Future perspectives of remote sensing

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Three Indian remote sensing satellites, IRS-1A, 1B and P2, are providing data to the global community in a continuous manner. 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. Towards this, a detailed assessment of the earth observation needs has been made. The future of earth observation from satellites will have to cater to the demands of monitoring global environment; cartographic mapping; long-term global change research and assessment; monitoring and managing the renewable and non-renewable resources, etc.

In this article we discuss 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. Critical amongst these are the missions which will be oriented towards enhancing the vegetation discriminability with multi-spectral data of 5–10 m; ocean observation mission for physical and biological parameters; observation of the atmospheric constituents, radiation budgets, clouds, etc. – much of which will be oriented towards global change applications; advanced systems with active microwave instruments; achieving 1 m resolution panchromatic data towards replacement of aerial photography needs for cartography and resource management applications; 5 m resolution multi-spectral data (green, red, near-IR and SWIR regions), etc. 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 utilization accruing from these proposed missions has also been assessed. A perspective of the Indian remote sensing programme for the next decade is provided.

THE Indian space programme aims at an integrated development of space technology and its utilization with a view to harnessing its potential for tasks of nation building – mainly providing operational services in the areas of communication, meteorology and resources survey. The space activities in India are mainly thrusted towards satellite communications and satellite-based remote sensing. The objectives pursued over the last few decades are gradually being realized. The development and successful launch of the Indian Remote Sensing Satellites (IRS) have established the fact that we have come of age in the space technology.

The Indian remote sensing satellites serve an important national goal in terms of providing continuous, operational services for the management of the natural resources of the country. IRS-1A, 1B and P2, the first three satellites in the series, have been the work-horse for generating resources information in a variety of application areas, such as, agriculture, forestry, geology and hydrology. The satellites, IRS-1A and 1B, are placed in a sun-synchronous orbit of 904 km in such a way as to provide a combined repetitivity cycle of 11 days. The satellites have been functioning normally meeting all the mission specifications. The operations of the ground systems have been flawless and high quality data products are generated and disseminated to the users on a regular basis.

With the launch of IRS-1C satellite new vistas for applications have been opened. IRS-1C, with the unique combination of LISS-III, WiFS and PAN sensors, will cater to various user requirements, such as, continuity of data, improved spatial resolution, enhanced spectral coverage, revisit capabilities, and stereo viewing. The IRS-1C will be the state-of-the-art civilian satellite providing highest spatial resolution information from the PAN camera, compared to other contemporary satellites, LANDSAT and SPOT.

User services from IRS-1C are envisaged to be significantly enhanced with the 23 m visible and near-IR data being able to discriminate mixed-crops to a larger extent and the middle-infrared data being able to detect moisture content in crops, thus making it suited for crop-stress studies and also for crop-growth analysis. The WiFS data are most suited for large-area and frequent crop and vegetation inventory. The 5.8 m PAN data will provide Digital Terrain Models (DTM) and facilitate better contour mapping and also high-quality cartographic mapping of features. The PAN data will also find greater utility in urban applications with the possibility of generating and updating maps at 1 : 10,000 scale.

IRS continuation series

As a continuation to IRS-1C/1D, plans are underway to define continuation missions – mainly addressing the gap areas of applications not covered by the present IRS satellites. Some of the key application areas which require better and enhanced observations are:

Cartographic applications where the need is for small-target detection and mapping of features in mixed-clusters. The needs of mapping and feature detection required 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) 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 1 : 10,000 scale. Elevation differences of about 1 m would also need to be mapped for cartographic applications. It would, thus, largely address the applications presently using aerial data.

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 5 m for different spectral bands. Another additional requirement is the pointability of the 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 m with larger swath to assist in discriminability of vegetation types.

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.

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

Realizing 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:

- the application gap-areas and the need to leap frog in technology and applications, and be a front-ranked leader globally
- state-of-art of technology in devices, optics, data handling, signal processing, etc. towards catering to the application needs and their timely availability.
- the opportunity of appropriately utilizing the already approved developmental flights of PSLV, viz. PSLV-C, C2 and C3 and plan low-cost fast turn-around, application-specific missions.

