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FUTURE PERSPECTIVES OF EARTH OBSERVATION: INDIAN SCENARIO

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Abstract—Civilian Earth Observation programmes have demonstrated the utility of space-based data to a variety of users—specifically those associated with the natural resources management. Its future will depend upon how the systems meet the demand of monitoring global environment; mapping, charting and geodesy; long-term global change research and assessment; monitoring and managing the renewable and non-renewable resources and national security applications. The future Earth Observation Systems (EOS) will have to take into consideration the aspects relate to the globalisation and standardisation of programmes world-over; data continuity and the need to monitor processes rather than events. Technological changes are also going to re-define many of the concepts of observation from space and issues like spatial resolution, spectral resolution and temporal resolution may no more be a concern for observation systems.

In the Indian context, with the launch of IRS-1C, in December 1995, user services have been significantly enhanced. Presently, plans are onway to define the continuity to these missions. A broad analysis has been done of the observation needs of the future and also what has been achieved today and suggestions are made for the future observation systems design and implementation. The need analysis has been done keeping in mind the global change applications; mapping and cartographic applications; natural resources and environmental management applications etc.

The paper discusses the strategy adopted for assessing the future requirements and also for defining the future Indian missions. Based on this evaluation and also the need for identifying low-cost, quick turn-around, application specific solutions, candidate payloads for the continuation series have been defined. These candidate payloads cater to a majority of the application needs and specific gap-areas would be taken care of. A decade profile of Indian Remote Sensing missions has been defined which addresses the concept of continuity, operational missions and the advanced missions up to 2005. The impact on utilisation accruing from these proposed missions has also been assessed. A perspective of the Indian Remote Sensing programme for the next decade is provided. © 1996 International Astronautical Federation. Published by Elsevier Science Ltd. All rights reserved

INTRODUCTION

Viewing the Earth from space emphasises the global nature of our planet and its resources and also the fragility of the environment to change from both natural and man-made resources. The human-race faces the conflicting challenge of an increasing population and limited natural resources. On the other hand, it is imperative to maintain the environment for the future generations. This necessitates the development of natural resources to meet the immediate needs of the present population and the requirements of the future generations without, in any way, endangering the ecology and environment—thus recognising the fact that economic growth and environmental protection are inextricably linked.

Earth Observation (EO) satellites provide the vantage point and coverage necessary to study our planet as an integrated, interactive physical and biological system. The key areas where EO data is of use is global environment change monitoring, management of renewable and non-renewable resources, resources mapping, geo-positioning applications and also for strategic applications of national security.

The trend in EO observation is towards contributing to sustainable development by serving as environmental and economic drivers for growth and development. Trends are towards:

(a) obtaining high resolution imaging of land and water features—oriented towards replacing aerial photography missions so as to address local-level resource management;
(b) intensification of observation of solid earth, atmosphere and oceans as an integrated system for understanding the Earth processes and global change.

Over the past decade, India has increasingly turned to satellite remote sensing to gather data about the Earth's atmosphere, land and oceans. The programme has evolved into an operational programme from the early seventies, when the experiment to detect coconut wilt disease using aerial survey data was conducted in Kerala, through an experimental phase of remote sensing missions - Bhaskara I and II, during 1979 and

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1982, respectively, and the Joint Experiment Programme (JEP) - initiated to dove-tail the users requirements with the sensor technology and development of applications packages.

With the launch of IRS-1A in March 1988, IRS-1B in August 1991, IRS-P2 in October 1994, IRS-1C in December 1995 and IRS-P3 in March 1996, remote sensing data services are continuously available to the users. The thrust has also been on applications of the data to support key sectors of development—land and water resources management, coastal and marine resources, forest management, agricultural crops monitoring, flood and drought management, environmental monitoring, geology and minerals etc.

Further, IRS data is also being distributed in the international market as part of an agreement between Department of Space (DOS) and EOSAT Co. of USA under which IRS data is being received at Norman, Oklahoma and Neurislitz, Germany. Many more ground stations are expected to receive IRS data in the coming days.

INDIA EO PROGRAMME - ACHIEVEMENTS

Recognizing the importance of EO satellite-based systems for the management of the natural resources, the Indian EO programme has been the mainstay for the establishment of the NNRMS - which has the participation of various Central and State agencies/departments.

