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Remote Sensing Data Acquisition, Platforms and Sensor Requirements

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ABSTRACT

Although data available from various earth observation systems have been routinely used in many resource applications, however there have been gaps, and data needs of applications at different levels of details have not been met. There is a growing demand for availability of data at higher repetivity, at higher spatial resolution, in more and narrower spectral bands etc.

Some of the thrust areas of applications particularly in the Indian context are:

- Management of natural resources to ensure sustainable increase in agricultural production,
- Study the state of the environment, its monitoring and assessment of the impact of various development actions on the environment,
- Updating and generation of large scale topographical maps,
- Exploration/exploitation of marine and mineral resources and
- Operational meteorology and studying various land and oceanic processes to understand/predict global climate changes.

Each of these thrust area of application has many components, related to basic resource areas such as agriculture, forestry, water resources, minerals, marine resources etc. and the field of cartography. Observational requirements for major applications have been summarized as under.

Monitoring vegetation health from space remains the most important observational parameter with applications, in agriculture, forestry, environment, hydrology etc. Vegetation extent, quantity and temporal changes are the three main requirements which are not fully realized with RS data available. Vegetation productivity, forest biomass, canopy moisture status, canopy biogeochemistry are some examples. Crop production forecasting is an

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The study was undertaken by the study group constituted by the Executive Council of ISRS. The findings of the study team (assisted by scientists from SAC) are reported here.

important application area. Remotely sensed data has been used for identification of crops and their acreage estimation. Fragmented holdings, large spread in crop calendars and different management practices continue to pose a challenge to remote sensing. Remotely sensed data at much higher spatial resolution than hitherto available as well as at greater repetivity are required to meet this need. Non-availability of cloud-free data in the kharif season is one of the serious problems in operational use of remote sensing for crop inventory. Synthetic aperture radar data at X & Ku bands is necessary to meet this demand. Nutrient stress/disease detection requires observations in narrow spectral bands. In case of forestry applications, multispectral data at high spatial resolution of the order of 5 to 10 metres is required to make working plans at forest compartment level. Observations from space for deriving tree height are required for volume estimation. Observations in the middle infrared region would greatly enhance capability of satellite remote sensing in forest fire detection. Temporal, spatial and spectral observational requirements in various applications on vegetation viewing are diverse, as they address processes at different spatial and time scales. Hence, it would be worthwhile to address this issue in three broad categories.

a) Full coverage, moderate spatial resolution with high repetivity (drought, large scale deforestation, forest phenology.....).

b) Full coverage, moderate to high spatial resolution and high repetivity (crop forecasting, vegetation productivity).

c) Selected viewing at high spatial resolution, moderate to high repetivity and with new dimensions to imaging (narrow spectral bands, different viewing angles).

A host of agrometeorological parameters are needed to be measured from space for their effective use in development of yield models. Estimation of root-zone soil moisture is an important area requiring radar measurements from space. Surface meteorological observations from space at the desired spatial and temporal distributions has not developed because of heavy demands placed on the sensor as well as analytical operational models. Agrometeorology not only provides quantitative inputs to other applications such as crop forecasting, hydrological models but also could be used for farmer advisory services by local bodies.

Mineral exploration requires information on geological structures, geomorphology and lithology. Surface manifestation over localized regions requires large scale mapping while the lithology can be deciphered from specific narrow bands in visible, NIR, MIR and TIR regions. Sensors identified for mapping/cartography in conjunction with imaging spectrometer would seem to cover requirements of this application. Narrow spectral bands in the short regions which provide diagnostics of relevant geological phenomenon are necessary for mineral exploration. Thermal inertia measurements help in better discrimination of different rock units. Measurements from synthetic aperture data which would provide information on geological structures and geomorphology are necessary for mineral exploration.

The applications related to marine environment fall in three major areas: (i) Ocean colour and productivity, biological resources; (ii) Land-ocean interface, this includes coastal landforms, bathymetry, littoral transport processes, etc. and, (iii) Physical oceanography, sea surface temperature, winds, wave spectra, energy and mass exchange between atmosphere and ocean. Measurement of chlorophyll concentration accurately on daily basis, sea surface temperature with an accuracy of 0.5 °K and information on current patterns are required for developing better fishery forecast models. Improved spatial resolution data are desirable for studying sediment and other coastal processes.

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Cartography is another important application area. The major problems encountered in relation to topographic map updation are location and geometric accuracy and information content. Two most important requirements for such an application are high spatial resolution data of 1 to 2 metre and stereo capability to provide vertical resolution of 1 metre. This requirement places stringent demands on the sensor specifications, geometric processing, platform stability and automated digital cartography.