IRS-P3 mission

Considering the contemporary nature of the mission, IRS-P3 maintains maximum possible commonality with

Table 1. Application requirements for observation

Theme	Pay-load	Observation characteristics
Cartography	PAN	1–3 m resolution for 1 : 10,000 and better scales of mapping and about 3–5 m height resolution; Stereo in fore-aft; swath of about 30 km
	XS	About 5 m in three bands
Agriculture	WiFS	About 100–150 m resolution with SWIR band also; 750–900 km swath; 2–3 days repeat
	XS	About 5–10 m resolution in three optical bands and SWIR at about 20–25 m resolution; possibility of sample-segment viewing
	Spectrometer	Resolutions of about 50 m and about 64 bands in optical/IR
Agrometeorology	Microwave sounders	radiometers and thermal sensors with spectrometric observations
Soils/crops/terrain	SAR	Multi-parameter SAR with about 10–20 m resolution for land and water resources assessment, cloud penetration, soil moisture, inteferometry, DEM, etc.
Ocean	Scatt/alt/OCM	Altimeter
Atmosphere	Spectrometer	Broad resolution; 64–128 bands in UV/optical and IR for radiation budget, trace gas, global warming studies, etc.

the IRS-1C mission. IRS-P3 mission specifications like orbit, attitude, repetitivity, data rate, etc. are similar to those in IRS-1C mission. The total spacecraft weight is estimated to be around 930 kg and the spacecraft power system is configured for 813 watts at EOL at normal incidence. Taking into account the user requirements and the data needs, IRS-P3 will carry 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 region and would provide an effective ground resolution of 500 × 500 m and a swath of around 200 km. The radiometric quantization is done up to 16 bits. The MOS payload is optimized for oceanographic applications. Table 2 shows the specification of MOS payload.

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. In conjunction with IRS-1C and suitably placed in orbit, WiFS is expected to provide 2–3 days coverage of the country.

X-ray astronomy payload (XAP) is planned to carry out primarily experiments to study the time variability and spectral characteristics of cosmic X-ray sources and the detection of transient X-ray sources. The payload consists of three pointed mode proportional counters (PPC) in the energy range 2–20 keV and an X-ray sky monitor (XSM) in the energy range 3–6 keV. The PPCs are co-aligned and pointed towards the X-ray sources. The X-ray sky monitor is a pin-hole camera and consists of a position-sensitive proportional counter.

Considering the nature of the payload operations, the IRS-P3 mission operations will involve time sharing between two modes, namely, earth-viewing mode and sky-viewing mode. In the sky-viewing mode, the X-ray detectors will be inertially pointed towards a pre-decided X-ray star. While the PPCs will be operated only during the sky-viewing mode, the X-ray sky monitor will operate both in the earth-viewing as well as the sky-viewing modes.

The IRS-P3 MOS and WiFS data together are expected to be useful in four major application areas: (i) oceanic chlorophyll mapping and modelling primary production; (ii) vegetation condition assessment, yield modelling, growth profile; (iii) snow metamorphism and snow-melt run-off studies; and (iv) regional geological mapping for identification of mineral prognostic zones.

The IRS-P3 is expected to be ready for launch in March 1996.

Continuity after IRS-P3

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. In this context, it would be essential to view the IRS continuation series as complementary to operational missions and as opportunities for proving technology and applications with newer payloads and instruments. The unique combination of the operational and the opportunity missions will also ensure commercial exploitation in the global market. The IRS-P missions will be for a nominal 800 km orbit and in weight category of 1000, 1050 and 1100 kg for IRS-P4, IRS-P5 and IRS-P6, planned to be launched by PSLV-C1, C2 and C3 respectively. The mission definition for the IRS continuation series is as follows:

IRS-P4 will have payloads specifically tailored for the measurement of physical and biological oceanography parameters. An ocean colour monitor (OCM) with 9 spectral bands and a multi-frequency scanning microwave radiometer (MSMR) operating in 4 frequencies will provide valuable ocean-surface-related observation

Table 2. IRS-P3 MOS specifications

	MOS-A	MOS-B	MOS-C
No. of channels	4	13	1
Spactral 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-vapour)	1600
Spectral channel (width in nm)	1.4	10	100
Spatial resolution (m)	2520 × 2520	720 × 580	1000 × 720
Swath (km)	248	248	248
Quantization 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: $uW.cm^{-2}.nm^{-1}.sr^{-1}$.

capability. Table 3 shows the broad specifications of the sensors.