Programmatic achievements

The EOS programme in India follows an application driven approach and this has enabled the optimum utilisation of the remote sensing technology to address national priorities. With active user-participation, the programme has evolved to provide vital inputs to decision-making at central and state levels. During the 8th Plan period, NNRMS activities have paved the programme to a turning point where the need is to transgress to true operational scenario of an end-to-end remote sensing programme for the country. Some of the major programmatic achievements are:

(a) *Institutionalising RS utilisation* with the establishment of NNRMS. The concept of a National Natural Resources Management System (NNRMS)—an integrated resource management system aimed at optimal utilisation of country's natural resources by a proper and systematic inventory of the resource availability using remote sensing data in conjunction with conventional techniques, was initiated in 1983 and has been the mainstay in the country for natural resources management.

The major thrust of NNRMS has been to encompass application studies as per user requirements, establishment of necessary infrastructure for remote sensing at various levels, technology development, generation of trained manpower etc.

(b) *Infrastructure establishment for the utilisation of RS data* in the country with the establishment of 5 Regional Remote Sensing Service Centres (RRSSC) and 23 State Remote Sensing Centres. Apart from these, RS Cells/facilities have also been established in a large number of central agencies/departments. Most of these centres/cells have been equipped with instruments and facilities for digital image analysis and also for integrated analysis using GIS.

(c) *Wide user base*. With the focus of resource management mainly in the Government sector, the establishing of the NNRMS has been a major achievement as it has helped in channeling the user needs for resource management vis-a-vis the capabilities of IRS systems. The thrust for the utilisation of IRS data in different sectors—agriculture, water resources, forest and environment, geology, soils and landuse, ocean and marine resources, etc. has led to a wide range of applications. This has resulted in the proliferation of IRS data into the activities of a large number of agencies/departments—both within and outside the Government and has led to the establishment of a wide user base—at different levels of management and decision-making.

User agencies of central, state and private sector utilise the data for their regular monitoring and planning activities. Most of the states have set up extensive facilities in the form of State Remote Sensing Application Centres.

(d) *Operational space and ground segment*. The Indian Remote Sensing (IRS) satellites are the main-stay of NNRMS, providing operational remote sensing data services. The IRS series of satellites was operationalised with the commissioning of the Indian Remote Sensing Satellite, IRS-1A, in March 1988. IRS-1B, was launched in August 1991, as an in-orbit replacement of IRS-1A, and has identical specifications to IRS-1A. The IRS series was further enhanced by IRS-P2, launched by India's own launch vehicle, PSLV in October 1994. While IRS-1B and IRS-P2 are providing data regularly, IRS-1A is still available for use when more frequent data is required. IRS-1A and IRS-1B, carry two types of cameras, LISS-I and LISS-II, with spatial resolutions of 72.5 m and 36.25 m, respectively. LISS-I has a swath of 148 km and the two LISS-II cameras have a composite swath of 145 km. IRS-P2 has LISS-II cameras similar to that of IRS-1A and IRS-1B.

IRS-1C, first in the second-generation of IRS series, was launched on December 28, 1995 and

Table 1. IRS-1A, 1B, P2 and 1C satellite system specification

Sl. No.	Parameters	IRS-1A/1B	IRS-1C/1D	IRS-P2	IRS-P3
A.	SATELLITE				
1.	Class	3-axis stabilised	3-axis stabilised	3-axis stabilised	3-axis stabilised
2.	Weight (kg)	975/989	1330		
3.	Power (W)	(a) 709 W from solar array (EOL) (b) 2 Ni-Cd batteries	(a) 813 W from solar array (EOL) (b) 2 Ni-Cd batteries		
4.	Mission life	Three years	Three years	Three years	Three years
5.	Launch	1988/1991	1995	1994	1996
B.	ORBIT				
1.	Height (km)	904	817	904	817
2.	Inclination (deg.)	99.028	98.12		98.69
3.	Type	Sun-synchronous	Sun-synchronous	Sun-synchronous	Sun-synchronous
4.	Equator crossing	1025 Hrs	1030 Hrs	1030 Hrs	1030 Hrs
5.	Repetitivity	22	24 (LISS-III)	22 days	22 days

has enhanced capabilities in terms of spatial resolution, additional spectral bands, stereoscopic imaging, wide field coverage and a more frequent visit capability than its predecessors. It carries a tape-recorder on board for recording the data when data is not being transmitted in real time. IRS-1C has three cameras on board:

- Panchromatic camera (PAN) which has a spatial resolution of 5.8 m, operates in panchromatic region of the electro-magnetic spectrum, with a swath of 70 km and can be steered up to ±26° across-track—thus enabling generation of stereoscopic imagery and improved visit capability.
- Linear imaging self scanning - III (LISS-III) camera operating in four special bands - three in visible/near infrared (VNIR) and one in short wave infrared (SWIR) region. It has a spatial resolution of 23.5 m in VNIR bands and 70 m in SWIR band and a swath of 142 km and 148 km, respectively.
- Wide field sensor (WiFS), a course resolution camera with spatial resolution of 188.3 m and covering a wide swath of 810 km with two spectral bands in visible and NIR region.

