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Future Indian Earth Observation Systems

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ABSTRACT

Indian Earth Observation (EO) capability has increased manifold since the launch of Bhasakra-1 in 1979 to Cartosat-2 in 2007. Improvements are not only in spatial, spectral, temporal and radiometric resolutions but also in their coverage and value added products. It has also entered into the arena of passive and active microwave remote sensing, stereo viewing and viewing from the geo-synchronous platform at moderately high resolution. Observations specific to oceans and atmosphere are getting further emphasis. Demand for a constellation of satellites for monitoring disaster situations is strongly made. In this context, India has made extensive plans for continuity and enhancement in EO capability, not only towards its own national needs, but also as a contributing participant towards Global Earth Observation System of Systems (GEOSS). Major emphasis of the future plan has been to consolidate theme-specific satellites, in order to fill the gaps in observation including those for disaster monitoring and mitigation, and also to develop synergy with international missions for complementing and supplementing Indian missions. The future Indian EO systems include those for land applications-Resourcesat with wide swath LISS-III, high resolution Cartosat (0.3 m) and Imaging Radar (RISAT: C-band, multi-polarization). It also proposes to develop space based hyper-spectral sensor and atmospheric corrector. The future ocean application sensors include improved Ocean Color Monitor, K_U band scatterometer and a thermal IR sensor. The two major satellites dedicated for atmospheric observations are INSAT-3D with 6 channel imager and 19 channel sounder, and the ISRO-CNES joint venture Megha Tropiques with three sensors viz. MADRAS, SAPHIRE and ScaRab. Satellite for Argos and Ka band radio altimeter (SARAL), a joint ISRO-CNES mission is also underway. L-band polarimetric radiometer, hyper spectral sounder, rain radar, millimeter wave sounder, high resolution imager from geo-synchronous platform are some of the sensors being considered for future missions.

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. 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 [1]. 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 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. 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 large 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 [2]. 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. The present paper discusses evolution of different Indian EO missions; additional observation needs and planned future Indian EO missions.

2. EVOLUTION OF PRESENT INDIAN EO PROGRAM

The Indian EO system began with experimental phase of Bhaskara- 1 and 2 satellites which continued with launch of a series of operational IRS satellites (IRS 1A, 1B, P2, P3, 1C, 1D, P5, P6, Cartosat2) for land and oceanic applications and INSAT satellites (IA,1B,1C,1D,2A,2B,2C,2D,2E, Kalpana and 3A) for meteorological applications. Details on sensor specifications and applications carried out using these sensors has been reviewed by Navalgund (2006)[5], Joseph (1996) [6] and Kasturirangan (2004)[7]. Summary of present and planned satellites and their sensor characteristics are given Table 1, Table 2 and Table 3. Brief description on evolution of different sensors and satellites starting from Bhaskara-1 to Cartosat-2 is as follows.

2.1 Beginning of Indian EO systems

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 a microwave radiometer. 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.

Following the successful operation of Bhaskara-1 and Bhaskara-2 satellites respectively, India embarked upon an indigenous operational Indian Remote Sensing Satellite programme to support national development in various areas of natural resources such as agriculture [8], 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) sensors. The IRS-1A was followed by 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 in 1994. Both LISS-I and LISS-II systems were found useful in many national level natural resource management studies [9].

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 PAN camera was the highest spatial resolution (5.8 m) 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 a SWIR band in place of the blue band. Need for detection of moisture-stress in crops and snow-cloud discrimination were the driving forces for inclusion of SWIR band. The WiFS camera was conceptualized from the observational need of frequent monitoring of crops and vegetation at national scale. 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.

2.2 Present EO Satellites (Oceansat-1, Resourcesat-1, Cartosat-1/2)

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.

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 an 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 for quantitative modeling for retrieval of ocean colour and aerosol characteristics. 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 [10]. 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.