IRS-P5 will be the state-of-art satellite mainly for agricultural applications and will have a 3-band multi-spectral LISS-IV camera with a spatial resolution of better than 10 m and a swath of around 40 km with across-track steerability for selected area monitoring. An improved version of LISS-III (LISS-III') with 4 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-III. These payloads will provide enhanced data for vegetation applications and will allow multiple-crop discrimination, species level discrimination and so on. Together with WiFS planned in IRS-1C/IRS-P3, these payloads will aid greatly in the integrated land and water applications.

IRS-P6 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 2.5 m resolution and 10 km swath and fore-aft stereo capability. The 2.5 m resolution data will cater to the specific needs of cartographers and terrain modelling applications. The 2.5 m stereo data could be modelled for obtaining terrain height information and it would be possible to map elevation differences of better than 5 m which will considerably improve the contour information for environmental management and implementation activities. Called Cartosat-1, this satellite will provide cadastral level information at 1 : 5000 scale.

IRS-P7 will be a dedicated ocean-observation satellite. OCEANSAT as it is christened is proposed to cater to the needs of oceanographic applications. The satellite 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.

Table 4 shows the tentative mission profile for the IRS-P series.

Table 3. Specifications of IRS-P4 payloads

Ocean colour monitor		
IFOV (meters)	VNIR: 250, SWIR:500	
Swath (km)	1500	
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
9	1500–1700	0.200
M.T.F	> 0.2 at Nyquist freq.	
Digitization	12 bits	
Data rate (Mbps)	17.35	
Along track steering	+20, 0, –20°	
Payload weight	75 kg	
Payload power	1 Electro-optics module	
No. of packages	4 Electronics packages	
Multi-frequency scanning microwave radiometer		
Frequency (GHz)	6.6, 10.6, 18, 21	
Altitude (km)	743	
Antenna dia (cm)	86	
Polarization	V&H, V&H, V&H, H	
3 dB Beam width (deg)	4.2, 2.6, 1.6, 1.4 for respective frequencies	
Spatial resolution (km)	120, 75, 45, 40 for respective frequencies	
Swath (km)	1500	
Temp. resolution (deg K)	> 1.0	
Dynamic temp. range (deg K)	10.330	
Data rate (kbps)	5	
DC power (W)	76	
Weight (kg)	6	

Looking beyond 2000

Subsequent to the IRS-P7, missions are being planned to provide a continuity in data services for resources management and environmental applications. Critical amongst these are the ATMOS mission which will be oriented towards observation of the atmospheric constituents, radiation budgets, clouds, etc. – much of which will be oriented towards global change applications. Advanced systems with active microwave instruments; achieving 1 m resolution panchromatic data towards replacement of aerial photography needs for cartography and resource management applications; 5 m resolution multi-spectral data (green, red, near-IR and SWIR regions) are some of the major mission goals for the early 2000s. These missions are planned for up to the 2000 and are a series of satellites to be launched to address specific gap-areas discussed above. The IRS continuation series not only addresses some of the gap-areas but also helps towards evolving the observation needs in the early 2000s. This unique concept of a meshed operational and application-specific missions of satellites is evoking global interest and this could be capitalized into a commercial edge in the global remote sensing market.

The thrusts of the IRS missions in the 2000s would be for:

High accuracy resource management applications, where the emphasis is on multi crop studies for type mapping, vegetation species identification and utilities mapping. This would be possible with the availability of 5/10 XS data in 3 bands (green, red, IR), having a steerable capability so that specific areas could be imaged more frequently. Apart from this, an improved wide field sensor with 125 m resolution in 4 bands (green, red, NIR and SWIR) would provide large area observation.

High accuracy terrain applications, where the emphasis will be on target identification, utilities mapping and obtaining digital terrain models of < 2 m height accuracy and approx. 1 : 4,000 scales of mapping. This is proposed to be achieved with an advanced panchromatic sensor having < 1 m resolution and pointability for stereo observations.

Global change applications, specifically for atmospheric constituents study, pollution study and monitoring the ozone and greenhouse effects. This would be possible with a mission for atmospheric applications – ATMOS which will have spectrometers, sounders and different radiometers.

All weather applications, with multi frequency and multi polarization 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.

A decade profile of RS missions has been defined which 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 utilization accruing from these proposed missions has also been assessed and is enclosed as Figure 2.