Table 1 shows the mission specifications of IRS satellites and Table 2 shows the characteristics of the IRS payloads. IRS-1C will be followed by a similar satellite, IRS-1D, to be launched during 1997–98 as an in-orbit replacement for IRS-1C.

The third developmental flight of PSLV, viz., PSLV-D3 was launched on March 21, 1996 and placed into orbit the IRS-P3 satellite. IRS-P3 carries sensors for applications related to oceanography and vegetation dynamics, as follows:

- Modular opto-electronic scanner (MOS), designed and developed by DLR, Germany, is a 18 channel imaging spectrometer in visible/near-IR/SWIR region and provides an effective ground resolution of 500 m × 500 m and a swath of around 200 kms. The MOS payload is optimised for oceanographic applications.
- Wide field sensor (WiFS), similar to that of IRS-1C but with an additional short wave IR (SWIR) band and is used for the study of vegetation dynamics.

Table 3 shows the sensor characteristics of the IRS-P3 sensors. Apart from the above sensors, IRS-P3 also carries a X-ray astronomy payload (XAP) to study the time variability and spectral characteristics of cosmic X-ray sources and the detection of transient X-ray sources.

(e) *Wide range of applications*. As a step towards establishing operational procedures for applications of remote sensing data for resources management, the Department of Space, along with user departments/agencies took up national-level projects in different resource management areas—oriented towards the goals of

Table 2. Sensor characteristics of IRS satellites

		IRS-1A/1B LISS-I/II	IRS-1C/1D (LISS-III)	IRS-P2 LISS-II	IRS-1C/1D (PAN)	IRS-1C/1D (WiFS)
1.	Type of cameras	CCD	CCD	CCD	CCD	CCD
2.	Spectral bands (In μm)	0.45–0.52 0.52–0.59 0.62–0.68 0.77–0.86	0.52–0.5 0.62–0.68 0.77–0.86 1.55–1.7	0.45–0.52 0.52–0.59 0.62–0.68 0.77–0.86	0.5–0.75	0.62–0.68 0.77–0.86
3.	Ground res. (m)	73/36.5	~23(VNIR) ~70 (MIR)	32 × 36	5.8	188 m
4.	Swath (km)	148/2 × 74	~140	131	~70	810
5.	Steering	Nadir	Nadir	Nadir	Steerable ±26	Nadir
6.	Radiometric levels	128	128	128	64	128
7.	Data rate (MBPS)	5.2 LISS-I 10.4 LISS-II	42.45 with WiFS	10.4 × 2	84.90	2 Mbps

Table 3. IRS-P3 MOS specifications

	MOS-A	MOS-B	MOS-C
No. of channels	4	13	1
Spectral channels (central in nm)	756.7, 760.6 763.5, 766.4 (O_2-A Absorption)	408,443,485,520 570,615,650,685 750,870,1010,815,445, (H_2O-Vapor)	1600
Spectral channel width in nm	1.4	10	100
Spatial resolution (m)	2520 × 2520	720 × 580	1000 × 720
Swath (km)	248	248	248
Quantisation bits	16	16	16
Signal noise ratio	> 100	> 100	> 100
Revisit period (day)	15	15	15
Minimum radiance (L_{min})	0.1	0.2	0.5
Maximum radiance L_{max}	40	65	18

Units of radiance: $uW\ cm^{-2}\ nm^{-1}\ sr^{-1}$

NNRMS. With active participation and funding support from user departments/agencies from both Central and State Governments, the technology, over the last two decades, has matured to cover diverse resource themes/areas such as forestry, wasteland mapping, agricultural crop acreage and yield estimation, drought monitoring and damage assessment, landuse/land cover mapping, wasteland mapping, water resources management, groundwater targeting, marine resources survey, urban planning, mineral targeting and environmental impact assessment etc.