The requirements for the future earth observation systems based on different application needs can be summarized as follows:

- Moderate spatial resolution (150-300m), high repetivity (2 Days), minimum set of spectral bands (VIS, NIR, MIR, TIR) full coverage.
- Moderate to high spatial resolution (20-40m), high repetivity (4-6 Days), spectral bands (VIS, NIR, MIR, TIR) full coverage.
- High spatial resolution (5-10m) multispectral data with provision for selecting specific narrow bands (VIS, NIR, MIR), viewing from different angles.
- Synthetic aperture radar operating in at least two frequencies (C, X, Ku), two incidence angles/polarizations, moderate to high spatial resolution (20-40m), high repetivity (4-6 Days).
- Very high spatial resolution (1-2m) data in panchromatic band to provide terrain details at cadastral level (1:10,000).
- Stereo capability (1-2m height resolution) to help planning/execution of development plans.
- Moderate resolution sensor operating in VIS, NIR, MIR on a geostationary platform for observations at different sun angles necessary for the development of canopy reflectance inversion models.
- Diurnal (at least two i.e. pre-dawn and noon) temperature measurements of the earth surface.
- Ocean colour monitor with daily coverage.
- Multi-frequency microwave radiometer, scatterometer, altimeter, atmospheric sounder, etc.

1. Introduction

The history of satellite remote sensing began with the launch of TIROS-1 spacecraft in 1960 carrying a single band TV camera which sent back first cloud images of the earth. Successful launching of the Earth Resources Technology Satellite (ERTS-1) in 1972, later renamed as LANDSAT heralded beginning of the era of satellite remote sensing for natural resources survey and monitoring. Since then, there has been tremendous progress in developing new earth observation platforms with a wide variety of remote sensing instruments. This, together with the progress made in data processing and data interpretation techniques has considerably widened the scope of remote sensing applications. The earth observation systems programme in India has been applications driven. While Bhaskara I & II satellites launched in late seventies and early eighties provided an experience in the design and development of spacecraft, data processing techniques and application packages, the successful launch of IRS-1A in 1988, IRS-1B in 1991 and IRS-P2 in 1994 heralded the era of operational remote sensing programme and provided the confidence to launch second generation satellite IRS-1C at the end of 1995 which will cater to local and international users.

Although data available from various earth observation systems have been used routinely in many areas of resources applications, there have been gaps, and data needs of applications at different levels of details have not been met. There is a growing demand for availability of data at higher repetivity, at higher spatial resolution, in more and narrower spectral bands etc.

In view of this, President, ISRS, constituted a study group to examine detailed observational requirements of agriculture, agrometeorology, forestry, hydrology, geological and mineral resources, cartography, marine and coastal applications and global changes. Observational requirements have been translated in terms of sensor parameters to suggest a group of sensors/earth observation systems. The study group also undertook a survey to get a feedback on the user needs, by circulating a questionnaire to more than 800 users of remote sensing technology. The feedback received was analysed to get a perception of data needs to meet their application requirements. Details of this analysis are given separately in Annexure-I.

2. Satellite Systems: Present and Immediate Future Scenario

2.1 *International scenario*

Depending on envisaged applications, the current satellite remote sensing programme can be grouped into two broad categories:

i) Earth observation systems for the management and regional inventory of renewable and non-renewable resources: This includes regional monitoring of vegetation, deforestation, soil, minerals, inland water bodies, snow/ice cover, urban sprawl, coast lines etc. and monitoring calamity zones like flood plains, volcanoes etc. Remote sensing missions like LANDSAT, SPOT, MOS and JERS belong to this category. There are also Space Shuttles Missions which carried microwave payloads. ERS-1 and RADARSAT are those developed for microwave remote sensing. Details of these missions are given in Tables 1, 2, 3.

ii) Environmental missions to study the dynamics of land-ocean-atmospheric interactive system to have a predictive knowledge about the evolution of earth's environment, climate patterns etc. This requires global monitoring of a large number of geophysical, chemical and biological parameters of the earth system over a long period of time. Thus environmental missions, in general, involve measurement of a large number of parameters using various kinds of imaging and non-imaging sensors operating in a wide range of electromagnetic spectrum. Remote sensing programmes like POES/NOAA, UARS/NOAA, ERS/ESA etc. and all operational meteorological satellite programmes may be grouped under this category. Here it has to be emphasized that satellite missions for earth resource applications have also contributed much to the understanding of environmental dynamics on a regional basis. On the other hand remotely sensed data from environmental missions such as NOAA/POES and ERS-1 have also been widely used for resources applications. Some of the details of these missions are listed in Table 4.

Table 1. Earth Observation Systems (VNIR, SWIR, TIR) launched till date (Jan. 1996).