Table 1. Indian 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	10 Jan. 2007
RISAT	SAR***	Planned
Megha Tropiques	MADRAS**, SAPHIR**, ScaRaB, GPS Occ.	Planned
Oceansat-2	Scatterometer***, OCM, ROSA	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

IRS-P6 Resourcesat-1 is a mission primarily dedicated for agricultural applications in India. The Resoursesat-1 satellite is equipped with three cameras viz. LISS-IV, LISS-III and Advanced WiFS (AWiFS). A high resolution LISS-IV camera operates in three spectral bands in the Visible and Near Infrared Region (VNIR) with 5.8-m spatial resolution. Medium resolution LISS-III operates 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 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, which has improved 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.

3.0 ADDITIONAL OBSERVATION NEEDS

3.1 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 infrastructure development including risk mapping and providing real time support for natural and human induced disasters [11]. 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 Photosynthetically 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. Crop stress detection, lithological discrimination, identification of specific tree species etc. require a hyper spectral imager. The cartographic and urban/rural planning is an important thrust area. The Cartosat-1/2 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.

Table 2: Major specifications of present IRS series of satellites.

Satellites (Year)	Sensor	Spectral Bands (µm)	Spatial Res. (m)	Swath (km)	Radiometric Res. (Bits)	Repeat Cycle (days)
IRS-1A/1B (1988, 1991)	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
IRS-P2 (1994)	LISS-II	Same as LISS-I	36.25	74	7	24
IRS-1C/1D (1995, 1997)	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
	WiFS	0.62-0.68 (R) 0.77-0.86 (NIR)	188	810	7	24 (5)
	PAN	0.50-0.75	5.8	70	6	24 (5)
IRS-P3 (1996)	MOS-A	0.755-0.768(4 bands)	1570x1400	195	16	24
	MOS-B	0.408-1.010(13 bands)	520x520	200	16	24
	MOS-C	1.6 (1 band)	520x640	192	16	24
	WiFS	0.62-0.68 (R) 0.77-0.86 (NIR) 1.55- 1.70 (SWIR)	188	810	7	5
IRS-P4 (1999)	OCM	0.402-0.885 (8 bands)	360x236	1420	12	2
	MSMR	6.6,10.65,18,21 GHz (V & H)	150,75,50 & 50 km respectively	1360	-	2
IRS-P6 (2003)	LISS-IV	0.52-0.59 (G) 0.62-0.68 (R) 0.77-0.86 (NIR)	5.8	70	10 (7)	24 (5)
	LISS-III	0.52-0.59 (G), 0.62-0.68 (R) 0.77-0.86 (NIR) 1.55- 1.70 (SWIR)	23.5	141	7	24
	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)
IRS-P5 (Cartosat-1) 2005	PAN (Fore (+26^0)& Aft (-5^0)	0.50-0.85	2.5	30	10	5
Cartosat-2 (2007)	PAN	0.50-0.85	0.8	9.6	10	5

3.2 Atmospheric and Oceanographic Applications

Major emphasis of the meteorological applications includes observation on atmospheric state variables, atmospheric composition, ocean characterization and study on Land-Ocean–Atmospheric interaction. Development of advanced techniques 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 an INSAT platform for profile studies and requirement of a constellation of Precipitation Radar.

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. Major requirement 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 study of coastal processes 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.

4.0 FUTURE INDIAN EO SATELLITES

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

4.1 Terrestrial Missions

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

Considering that the 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 continuity of 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, shall be modified to LISS-III-WS (Wide Swath) having swath around 700 km and revisit capability similar to AWiFS (5 days), thus overcoming any spatial resolution limitation of AWiFS. It was observed that large tilt of LISS-IV camera creates difficulty in terms of geometrical and radiometry as well as terrain related issues. It is planned to increase the swath of LISS-IV to 70 km with associated innovative methods for full swath transmission. The payload tilt of LISS-IV should be minimized to less than 5 degree. Resourcesat-3 will also carry an Atmospheric corrector (ATCOR) sensor for characterization of atmospheric properties (Aerosol, water vapour).