(f) *Reaching the local-level.* Realising the importance of adopting an integrated approach and recognising the mutual inter-dependencies of natural resources, the Department of Space at the behest of the Planning Commission and the Ministry of Rural Areas and Employment, initiated a major programme—Integrated Mission for Sustainable Development (IMSD). Under this mission, remote sensing based integrated land and water resources studies for 174 problem districts has been taken up. The IMSD approach involves integration of thematic information on various natural resources—land use/cover, types of wastelands, forest cover/types, surface water resources, drainage pattern, potential ground water zones, geomorphology (landforms), geology (rock types, structural details, mineral occurrence), soil types, etc. derived from satellite data and integrating them with other ancillary information, meteorological and socio-economic data in a geographic information system environment to arrive at locale-specific prescriptions for development. The locale-specific action plans include recommendations on water harvesting through ponds and check dams; soil conservation through terracing and contour bunding; afforestation, agro-forestry and agro-horticulture; fuel wood and fodder development; sand-dune stabilisation; mining and necessary conservation measures, etc.

With action plans already generated for 90 districts, the thrust for the remaining districts and the implementation of the plans at the cadastral level will be the major thrust in the coming years.

(g) *Advanced technology development.* Technology development—either to support the future needs of the EO programmes or to strengthen the applications and services from the present set of data have resulted in many new areas of EO maturing to higher stages. Some of the significant ones are:

- Development of an airborne synthetic aperture radar (A-SAR) operating in the C-band and with a resolution of 6 m and 20 km swath has been completed. The system has real-time motion compensation, real-time processor, quick-look display and data recording etc. All the elements for the data processing of the A-SAR data has also been developed. Test flights of the system has provided good quality data for applications. Thus development has provided valuable experience in the realisation of a satellite SAR for future missions.
- R&D activities in areas of expert systems and artificial intelligence systems for image analysis; neural-network software for image classification; development of an imaging spectrometer; multi-satellite mission management software etc. to feed into future programmes.
- Future technology development for sensors—optics design, electronics and devices, mass storage systems etc. and for satellite design for orbit control, bus design, electronics etc.

(h) *Involving industry.* The EO programme very much depends on the support and involvement of the Indian industry. Indian industry is involved in fabrication, electronic design, software development, equipment development, remote sensing data utilisation by value-addition etc.

The Antrix Corporation, the marketing front of the Department of Space, provides a single window interface to and from the Indian industry. With Antrix Corporation also making forays into

the international market with key tie-ups with various industries abroad. Recently the tie up with EOSAT Company of USA has ensured the worldwide availability of the Indian Remote Sensing Satellite (IRS) data through the various ground stations. Today, apart from India, IRS data is also received at Norman, USA; Neuristlitz, Germany with other countries planning to do so in the future.

Development of value-added services on commercial basis has been the thrust for a commercial programme in RS. Seeds for the commercial programme has been sown with definition of initial programs concentrating in different regions where there is an intense need for VAS in areas such as resource evaluation, land planning, agriculture assessment, non-renewable resources exploration, forest monitoring and environmental analysis etc.

(i) *Training and education.* Recognising the importance of human resources development for space related activities, regular training and education courses are conducted for professionals, students, teachers etc. The Indian Institute of Remote Sensing (IIRS) and other ISRO/DOS centres—Space Applications Centre, National Remote Sensing Agency and Regional Remote Sensing Service Centres provide regular courses in remote sensing. All these training facilities have helped in creation of a trained manpower base of about 3000 persons in the country.

The United Nations has selected India to host the Centre for Space Science and Technology Education in Asia and the Pacific (CSSTE-AP) as an affiliated Centre to the United Nations. Through the Centre, it is envisaged that India will be able to share its experiences with other countries in the region through appropriate education programme. The Centre has been established in Dehradun and has started its regular education programmes—the first of which is on remote sensing and GIS.

(j) *Involvement of Universities.* Universities are actively involved in the EOS programme and take up research project/activities under the RESPOND scheme. Universities also have courses in RS which are at PG level or as papers in specific thematic courses.

(k) *International Cooperation.* India has shared its experiences gained in space research and technology with neighboring countries - mainly by training personnel in various centres of ISRO/DOS for remote sensing, satellite communications and developmental and educational communication. The EO programme, since its inception, had the benefit of international cooperation.

FUTURE SCENARIO OF THE EO PROGRAMME

The overall goal is envisioned as an investment for the future and to boldly pursue the utilisation of space for the betterment of quality of life of the people of India and on Earth. The EO vision includes:

(a) *Expand scope of NNRMS* to States and to include a Government-NGO-Industry partnership and widening the scope of resource areas and user-interaction. Involving districts in RS applications for the actual implementation is very important.

(b) *Continue to provide RS services* with improvements for national development tasks and maintain leading edge in EO programme and expand data and application services in the national and global market. This will call for developing a total solutions approach for information service to user community - RS data, h/w, s/w, Applications, GIS/GPS, Digital photogrammetry etc.