Mission	*LANDSAT 1&2*	*LANDSAT-3*	*LANDSAT-4/5*	*SPOT-1/SPOT-2/ SPOT-3*	*MOS-1a/ MOS-1b*	*JERS-1*
Launch Year	1972,1975	1978	1982,1984	1986,1990,1993	1987,1990	1992
Altitude (km)	919	919	705	830	908.7	568
Inclination	99.1°	99.1°	98.2°	98.7°		98°
Spectral band(s) in μm	RBV B1:0.475-0.575 B2:0.580-0.680 B3:0.698-0.830 Multispectral Scanner (MSS4): B4:0.5-0.6 B5:0.6-0.7 B6:0.7-0.8 B7:0.8-1.1	RBV 0.505-0.75 Multispectral Scanner (MSS5): MSS4 + B8:10.4-12.6	MSS 5 TM 0.45-0.52 0.52-0.60 0.63-0.69 0.76-0.90 1.55-1.75 10.4-12.5 2.08-2.35	Panchromatic 0.51-0.73 Multispectral (XS) 0.50-0.59 0.61-0.68 0.79-0.89	MESSR B1:0.51-0.59 B2:0.61-0.69 B3:0.72-0.80 B4:0.8-1.1 VTIR B1:0.5-0.7 B2:6.0-7.0 B3:10.5-11.5 B4:11.5-12.5 MSR	Optical Sensor 0.52-0.60 0.63-0.69 0.76-0.86 0.76-0.86 (stereo) 1.60-1.71 2.01-2.12 2.13-2.25 2.27-2.40
Spatial resolution	MSS4:79m	MSS1:79m MSS (B8):240m RBV:30m	TM 30m 120m for B6	10m in PAN 20m in XS	MESSR:SOM VTIR-B1:900m VTIR-B2,3,4: 2700m	18.3×24.2 (R×A)
Swath (km)	185	185	185	117	MESSR-100 VTIR-1500	75
Repeat cycle (days)	18	18	16	26 5 (with steering)	5-6*	44
Equatorial crossing in LST	9:30 am	9:30 am	9:45 am	10:30 am	"non-sunsynchronous"	
Quantization level (bits)	6	6	8	PAN-6/8 XS-8		

LST : Local Solar Time XS : Multispectral RBV : Return Beam Videon (RBV)

* : not an integral multiple of day

Table 2. Synthetic Aperture Radar (SAR) Missions launched till date (Jan. 1996).

	Seasat	*SIR-A*	*Shuttle/ Space Lab*	*SIR-B*	*SIR-C*	*ERS-1 ERS-2*	*JERS-1*	*Radarsat*
Year of launch	1978	1981	1983	1984 1995	1994 1995	1991	1992	1995
Altitude (km)	794	252	250	250	250	785	568	793-821
Inclination	98.5°	38°	57°	57°	57°	98.5°	98°	98.6°
Band	L	L	X	L	CLX	C	L	C
Frequency (GHz)	1.275	1.275	9.4	1.275	5.289, 1.239, 9.602	5.3	1.275	5.3
Wavelength (cm)	23.5	23.5	31.7	23.5	5.8, 23.5 31	5.6	23.5	5.6
Nominal Resolution (m)	25	40	25	15-50	10-200	26 × 28	18 × 18	9 × 9 to 100 × 100
Incidence Angle	20°	47°	31-54°	15-60°	17-60°	23°	35°	10-50°
Polarisation	HH	HH	HH	HH	HH,VV HV,VH	VV	HH	HH
Swath Width (km)	100	50	8.5	20-50	15-90	100	75	45/510
Repeat Cycle (days)	17	–	–	–	–	3/35/168	44	27/7/17

Table 3. Satellite altimeter missions flown till date (Jan. 1996).

	Skylab	*GEOS-3*	*Seasat*	*Geosat*	*ERS-1 ERS-2*	*TOPEX/ POSEIDON*
Launch Year	November 1973	April 1975	June 1978	March 1985	July 1991	August 1992
Mean altitude (km)	435	845	800	800	780	1335
Orbit inclination	50°	115°	108°	98°	63°	
Repeat cycle	–	–	(17)/3	-/17	(3)/35/168	10
Frequency (GHz)	13.9	13.9	13.5	13.5	13.8	5.3/13.6
Precision (cm)	< 100	30	7	5	8	2/4

*Source: Wakker *et al.*, 1988

Table 4. Environmental Earth Observation Systems launched till date (Jan. 1996).

