water Resources

Providing safe drinking water to hundred thousands 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 conjunctively with ground information. 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 by EO satellite data have been extensively used to map surface water bodies, monitor their spread and empirically estimate volume of water. Monitoring reservoir spread through seasons has helped irrigation scheduling. Snowmelt runoff forecast are being made using IRS-AWiFS and NOAA-AVHRR data. These forecasts have enabled better planning of water resources by the respective water management boards. Inventory of the Himalayan glaciers and monitoring their retreat is another important area of study. Remote sensing data along with GIS tool is being used towards national river-linking programme aimed at reducing the unevenness in water availability.

4.3 Biodiversity and Ecosystem Sustainability.

Forest has a profound effect on global carbon cycle. Satellite remote sensing has enabled generation of biennial forest cover maps and monitoring changes therein at 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 generates forest-working plans. Afforestation and deforestation could also be assessed using multi temporal satellite data. Conservation of biodiversity can only be achieved through conservation of biological habitats, which require detailed survey and inventory of the existing bio-resources. Remote sensing techniques have been useful in locating different types of bio-resources, identifying appropriate corridors surrounding natural habitats and protect 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 the purpose of coral reefs includes the spatial distribution of the reefs, vegetation cover, reef zones and reef morphology, biodiversity of fauna and condition assessment. EO 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 the 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.

4.4 Disaster Monitoring and Mitigation

The disaster management support services are mainly directed towards creation of digital database for facilitating hazard zonation, damage assessment, etc., monitoring of major natural disasters using satellite and aerial data and development of appropriate techniques/tools, acquisition of close contour data for hazard prone areas using air-borne Laser Terrain Mapper, strengthening the communication back-bone for 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 NRSA as a single-window service provider and support the International Charter on Space and Major Disasters, as a signatory. The important components of the Decision Support Centre (DSC) established at NRSA 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 etc.

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, damage assessment and for 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 monsoon season at 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 database for hazard zonation. The availability of high-resolution data provides the necessary inputs for micro-seismic hazard zonation.

4.5 Health & Energy

A small number of investigators[12] in the health community have explored remotely sensed environmental factors that might be associated with disease-vector habitats and human transmission risk. In many of these studies remotely sensed data are used to derive vegetation cover, landscape structure, and water bodies. Integration of remotely sensed environmental parameters with health data using Geographic Information System and global positioning system technologies allows developing models for disease surveillance and control.

The optimum management of the energy sector which includes non renewable resources such as coal, oil and gas, as well as renewable resources such as solar, wind, geothermal, biomass and hydropower generation, is of crital concernt to global community. The EO plays important role in systematic detection of marine oil pollution and oil drift monitoring for coastal zone protection. Altimeter data have been used in generating gravity anomaly maps over the Indian Ocean regions to identify prospective off-shore zones for the hydrocarbons. Aerial thermal data have been utilized to identify underground coal fire regions.

4.6 Weather and Climate

Using remote sensing data wetlands and rice growing regions have been stratified to make methane emission estimates at the national level[13].The major application in the field of satellite meteorology has been the monitoring of synoptic weather systems ranging from thunderstorms to cyclones and planetary scale phenomena such as monsoon. The dynamic nature of the weather systems could be captured through the time series of satellite observations leading to better understanding of the process of genesis, growth and decay. This has led to developing a satellite-based technique to assess the intensity of tropical cyclones accurately and estimate the growth potential. The specific applications include identification of primary weather systems such as low pressure, depression, troughs/ridges, jet streams, regions of intensive convection, inter-tropical convergence zone. One of the major applications of satellite data has been for study of monsoon in terms of onset, dynamics and intra-seasonal variability. Detailed characterization of inter tropical convergence zone has been carried out using satellite data. The INSAT and NOAA data have brought out unique nature of monsoon onset with large-scale changes in wind and moisture profiles in lower troposphere prior to monsoon onset[14, 15]. The critical role-played by sea surface temperature in Indian Ocean and Pacific Ocean regions were clearly brought out by several studies. The INSAT series of satellites have carried a Very High Resolution Radiometer (VHRR) payload operating in two spectral bands – visible (0.55 – 0.75 um) and thermal infrared (10.5-12.5 um) to provide weather observations. INSAT-2E launched in 1999 carried an advanced VHRR payload operating in three channels – visible (2 km), thermal and water vapour (8 kms). Besides this, INSAT 2E also carries a CCD camera with 3 channels- visible, near infrared and shortwave infrared with 1 km resolution to map the vegetation cover. METSAT (Kalpana-1) with VHRR payload became first exclusive Indian meteorological satellite in geo-stationary orbit. INSAT-3D planned in future will carry a nineteen channel atmospheric sounder for estimating temperature and water vapour vertical profiles and also a six-channel imager.