(c) *Establish EO missions for global and local observations* as a dual-mission strategy in order to address the global-scale problems of climate change, environmental assessment (by considering applications in atmospheric and climate dynamics, atmospheric chemistry, geodesy, ocean etc.) and also local-scale problems of land and water resources management (by considering the applications for operational farm management, crop inventory and yield assessments, landuse management, irrigation planning, water budgeting, forestry, coastal dynamics, minerals etc.)

Developing strong R&D initiatives in EO satellites/sensor design and development, applications modelling, newer applications, GIS-based integration etc. feeding to future plans is called for.

(d) *Expansion of concept of sustainable development to other areas*—specially urban areas/towns, coastal areas, hill areas etc. is also called for. There is also a need to synergise programmes of resources survey, climatology/meteorology, environment and disaster management for a well-defined and integrated applications and utilisation strategy.

As part of this, widening the scope of aerial market by providing services with newer instruments—minerals, terrain, SAR etc. develop a comprehensive programme for integrating these as part of RS applications.

(e) *Establish a viable system for disaster management* with a dove-tailing of EO, satellite-based communications, conventional survey information and local networks. These disaster management systems (DMS) are visualised to

provide the backbone support for management of disasters in near-real time and also for disaster zonation studies and effective mitigation strategies.

(f) *Establish the national (natural) resources information system* (NRIS) as the repository of all natural resources data which are critical for planning development and implementation strategies. The NRIS is an inter-connected network of resources databases in the concept of a "Resource Information Shop".

(g) *Balanced commitment to national and global market.* The Indian EO programme has proven its ability to meet the national demands and cater to the resource management problems of the country. Commitment to the national problems will be the prime consideration for the EO programme. A balance needs to be struck for the commitments for the national and global user community so as to be able to cater to the needs of sustainable development and environment management - both at global and local levels.

(h) *Develop commercial programmes in EO* with active industry involvement so that the programme can start to develop a self-sustaining character. Even though the government sector may continue to be the major user of the technology, the increasing involvement of private sector in developmental activities (power, roads, telecom and other sectors), thanks to the liberalisation policies, could open up newer avenues for the development of the private sector market. Further, the exploitation of the global market would also be best achieved by farming out commercial enterprises to cater to the world user community.

(i) *Strengthening international initiatives for EO* by adopted a concerted strategy to contribute in a significant manner to the global initiatives and programmes. As part of this, it is also planned to provide opportunities to the International community to provide suitable EO payloads that can be launched onboard future IRS mission.

(j) *Increase and enhance scope of human resources development* programmes.

Thrust area of applications

As mentioned earlier, the EO programme is primarily driven by the needs of the nation. Until now, a wide variety of applications have been operationalised and the benefits of satellite data has been widely felt. However, in the Indian context, the key areas of applications that will require enhanced observation capability are:

(a) *Management of natural resources to ensure sustainable increase in agricultural production.* Meeting the needs of food, fiber and shelter of the growing population is the country's prime concern. It is important to recognize that today's developmental prospects should not deprive the future generation its legitimate needs. As food is the most critical requirement of a human being, agricultural sustainability assumes the topmost priority in sustainable development.

Increase in production is possible by bringing more areas under cultivation, by improving crop yields, by increasing cropping intensities and by integrated nutrient and pest management. Sustainable agriculture production would call for identification of problems at watershed level, adoption of proper soil and water conservation measures and optimal land-use planning at watershed level. Watershed characterization requires information on parameters like size, shape, topography, drainage, soils, landuse, landcover, climate and socio-economic data. Each of the applications mentioned above would require different sets of data from EO satellites.

(b) *Study the state of the environment, its monitoring and assessment of the impact of developmental actions.* Development programmes have been and continue to be conceived, planned and executed, often causing detrimental effect on the environment. The rapid industrialization, urbanization and commercialization are responsible for increasing amounts of CO_2 and other green house gases, air pollution and water and degrading lands. Deforestation trends have caused serious effects on global climate, soil erosion, water resources and food production. River valley projects, thermal power generation, mining, tourism etc. cause extensive damage to our ecosystem.

Impact analysis and assessment needs must be done to minimize adverse impacts. The study of impacts for an environmental impact analysis generally varies according to the type of project, development or action under evaluation. There are numerous bio-physical and socio-economic parameters which need to be measured and monitored as part of the analysis.

(c) *Large-scale mapping.* The need for large-scale, high quality, thematic and topographic data have long been realized in various fields. In addition to the problem of producing maps of up to 1:10000 scale, there is a need for updating the existing information on topographic maps. Mapping and detection of changes in urban and cultural features are essential towards management of our settlements and planning of facilities. Similarly, the mapping of forests, landuse, geology etc. at large scales are essential for the management of the resources at the local level.