Mission	*TIROS-N*	*NOAA-9,10,11,12,14 (F,G,H,D)*	*CZCS*
Launch year	1978, 1979, 19--, 1983	1985, 1986, 1988, 1991, 19--	1978-86
Altitude (km)	833	833	955
Inclination	98.9° AVHRR	98.9° AVHRR	99.3° CZCS
Spectral band(s) in μm	0.55-0.9 0.725-1.1 3.55-3.93 10.5-11.5 10.5-11.5	0.58-0.68 0.725-1.1 3.55-3.93 10.3-11.3 11.5-12.5	0.433-0.453 0.510-0.530 0.540-0.560 0.660-0.680 0.70-0.80 10.5-12.5
Spatial resolution	1.1 km at nadir, offnadir monimoms: along track 2.4 km	across task = 6.9 km	825 m at nadir
Swath (km)	2400 cross track scan ± 55.4° from nadir	2400 cross track scan ± 55.4° from nadir	1640
Repeat cycle (days)	Twice a day	Twice a day	2 (repetivity) 6 (revisit period)
Ascending node equatorial crossing in LST	1500, 1930, 1430, 1930	1420, 1930, 1340, 1930, 1340	
Descending node equatorial crossing in LST	0300, 0730, 0230, 0730	0220, 0730, 0140, 0730, 0140	2400
Quantization level	10	10	8

AVHRR : Advanced Very High Resolution Radiometer

CZCS : Coastal Zone Colour Scanner

2.2 *Indian earth observation capability*

India has three first generation operational remote sensing satellites (IRS 1A & 1B, IRS-P2) and four meteorological satellites (INSAT 1D, INSAT 2A, 2B & 2C) providing earth observation capability in visible, near infra red and thermal infra red regions of electromagnetic spectrum. The IRS satellites provide imagery in four spectral bands (B1 0.45-0.52, B2 0.52-0.59, B3 0.62-0.68 and B4 0.77-0.86 microns) with a ground resolution of 36 metres using LISS-2 cameras and 72 metres using LISS-1 cameras covering a swath of 140 kilometres across track at a repetivity of 22 days. The satellite provides imagery over the Indian sub-continent and the United States of America using the data reception facilities at the National Remote Sensing Agency (NRSA), Hyderabad and Norman-Oklahoma, U.S.A. The data received at NRSA is marketed by NRSA Data Centre, while the same at Norman is being marketed by EOSAT company. IRS-P2 was launched by one of India's launcher, the Polar Satellite Launch Vehicle (PSLV), on October 15, 1994. This satellite provides earth observation capability in the same four spectral bands as in IRS 1A and 1B with a spatial resolution of about 37 metres covering a swath of 140 kilometres across track

The INSAT VHRR instrument provides visible and thermal infra red imageries of the earth disc with a spatial resolution of 2 kilometres for visible (0.55-0.75 micron) and 8 kilometres for thermal infra red (10.5-12.5 micron) wavelengths from INSAT 2A @ 74 degree E, INSAT 2B @ 93 degree E and INSAT 1D @ 83 degree E. The earth observation can be carried out in three different modes namely full scan mode (this mode covers full earth disc and takes 33 minutes for providing one image), normal scan mode (this mode covers 50 degree north to 40 degree south and takes 23 minutes to provide one image) and sector scan mode (this mode covers approximately one fourth of the earth disc in the north-south direction and takes about 7.2 minutes to provide one image. It enables quick coverage of any specific region and enables tracking of cyclones etc.). The data reception facilities exist at MCF (Master Control Facility), Hassan, Space Applications Centre, Ahmedabad and India Meteorological Department (IMD), New Delhi. IMD has the responsibility of data dissemination.

India has launched its second generation operational satellite of IRS series namely IRS 1C on December 28, 1995. This satellite provides a significant improvement in earth observation capability as it provides three tier imaging capability. It has a high resolution stereo imaging capability through a single band Panchromatic (0.5-0.75 micrometre) camera. LISS-3 a multispectral sensor (B2, B3, B4 bands: 23m resolution and B5 SWIR band 70.5m resolution) and a wide field sensor operating in red and near infra red bands (B3, B4) providing 188m resolution and 5-day repetivity are the other two sensors. The data from this satellite is being received at NRSA ground station at Shadnagar near Hyderabad, EOSAT Norman U.S.A. and is also expected to be received at other international ground stations.

On March 21, 1996, India launched IRS P3 satellite from its own PSLV launcher (PSLV-D3 flight). This satellite carries wide field sensor covering B5 band in addition to B3 and B4 bands available in the WiFS of IRS 1C satellite. This satellite also carries MOS (Multispectral Opto-electronic Scanner) payloads built by DLR Germany, which caters to ocean and atmospheric studies. Table 5 summarizes the sensor characteristics of Indian Earth Observation systems.

Table 5. Sensor characteristics of Indian satellites for earth observation.