Table 4. Mission profile for IRS-P series satellites

Mission	Payload-1	Payload-2	Payload-3
IRS-P4	OCM in 9 bands	Multi-frequency scanning microwave radiometer	AO
IRS-P5	LISS-IV 3 band XS, steerable, better than 10 m resolution, 40 km swath, 6/7-bit	LISS-III 4 bands (VNIR and SWIR with 23 m resolution)	AO
IRS-P6	PAN 2.5 m resolution, 10 km swath fore-aft stereo	AO	–
IRS-P7	OCEANSAT mission (Ku-scatterometer, Ku-altimeter, radiometer)		
IRS-P8 (2000)	Environmental/atmospheric satellite mission		

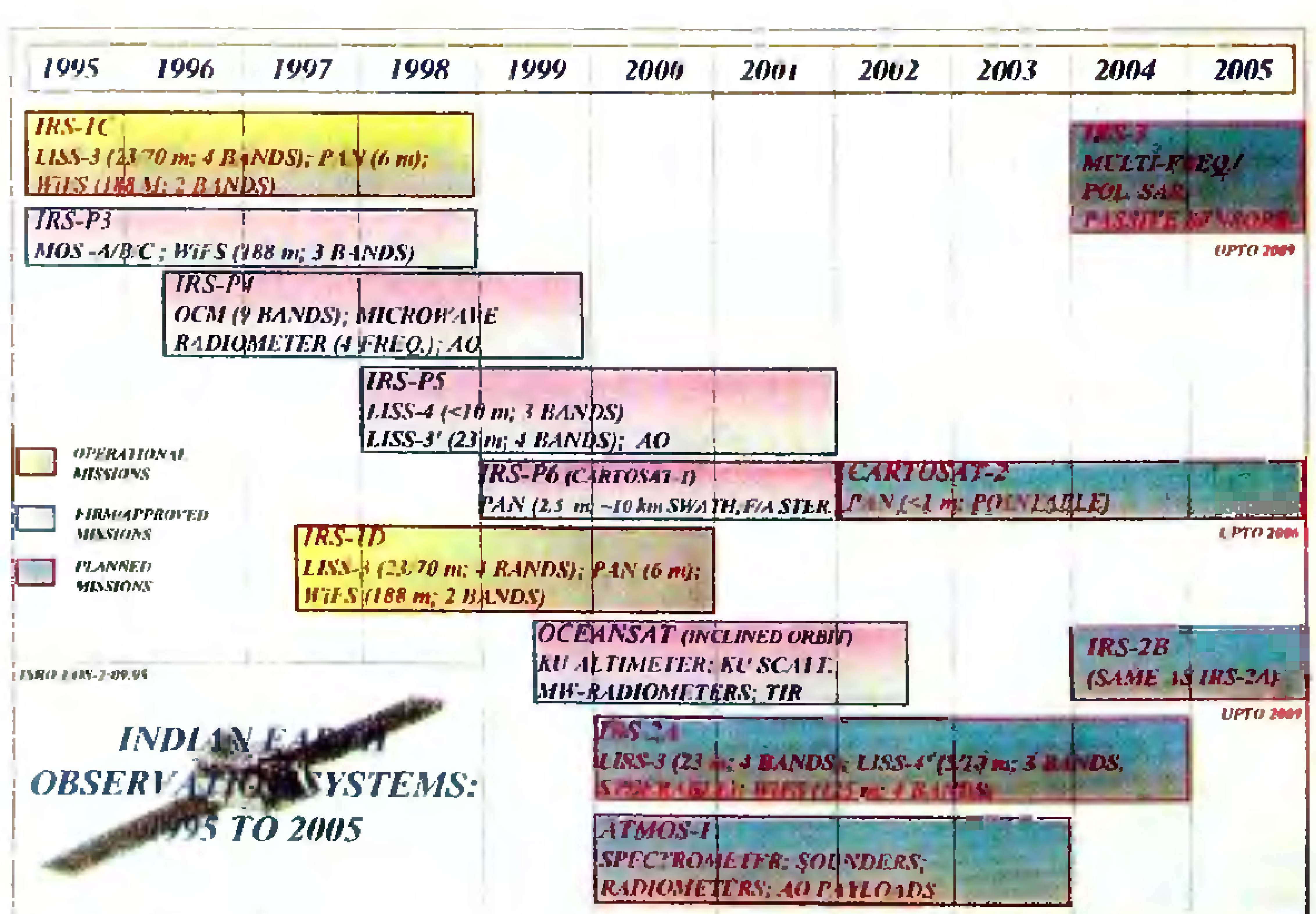

Figure 1. Indian earth observation systems: 1995 to 2005.