All developmental activities require elevation information at different scales. The generation of digital elevation models (DEM) from satellite data will be a major application area.

(d) *Exploration of marine resources and Oceanography*. India has a long coastline of about 7500 km including its island territories. Exploitation of its marine resources including living and non-living resources is a necessity to meet the food and fuel demands of the increasing population. Fisheries, aquaculture, seaweed harvesting etc., are some of the fields which need to be explored. An understanding of photosynthetic processes (primary production) is required to assess the marine biological resources of the globe, including pelagic and demersal fisheries, shellfish and even organic sedimentary deposits. Determining accurately the concentrations of photosynthetic pigments and the rates of photosynthetic carbon fixation in the surface euphotic layer lead to improved estimates of primary production in the ocean. Global information on geographical and seasonal variations in primary production will allow a more complete assessment of secondary production processes in the oceans.

(e) *Inventory of non-renewable resources*. Unlike other surface phenomena, mineral resources are generally sub-surficial in nature. Occurrences of petroleum/mineral deposits are never haphazard. All the mineral/petroleum deposits follow certain mineralisation/structural patterns with various surficial indicators/guides which helps in their identification. Although many such guides exist in the conventional geological/geophysical method of prospecting, all of them cannot be followed in through airborne/space-borne remote sensing. Main limitation in usage of remote sensing for mineral/petroleum exploration is due to the fact that the mineral deposits are often relatively small targets located at considerable depths. The petroleum basins are in general highly deep-seated with limited surficial expressions. These limitations restrict the usage of remote sensing only to a reconnaissance level, providing input to further detailed ground-based geological/geophysical investigations.

(f) *Process studies to study climatic change dynamics*. Climatic changes are affected by biological and geophysical processes. Oceans, forests and human activities, over the years have control over global climate. Earth's environment is the cumulative result of various biogeochemical interactions within the land–ocean–atmospheric system as well as energy-mass transfer between the earth and planetary space. A predictive knowledge about the environment require elaborate observation capabilities with adequate temporal and spatial resolution so that regional and global variations in geophysical, chemical and biological state of the earth system can be monitored. Various phenomena which influence the environment and thus have to be monitored include:

- energy, mass exchange between space and Earth;
- energy, momentum and mass exchange between earth and atmosphere;
- biological activities on land and near surface water;
- atmospheric chemistry and atmospheric dynamics;
- precipitation, lightening etc;
- ocean dynamics, sea surface temperature etc;
- sea ice dynamics;
- surface geology, tectonic plate motion, tides, geologic faults etc.

(g) *Operational meteorology and weather prediction*. Operational meteorology is concerned with forecasting the weather over all geographical scales and for periods ranging from up to a week to months. A number of measurements are required on a regular basis for operational meteorology. Temperature and humidity profiles, wind fields, cloud cover and temperature, cloud heights, liquid water content, precipitation, ocean topography etc. are some of the parameters that need to be measured not only for operational meteorology but also for climate monitoring and predictions.

Future EO needs

The application thrust areas can be categorised into major areas of observation needs, as follows:

(a) *Cartographic applications* where the need is for small-target detection and mapping of features in mixed-clusters. The needs of mapping and feature detection require better elevation information and spatial scales of about 1:10,000+ would be essential. While resolutions of about 6 m (as provided by IRS-1C/1D) are adequate for updation of these thematic maps, information generation at this scale requires about 1–3 m resolution. Ideally, it is said that from information content point of view, a resolution of 1 m would be essential to detect and map features at better than 1:25000 scale. Elevation differences of about 1 m would also need to be mapped for cartographic and cadastral applications.

This segment would also be able to cater to the larger aerial photography market - which is a major share of the total EO market. As a result, many of the applications using aerial photographs can be done using this data and thus

Table 4. Mission profile for IRS-P series satellites

Mission	Payload-1	Payload-2	Payload-3
IRS-P4	OCM in eight bands, 350 m res. 1500 km swath	Four frequency scanning microwave radiometer	AO
IRS-P5	PAN 2.5 m resolution, 10 km swath fore-aft stereo (possibility of solid-state tape recorder)	AO	–
IRS-P6	3-band XS, steerable, 6 m resolution, 24 km swath, 7-bit	LISS-III as in IRS-1C, SWIR - 23 m, (WiFS 80 m, Swath 800 km and 10 bit)	AO
IRS-P7	OCEANSAT mission with Ku-scatterometer, Ku-altimeter, radiometer		
IRS-P8	Environmental/atmospheric ocean satellite mission		

AO = Announcement of opportunity payloads

dependency on aerial surveys would reduce to a large extent.