Cloud cover remains a major hurdle in optical remote sensing in India 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 provide service continuity, it is 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 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. 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 shall overcome all limitations posed on AWiFS availability. Since geostationary satellites have longer life, GEO-HR Imager will assure 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 hyperspectral spectrometer on board IRS satellites. This is proposed as an EO Technology Experimental Satellite (TES). The Hyperspectral spectrometer may have 200 channels with 12.5 m spatial resolution. 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.

Along with the improvements in sensor systems, efforts are being made to retrieve geophysical products. The important products planned to be generated from Indian missions are land surface temperature, insolation, albedo, soil moisture, leaf area index, fraction absorbed photosynthetically active radiation (fAPAR), snow type and snow water equivalent etc. It is suggested to have real time dissemination of remote sensing derived information to the user. There is need to strengthen the process modeling (crop growth, hydrology), which can be used for simulation, and forecasting using satellite derived inputs.

4.2 Meteorology & Oceanography Missions

Numerical weather prediction involves solving 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 include 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. Placement of more channels on INSAT system as well development of other sensors (scatterometer, microwave sounder, altimeter, GPS occultation) has been planned to resolve some of these observation needs. The three future satellites planned for atmospheric sounding, studying the water vapour and radiation balance and ocean surface wind vector are INSAT-3D, Megha Tropiques and Oceansat-2 respectively.

The INSAT-3D would carry six-channel imager and 19 channel sounder (Table 3) and provide profiles of atmospheric temperature (50 x 50 km grid with accuracy 1-2 ^{0}C) and water vapour (50 x 50 km grid). The other geophysical products planned from INSAT-3D data are total ozone content, 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 estimation of rainfall, atmospheric and cloud water vapour and radiation balance will be launched in low inclination angle orbit (20^0) covering tropical region (Table 3). The MADRAS, which is a passive microwave radiometer, has 89 &157 GHz channel for estimation of ice particles in cloud tops, 18 & 37 GHz channels for estimation of cloud liquid water and precipitation and 23 GHz channel for integrated water vapour estimation. The 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 estimation of water vapour profile in six atmospheric layers up to 12 km height at 10 km Horizontal Resolution. The Megha Tropique mission will also carry a GPS occultation system.

Availability of data from INSAT-3D and Megha Tropiques will fill some of the gap areas of meteorological applications but the technology for further advanced sensor system such as hyperspectral sounders (Michelson interferometer), rain radar and millimeter wave sounder is currently being explored and developed. The Technology development activity would be initiated for atmospheric gaseous constituent estimation.

As a continuity of Oceansat-1, Oceansat-2 will be launched with OCM and Ku band Scatterometer. Scatterometer will operate at 13.515 GHz with resolution of 50 km and will be useful in measuring ocean surface wind vector 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 generation of potential fishery zones. It is also planned to have a Ka band radio altimeter in a joint ISRO-CNES mission of satellite for Argos and altimeter (SARAL). Technology development towards L-band synthetic aperture microwave radiometer is needed for estimation of ocean salinity.

4.3 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-2/3 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.

Table 3. Proposed future satellites and their major sensor characteristics.

Satellite	Sensor	Spectral Bands (μm) Frequency (GHz)	Spatial Resolution (m)
TWSAT	Multi-spectral camera	0.45-0.52 (B) 0.52-0.59 (G) 0.62-0.68 (R) 0.77-0.86 (NIR)	37
RISAT	SAR	5.3 GHz, HH, VV, HV	3-50
Megha Tropiques	MADRAS	18.7 (H+V), 23.8 (V) , 36.5(H+V)., 89.0(H+V)., 157(H+V). GHz	40, 40,40. 10. 6 km
	SAPHIR	183.31 ± 0.2, 1.2, 2.7, 4.2, 6.8, 11GHz	
	SCARAB	0.5-0.7, 0.2-4.0, 0.2-100, 10.5-12.5	
Oceansat-2	Scatterometer	13.4 GHz (Incidence angle: 50.06^0 (inner beam), 57.31^0 (outer beam)) (Polarization: HH (inner beam), VV (outer beam))	50 km
	OCM	8 bands (0.412, 0.443, 0.490, 0.510, 0.550, 0.620, 0.740, 0.865)	360x236
INSAT-3D	Imager	6 Channels (0.55-0.75 1.55-1.70, 3.80-4.00,6.50-7.00, 10.2 – 11.3, 11.5 – 12.5)	1-4 km
	Sounder	19 channels LWIR: 14.71, 14.37,14.06,13.64,13.37, 12.66,12.02, MWIR: 11.03, 9.71, 7.43, 7.02, 6.51, SWIR: 4.57,4.52, 4.45,4.13,3.98, 3.74 Vis: 0.696	10 km