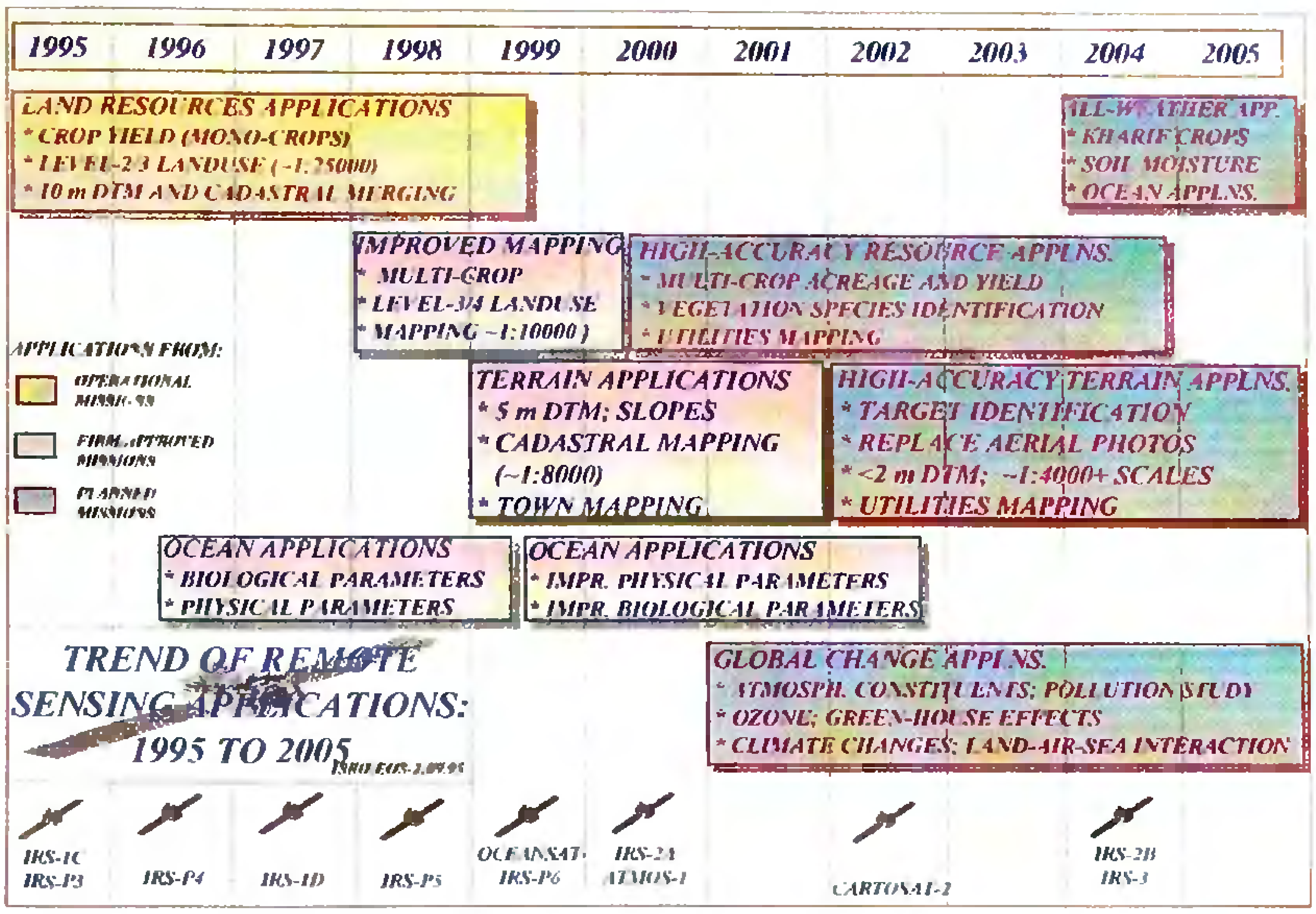

Figure 2. Trend of remote sensing applications: 1995 to 2005.

Conclusion

The launch of the Indian remote sensing satellites, IRS-1A, IRS-1B, IRS-P2 and IRS-1C has provided India with an unique opportunity to use remote sensing data for monitoring and management of our natural resources and environment. Today, India has four RS satellites in orbit – which is a unique achievement.

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 cognisance of state-of-the-art technology development scenario in the world and the user requirements during 1990s. 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 competitive and have an edge in the world-wide remote-sensing industry.