(b) *Crop and vegetation applications.* With specific reference to crops and vegetation, the parameters of observation for agrometeorology, crop detection etc. need to be encompassed with better spectral resolutions—specifically in the shortwave-infrared and ground resolution of about 10–20 m for different spatial bands. Another additional requirement apart from 10–20 multispectral is the pointability of the 5–10 m multispectral sensor that would enhance the coverage and allow selective area addressing—which is crucial for the sample sites in the crop acreage and yield estimation applications. In conjunction, the WiFS ground resolution could be improved to around 100–150 m with larger swath to assist in discriminability of vegetation types.

(c) *Oceanographic applications.* Observation of physical oceanographic parameters like winds, sea surface temperature, waves, bathymetry, internal waves etc. and biological parameters like phytoplankton etc. are essential towards the exploitation of the ocean resources. Targeting fish schools at deeper depths of the oceans is also important to help fishermen community increase their fish-catch, which has an important bearing on exports.

(d) *Atmospheric applications.* Towards the study of land, air, ocean interaction (in the context of IGBP and other global initiatives) which are essential for monitoring global-changes—specifically of the ozone and other green-house effects, earth radiation-budgets, clouds, atmospheric constituents etc. observation of the atmosphere at coarser resolutions, high repetitivity and with instruments suited for atmospheric compositional analysis are essential. Synergy and simultaneity are the essential elements of a global system for these applications, and planning complementary, supplementary missions is the essential need.

Table 4 shows the gap-areas and the observational needs to cover these areas.

Definition of future EO missions

Realising that these gap-areas and thrust applications need to be covered in the future IRS mission, a definition of the IRS Continuation missions has been made considering:

(a) the application gap-areas and the need to leap frog in technology and applications, and be a front-ranked leader globally;

(b) state-of-art of technology in devices, optics, data handling, signal processing etc. towards catering to the application needs and their timely availability;

(c) the opportunity of appropriately utilising the already approved developmental flights of PSLV viz., PSLV-C, C2 and C3 and plan low-cost fast turn-around, application specific missions. As a result, all EO missions are planned for PSLV launch.

The continuity after IRS-P3, in the IRS-P series, will be provided by four application-specific missions. Candidate payloads for the continuation series have been broadly defined. These candidate payloads cater to a majority of the application needs in specific gap-areas. The mission definition for the IRS series for the future is as follows:

(a) *IRS-1D* as a follow-on to IRS-1C and carrying the same payloads—PAN, LISS-3 and WiFS.

(b) *IRS-P4 (OCEANSAT-1)* will have payloads specifically tailored for the measurement of physical and biological oceanography parameters. An ocean colour monitor (OCM) with 8 spectral bands and a multi-frequency scanning microwave radiometer (MSMR) operating in four frequencies will provide valuable ocean-surface related observation capability. The IRS-P4 is slated for early-1998 launch by PSLV-C2. Table 5 shows the specifications of IRS-P4 payloads.

(c) *IRS-P5 (CARTOSAT-1)* will have a cutting-edge technology in terms of sensor systems and will provide state-of-art capabilities. The satellite will have only a PAN camera with 1–2.5 m resolution and ~12–30 km swath and fore–aft stereo capability. The 1–2.5 m resolution data will cater to the specific needs of cartographers and terrain modelling applications. The 1–2.5 m

Table 5. Specifications of IRS-P4 payloads

(A)	Ocean colour monitor		
1.	IFOV (M)	~350 m	
2.	Swath (Km)	1500	
3.	Instrument bands	Wavelength (nm)	(NE(%))
	1	402–422	0.045
	2	433–453	0.039
	3	490–510	0.030
	4	500–520	0.035
	5	555–575	0.030
	6	655–675	0.030
	7	745–785	0.025
	8	845–885	0.060
4.	M.T.F	>0.2 at Nyquist Freq.	
5.	Digitisation	12 bits	
6.	Data rate (MbPS)	17.35	
7.	Along track steering	+20, 0, −20 degrees	
8.	Payload weight	75 kilograms	
9.	Payload power	1 Electro-optics module	
10.	No. of packages	4 Electronics packages	
(B)	Multi-frequency scanning microwave radiometer		
1.	Frequency (Ghz)	6.6, 10.6, 18, 21	
2.	Altitude (Km)	743	
3.	Antenna Dia (cm)	86	
4.	Polarisation	V&H, V&H, V&H, H	
5.	3 dB Beam width (deg.)	4.2, 2.6, 1.6, 1.4 for respective frequencies	
6.	Spatial resolution (km)	120, 75, 45, 40 for respective frequencies	
7.	Swath (Km)	1500	
8.	Temp. resolution (deg. K)	~1.0	
9.	Dynamic temp. range (deg. K)	10.330	
10.	Data rate (kbps)	5	
11.	DC Power (W)	76	
12.	Weight (kg)	6	

stereo data could be modelled for obtaining terrain height information and it would be possible to map elevation differences of about 2–5 m which would considerably improve the contour information for environmental management and implementation activities. This satellite will pro-