Satellite Sensors	*Launch year*	*Spectral bands (in micrometre)*	*Ground Res. (m)*	*Swath (km)*
Bhaskara I/II (TV)	1979/1981	0.54-0.66 0.75-0.85	1 km	341
Bhaskara I/II (Samir)	1979/1981	19, 22, 37 GHz	125 km	–
IRS-1A/1B (LISS-I/II)	1988/1991	0.45-0.52 0.52-0.59 0.62-0.68 0.77-0.86	72.50 36.25	148/2 × 74
IRS-P2 (LISS-II)	1993	As above	37 × 32	131
IRS-1C/1D* (LISS-III)	1995/1988	0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.70	~ 23 (VNIR) ~ 70 (MIR)	~ 140
IRS-1C/1D* (PAN) Steerable ± 26°	1995/1998	0.5-0.75	5.8	70
IRS-1C/1D* (WiFS)	1995/1998	0.62-0.68 0.77-0.86	188	~ 770
IRS-P3 (WiFS)	1996	0.62-0.68 0.77-0.68 1.55-1.70	188	~ 774
IRS-P3 (MOS-A)+		0.7567 0.7606 0.7635 0.7664 Band width 0.0014	2520	248
(MOS-B)+		0.408, 0.443 0.485, 0.520 0.570, 0.615 0.650, 0.685 0.750, 0.815 0.870, 1.010 0.445 Band width 0.01	720 × 580	248
(MOS-C)+		1.600 Band width 0.1	1000 × 720	248
IRS-P4* OCM	1997	0.412, 0.443 0.490, 0.510 0.555, 0.670 Band width 0.02 0.765, 0.865 Band width 0.04 1.550 to 1.700	250 500	1500 1500
MFSR		6.6, 10.6, 18 and 21 GHz	120, 75, 45, 40	1500

* Proposed/scheduled

+ Payloads designed and developed by DLR, Germany. Central wavelength is given against the spectral bands.

3. Thrust Areas in Applications

Various application projects have been carried out using the present national as well as international earth observation systems. Yet, in the Indian context following areas are likely to receive more attention in immediate future:

- Management of natural resources to ensure sustainable increase in agricultural production.
- Study the state of the environment, its monitoring and assessment of the impact of developmental actions.
- Updating and generation of large scale topographical maps.
- Exploration of marine and mineral resources.
- Operational meteorology and monitoring of land and oceanic processes to predict climatic changes.

3.1 *Management of natural resources to ensure sustainable increase in agricultural production*

The world population is increasing at an alarming rate and is expected to reach a figure of 11.2 billion around the year 2100 before stabilizing around 11.6 billion beyond 2100. Meeting the needs of food, fiber and shelter of this growing population is a major concern. On a finite earth, population cannot grow indefinitely and 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. Fig. 1 shows different aspects involved in achieving a sustainable increase in agricultural production (Navalgund, 1991). Increase in production is possible by bringing more areas under cultivation, improving crop yields, increasing cropping intensities and through integrated nutrient and pest management. Sustainable agricultural production would call for identification of problems and optimal land-use planning at watershed level, and adoption of proper soil and water conservation measures. 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 require different observational requirements which are summarized in the next section.

3.2 *Study the state of the environment, its monitoring and assessment of the impact of development actions*

Environmental impact may be defined as any alteration of environmental conditions or creations of a new set of environmental conditions, adverse or beneficial, caused or induced by the action or set of actions under consideration. Development programs 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