5. INDIAN EARTH OBSERVATION SATELLITES : THE ROAD AHEAD

5.1 Terrestrial Applications

Although data available from various EO systems have been routinely used in many resource management applications, there have been certain gaps and inadequacies. There is need for high-resolution data to support for infrastructure development including risk mapping and providing real time support for natural and human induced disasters. The present sensors on IRS satellites (LISS-IV, LISS-III and AWiFS) although providing valuable input for resource mapping and monitoring, are limited by the absence of thermal channel which is needed for land surface temperature estimation and quantifying evapo-transpiration in land surface process modeling. The resource management applications particularly crop assessment and monitoring would involve inventory of multiple crops in a phased manner for which the spatial resolution of AWiFS and temporal revisit of LISS-III are not adequate for scattered crops particularly with cloud cover. Moreover, estimation of biophysical parameters such as Leaf Area Index (LAI) and Fraction Absorbed Photosynthetic Active Radiation (fAPAR) would require atmospherically corrected surface reflectance. Non-availability of sensor on board Resourcesat mission, which characterizes the atmospheric properties such as aerosol optical thickness and water vapour, is another gap area. The cartographic and urban/rural planning is an important thrust area. The Cartosat-1 data has immense potential in this field. There is further need for high resolution mapping for preparation of rural development plans and creation of land information system, land parcel mapping at 1: 1000 to 1: 4000 scale cartographic maps.

The EO missions related to terrestrial applications, planned for launch in the next 2-3 years include Cartosat-2, Resourcesat-2, RISAT and Third World Satellite (TWSAT). The TWSAT is a 90 kg remote sensing micro satellite. It will carry a multi spectral CCD camera with single optics and beam splitter with spatial resolution of about 30-35 meter and 140 km swath. It will have three spectral bands, green (520-590 nm), red (620-680 nm) and NIR (770-860 nm) with 10 bit quantization. The Cartosat-2 would supplement Cartosat-1 with enhanced spatial resolution (better than 1 m) for terrain and large scale mapping applications. It is proposed that series be continued with launch of a very high spatial resolution camera on board Cartosat-3. The Resourcesat –2 will follow Resourcesat-1 and these two missions would provide service of AwiFS, LISS-III and LISS-IV for more than a decade. In Resourcesat-3, LISS-III, which is currently the workhorse sensor may be modified to LISS-III-WS (Wide Swath) having swath around 700 km and revisit capability similar to AWiFS, thus overcoming any spatial resolution limitation of AWiFS.

The cloud cover remains a major hurdle in optical remote sensing during monsoon season. Imaging RADAR applications will be served through RISAT-1 satellite. The C- band SAR sensor would be flown on the RISAT-1 satellite for resource monitoring and disaster monitoring. In order to develop large user community and service continuity, it is suggested that a follow on mission should have similar features similar to RISAT-1 (C-band and multi-polarization) with multi resolution capability. The L-band SAR is suggested on 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 needs of monitoring disaster situations.

Geostationary orbit provides constant surveillance, and 1 km imaging capability in visible and Near Infra red region already exists on INSAT 3A and additional channels will be available on INSAT-3D slated for 2007 launch. Beyond Resourcesat-2, high repetivity sensor would be continued on geostationaty platform as a Geo-HR-Imager. This will provide multiple/day acquisition capability and overcome all limitations posed on AWiFS availability. Since geostationary satellites have longer life, GEO-HR Imager will assure 60 m 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 hyperspectral spectrometer on board IRS satellites. This is proposed as an EO Technology Experimental Satellite (TES). The Hyperspectral spectrometer may have 64 channels with swath of 30 km. The TES can be optimized for a number of spectral bands and have further fine spectral bands in specific regions of the EM spectrum to address specific applications.