Fig-1 : INDIAN EARTH OBSERVATION SYSTEMS: 1995 TO 2005

Fig. 1. Indian Earth Observation systems: 1995–2005.

Fig. 2. Trend of remote sensing application: 1995–2005.

vide cadastral level information up to 1:5000 scale for thematic applications.

(d) *IRS-P6* (*RESOURCESAT*) will be the state-of-art satellite mainly for agricultural applications and vegetation applications and will have a 3-band multispectral LISS-4 camera with a spatial resolution of better than 6 m and a swath of around 25 km with across-track steerability for selective area monitoring. An improved version of LISS-3 - LISS-3' with four bands (red, green, near-IR and SWIR), all at 23 m resolution and 140 km swath will also provide the much essential continuity to LISS-3. These payloads will provide enhanced data for vegetation applications and will allow multiple-crop discrimination; species level discrimination and so on. Together with an enhanced wide-field sensor, WiFS' with 80 m resolution and 1400 km swath, the payloads will aid greatly for crop and vegetation applications and integrated land and water applications. The data will also be useful for high accuracy resource management applications, where the emphasis is on multi crop studies for type mapping, vegetation species identification and utilities mapping.

(e) *IRS-P7* (*ATMOS-1/OCEANSAT-2 CLIMATSAT-1*) an integrated mission which will cater to global observations of climate, ocean and the atmosphere. The satellite will have:

- instruments to cater to the needs of oceanographic applications and will have microwave instruments—mainly a Ku-band altimeter, Ku-band scatterometer, microwave radiometer and a thermal infrared radiometer. Observation of oceanographic parameters like winds, sea surface temperature, waves, bathymetry, internal waves etc. would be possible using the data from these instruments. These parameters are essential towards the exploitation of the resources of India's exclusive economic zone.
- instruments for atmospheric chemistry applications and mainly for global change applications, specifically for atmospheric constituents study, pollution study and monitoring the ozone and greenhouse effects. This would be possible with instruments for atmospheric applications—ATMOS which will have spectrometers, sounders and different radiometers.
- instruments to observe climate and meteorological parameters. The instruments for this have to be firmed up but will include microwave sounders, radiometers, rain radars etc.

(f) *IRS-3*, beyond 2000 and the continuation of EO mission, the thrust will also be placed for missions having all weather applications, with multi frequency and multi polarisation microwave payloads - both synthetic aperture radar and other passive instruments. These data sets could

also be useful for soil moisture estimation applications and oceanography studies. The development of this satellite is planned to be initiated in the 9th Plan period itself.

Apart from these the development of hyperspectral imaging sensors, spectrometers, synthetic aperture radar (SAR) etc. will also be taken up leading into future EO missions.

The profile of RS missions addresses the concept of continuity, operational missions and the advanced missions up to 2005. Figure 1 shows the profile of Earth Observation systems for the decade 1995–2005. The impact on utilisation accruing from these proposed missions has also been assessed and is enclosed as Fig. 2.

CONCLUSIONS

The Indian Remote Sensing Satellite, IRS-1A, IRS-1B, IRS-1C, IRS-P2 and IRS-P3 have provided India with a unique opportunity to use remote sensing data for monitoring and management of our natural resources and environment. India, today has five RS satellites in orbit and in a combined manner one can get RS data once in 7 days.

The trend is to move to better resolutions—spatially to observe local-details and map more details; spectrally to discriminate more features and temporally to observe more frequently. The second generation IRS satellites take cognisánce of state-of-the-art technology development scenario in the world and the user requirements during 1990 s. The better spatial and enhanced spectral resolutions, more frequent re-visit and stereo viewing capabilities will no doubt throw open many new thrust areas in applications. Application-specific missions for cartography, environment, oceanography etc. in the immediate future are also being planned and these will also provide high-quality data for specific applications. Now that the IRS is catering to the global market, the continuity of existing services and enhancing the scope of the applications is a prime consideration so as to be able to provide cost effective solution for environment management and sustainable development.

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