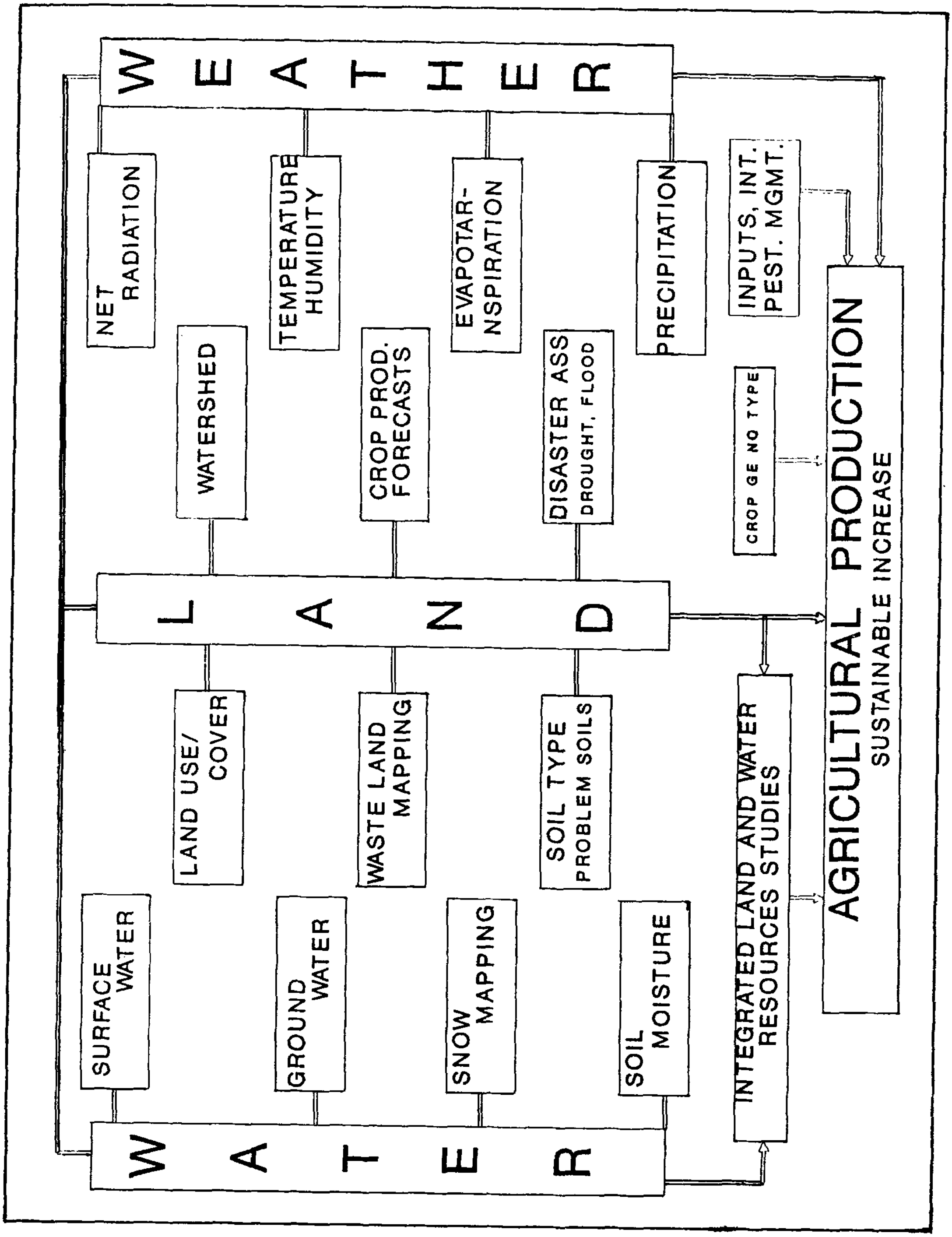

Fig. 1. Remote sensing applications in sustainable agriculture.

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 to be done to minimize adverse effects. The choice of impacts to be considered in performing 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 before a project is cleared from environment angle and which need to be monitored after commissioning of the project. Various applications which need to be considered are given in Figure 2 (Sahai, 1993).

3.3 *Updating and generation of large scale topographical maps*

The need for high quality topographic data have long been realized in various fields. In addition to the problem of producing good topographic maps at 1:25000 scale, there is a need for updating the existing information on Survey of India maps. Detection of changes in cultural features such as buildings and communication links are yet to be achieved. Any topographic map consists information on content, position and elevation. In case of undulating regions, the tilted view of sensors leads to significant distortions in geometry due to terrain relief. In order to rectify these distortions, Digital Elevation Models (DEM) of the terrain need to be used to generate orthoimages. Hence, it will be desirable to derive thematic information and digital elevation models using spaceborne data.

3.4 *Exploration of marine and mineral resources*

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 dire necessity to meet the food and fuel demands of the increasing population. Fisheries, aquaculture, seaweed harvesting, petroleum exploration etc. are some of the fields which are being 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.

Unlike other surface phenomena, mineral resources are generally subsurfacial in nature. Occurrences of petroleum/mineral deposits are never haphazard. All the mineral/petroleum deposits follow certain mineralisation/ structural patterns with various surfacial indicators/guides which help in their identification. Although many such guides exist in the conventional geological/