5.2 Atmosphere

The major emphasis of the meteorological applications includes observation on atmospheric state variables, atmospheric composition, ocean characterization and study on Land-Ocean–Atmospheric interaction. The development of the advanced technique for data assimilation in atmospheric models, extended range monsoon prediction and regional climate modeling are major research areas, which is limited by gaps in EO data from the Indian satellites. The major gap areas include need for atmospheric sounders with hyper spectral channels on INSAT platform and requirement of constellation of Precipitation Radar. The INSAT-3D scheduled for launch in 2007 would carry 6 channel imager and 19 channel sounder and provide profiles of atmospheric water vapour and temperature, in addition to SST and cloud motion. The Megha Tropiques, a collaborative endeavor with French CNES with three sensors viz. MADRAS, SAPHIR and ScaRab for estimation of rainfall, atmospheric and cloud water vapour and radiation balance is planned for launch in 2009. The Technology development activity would be initiated for Hyperspectral Sounders, Rain Radar and Millimeter wave sounder for atmospheric profiles and constituent estimation.

5.3 Oceanographic Applications

The major gap areas are in observations of ocean salinity, surface pressure, wave spectra, sea level anomaly and more frequent observations of wind vector and coastal ocean parameters and estimation of SST with better resolution especially in Indian Ocean region. The major task in biological ocean application is algorithm development for Case II waters and validation of ocean colour products and estimation of primary productivity and fish stock assessment. There is a need to carry out coastal processes study and develop coastal zone information system (CZIS). Major gap area in this field is simultaneous observation of ocean colour and sea surface temperature. Placement of a few additional bands in the present OCM sensor is needed for accurate ocean biology. As a continuity of Oceansat-1, Oceansat-2 will be launched with OCM and Ku band Scatterometer during 2007. Scatterometer will operate at 13.515 GHz with resolution of 50 km and will be useful in measuring ocean surface wind speed from 4 m/sec to 24 m/sec with accuracy of 10% or 2m/sec which ever is higher. There will be improvement in OCM sensor configuration in terms of replacement of earlier 765 nm channel into 740 nm to avoid O_2 absorption and replacement of 670 nm channel into 620 nm channel for better quantification of suspended sediments. It is proposed to include thermal channel of 1 km spatial resolution to go along with OCM in presence of Scatterometer on the same platform in future Oceansat missions. The Thermal Infra red combination with OCM will support joint analysis for operational PFZ. It is also planned to have an altimeter in Altika-Argos mission to be launched in 2009. Technology development towards L-band synthetic aperture microwave radiometer is needed for estimation of the ocean salinity.

5.4 Disaster Monitoring and Mitigation

Existing EO Systems are not able to capture real time events in spatial and temporal domains. The Resourcesat-1/2, RISAT-1 and Oceansat-2 along with TWSAT shall enhance frequency of observation and information content for monitoring disasters. The LISS-III-WS, DMSAR C/X and Geo-HR-Imager and Cartosat-3 shall form the core of the constellation of satellites for disaster monitoring and mitigation in future. To meet all the observational requirements, it is realized that international participation/cooperation would be needed to address global issues.

CONCLUSIONS

The Indian Remote Sensing satellite series from IRS-1A to IRS-P6/IRS-P5 and sensors onboard-INSAT series of satellites have established space technology for operational applications related to areas of societal benefits. The missions planned in near future v.i.z., Cartosat-2, RISAT, Oceansat-2, Megha Tropiques, INSAT-3D, TWSAT shall enhance utility of EO data in meeting needs of societal benefit areas. Institutional framework for ensuring utilization of EO data is in place. Capacity building at different levels including decision makers is organised. Indian EO data is available to global users through the international ground stations set up and capacity building is extended to countries in the Asia-Pacific region. Continuity of EO missions with enhanced capability has been ensured. Road ahead for the EO programme has been visualized. Thus, Indian Earth Observation Programme is complementing GEOSS and adding to the remote sensing infrastructure in the world.

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