5.0 GROUND SEGMENT & TECHNOLOGY DEVELOPMENT

Strengthening of ground segment is needed in order to realize the objectives of EO mission. Systematic studies are being carried out to define optimal parameter for new proposed missions based on user needs. Algorithm development to realize operational geophysical products and its applications are the focus areas of each mission. Products are planned to be generated in near real time basis so that they can be distributed to user in easily accessible i.e. web based service format. A simultaneous targeted effort for capacity building and outreach is organized for each mission to educate and prepare various segment of the users.

In order to achieve the planned mission and develop advanced sensors in future, a variety of related technologies are needed to be developed and assimilated through systematic process of resource allocation and collaboration. Some of the advance technology elements in development of electro-optical sensors are active pixel detector, multi segment mirror, adaptive optical elements, high-speed data acquisition and processing, onboard correction and processing, data compression techniques and mechanism of positioning optical/ opto-electronics components. The advance technology elements required for microwave sensor include programmable and miniaturized design hardware, multi mode polarization capability for passive and active radar system, polarimetric interferometry, advanced transmit-receive technology, reconfigurable planar antenna from L-X and Ku band, inflatable reflector and onboard payload data processing technology. Advances in electronics and small satellite technology can result in significant change in future earth observation scenario.

6. SUMMARY

Indian Earth Observation (EO) is an end-to-end Programme engaged in development of appropriate sensor and spacecraft system and institutionalization towards advancing the benefits of remote sensing applications for the cause of national development. Present EO system consists of constellation of both polar and geo synchronous satellites operating in optical, thermal and microwave spectral regions, providing data at various resolutions for land, ocean and atmospheric applications. The major applications include periodic inventories of natural resources, generation and updation of large scale maps, disaster monitoring and mitigation, weather forecasting, ocean state forecasting and facilitating infrastructure development, providing information services at the community level for better management of land and water resources. Based on the observational requirements of these applications a series of different Indian EO missions viz. operational polar orbiting (Resourcesat, Cartosat, Oceansat and RISAT), experimental polar orbiting (Megha Tropiques with low inclination orbit and TES hyperspectral) and Geo-stationary (METSAT, INSAT with imager and sounder) have been conceptualized [12]. Although data from presently available EO system (Resourcesat-1, Oceansat-1, Cartosat-1/2, Kalpana, INSAT-2E/3A) are routinely used in many applications, there have been certain gaps in observations. It was observed that Hyperspectral, thermal and microwave remote sensing capability is needed in future missions. Major satellites planned in future for land application include Resourcesat-2/3, Imaging Radar, Cartosat-3, GEO-HR-Imager and TES-Hyperspectral spectrometer [13].

The major future EO Programme related to meteorology and oceanographic applications are INSAT-3D, Megha Tropiques and Oceansat-2. The 6-channel imager and 19 channel sounder sensors on INSAT-3D would cater to the need of vertical profile of temperature and humidity, the Ku band scatterometer in future Oceansat-2 mission shall enhance the capability of ocean state forecasting by improved estimation of ocean surface wind vector, the advanced payloads of Megha Tropique mission such as MADRAS, SAPHIR and ScaRab would be of great value in modeling water and radiation balance of tropical region for improved weather forecasting. The moderately high resolution multi spectral sensing from geo-stationary platform (GEO-HR system) using CCD detector and constellation of small satellites would enhance ability in the disaster monitoring. There is need to develop synergy [14] with the international missions for complementing and supplementing Indian missions.

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