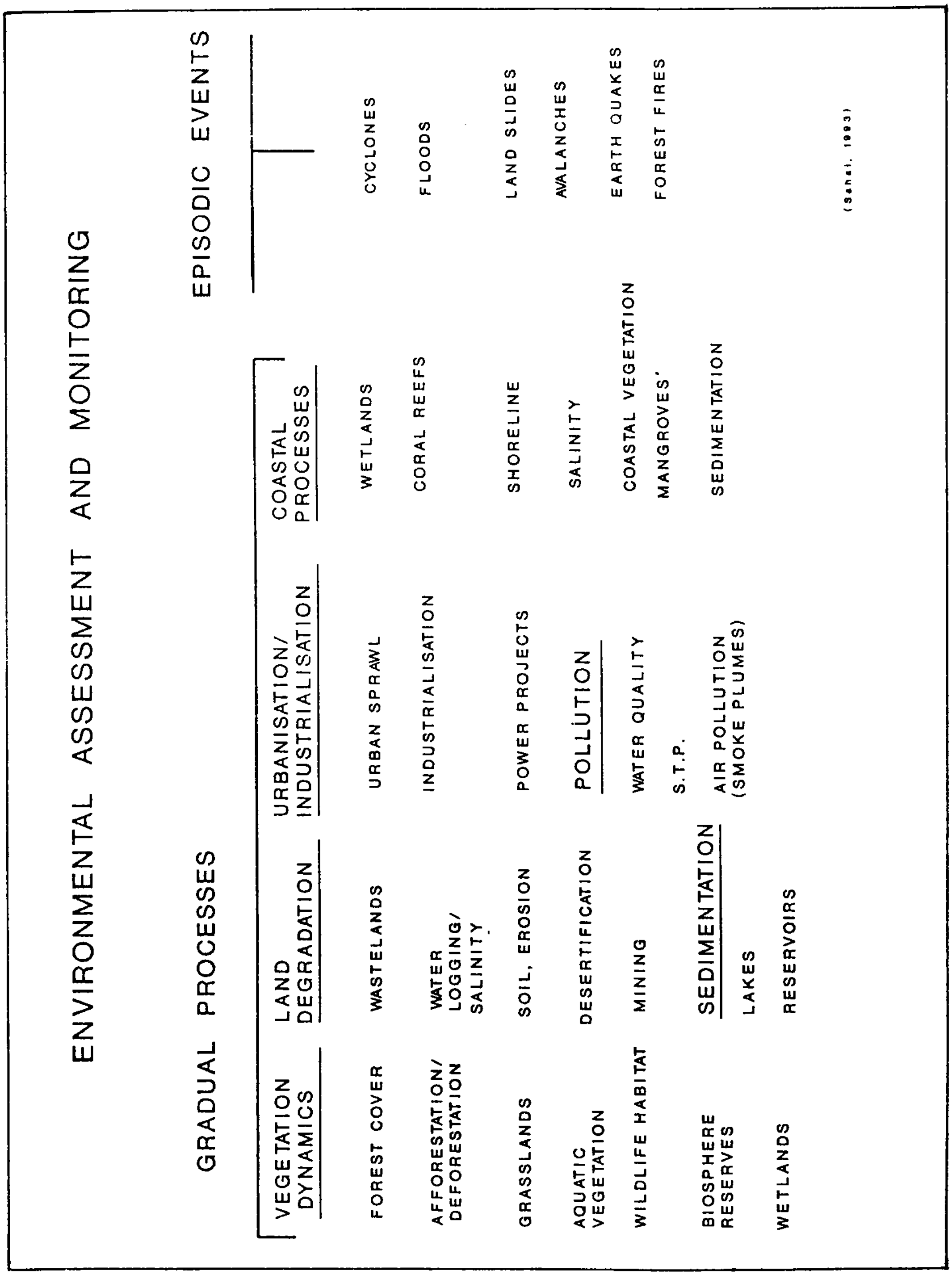

Fig. 2. Environmental assessment and monitoring using remote sensing.

geophysical method of prospecting, all of them cannot be followed in toto 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 surfacial expressions. These limitations restrict the usage of remote sensing only to reconnaissance level, providing input to further detailed ground-based geological/geophysical investigations.

3.5 *Operational meteorology and monitoring of land and oceanic processes to predict climate changes*

Operational meteorology is concerned with forecasting the weather over all geographical scales and for the periods upto a week or even a month. 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.

Climatic changes are affected by biological and geophysical processes. Oceans, forests and human activities, over the year 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.

4. Application goals and Observation requirements

As a thrust area would consist of many themes which are to be addressed in a multi-disciplinary manner, all the thrust areas have been examined on the basis of major application themes. Theme-wise requirements in terms of objectives, the parameters to be measured and the sensor specifications required for these studies are given in this section.

4.1 *Agriculture, Landuse, Soils*

At present, remote sensing is operationally used for acreage estimation of crops in single crop dominated regions. Remote sensing based yield relationships have been shown to be useful for crop yield predictions in some areas. However, crop production forecasting is yet to be established for areas with multiple cropping patterns. Fragmented holdings, different crop calendars and different management practices adopted by farmers continue to pose a challenge to remote sensing. A sample study in Gujarat suggests that the field size varies from 0.047 to 4.14 ha with a mean area of 0.61 ha where 50 per cent of the fields have areas greater than 0.4 ha (Sahai *et al.*, 1988). Identification of crop varieties, field level monitoring of crops at different growth stages, early warning of disease, early detection of stress for irrigation management and estimation of soil moisture with accuracies greater than 95% are some of the major problems which need to be studied using RS techniques. Table 6 shows the needs and sensor requirements to meet some of these objectives. A three-tier sensor system would be required to fulfill the observation needs at regional level, district level and field level. For crop monitoring a spatial resolution of 150-300m with a high repetivity (2 days) would be sufficient but for detection of disease/pest attack and yield forecasting, it will be desirable to image at moderate resolutions of 20-40m and a repetivity of 4-6 days while in regions of small field sizes and mixed cropping, crop identification will require a high resolution data of 5-10m. In general, a spectral bandwidth of 60-80 nm is required in VIS & NIR, MIR & TIR bands but disease and stress detection will require specific narrow spectral bands of few nm bandwidth (Table 7). Use of microwave data is envisaged particularly during kharif season when optical data availability is reduced. Two incidence angles or two polarizations may be used to get extra dimensions in the data which may compensate for the lack of multi spectral dimension here.

Agrometeorological parameters are important inputs for studying crop growth processes and crop yield modelling. As of now, parameters such as soil moisture and albedo have been attempted to some extent. However, validation of agromet spectral yield models would require many other parameters such as rain fall, insolation, land surface temperature etc. to be measured at higher accuracies. Table 8 shows the agrometeorological requirements of satellite sensors.

Remote sensing data have contributed greatly to landuse mapping, monitoring and planning by providing landcover information. Regional perspective planning requires mapping at scale of 1:250,000, while detailed planning requires mapping at 1:50,000 scale. However, implementation of these plans requires mapping at much larger scale e.g. 1:10,000 for indicating the field ownership limits. Table 9 gives the sensor requirements for agriculture landuse and soils. Very high spatial resolution with increased spectral resolutions will be desirable for discriminating more cover types.

4.2 *Forestry*

Space-borne data have proved useful

for forest mapping, inventory and monitoring. Discrimination between closed and open forests and wooded shrub land is possible in many cases. Also, coniferous and deciduous forests can be distinguished from satellite data. Distribution of forest types and information on stand characteristics mainly related to timber volume and growth is required for estimating production potential. Forest management would require information on species composition and canopy structure, site characteristics such as terrain and soil moisture and stresses in forest due to disease, insect infestation etc. High spatial resolution of few metres and imaging in narrow spectral bands (Table 10) is required to meet these objectives. Stereo images would help in determining stand characteristics based on tree heights. Bio-diversity studies would require species identification which is possible only through high resolution data. Fire is the major single factor of vegetation transformation in the tropical areas. Detection and monitoring of fires and identifying fire prone areas would require thermal infrared images during day and night time.

Table 6. Agricultural Applications: Crop Production Forecasting.

S.No.	*Application objective*	*Required physical quantities*		*Issues*
1.1	Crop identification	VIS, NIR, MIR at different growth stages	20-40m, 4-6 days 5-10m, 8-12 days	- Infrequent repetivity - Lack of data during kharif - Small field size
		Backscattered MW intensities	20-40m, X, Ku bands Two incidence angles/polarisations	- Operational processing techniques (Multidate, Sensor, Texture)
		Polarised Radiance	(plant morphology)	
1.2	Monitoring crop health on regional scale	VIS, NIR and MIR, Thermal indices, Red edge (position of the inflection point) and Red slope (670-760nm)	150-300m, 2 days	- Stress manifests through TIR indices earlier
1.3	Crop yield forecasting	VIS, NIR, MIR and TIR data at different growth stages in absolute units - Narrow bands, Red edge - Data at different sun/ view angles	20-40m, 4-6 days C, X, Ku	Infrequent repetivity - In absolute units (multi sensors) - Lack of validated Agromet spectral yield models - Agromet parameters such as soil moisture, ET, albedo, insolation
		Back scattered MW intensities	20-40m, 4-6 days 1db	
1.4	Disease, Pest attack, Nutrient stress	Specific narrow bands	20-40m	Post-event assessment only

Table 7. Narrow spectral band needs.

Application	*Objectives*	*Spectral region*	*Band widths*
Soils & Rocks			
– Mineralogy	Identification of minerals		
	$-CO_3$, -OH & $-SO_4$ bearing minerals	1740 nm	
		1760 nm	10 nm
	Calcite	2320 nm	
	Dolomite	2310 nm	
	$Mg(OH)_2$ bearing minerals	2300 nm	10 nm
	$-OH^-$ & $Al(OH)_3$ bearing minerals	2200 nm	
– Soil Moisture	–	2160 nm	20 nm
		2040 nm	20 nm
Vegetation			
– Productivity	Chlorophyll/Carotenoid ratio	700 nm, 740 nm	5-10 nm
	Leaf water content	1650 nm	20 nm
– Crop growth modelling	Lignin & proteins	1510 nm, 1690 nm	≤ 10 nm
		2060 nm, 2140 nm, 2380 nm	
	Cellulose, starch	2100 nm, 2280 nm, 2340 nm	≤ 10 nm
– Nutrient Stress	Nitrogen deficiency	700 nm, 740 nm	5-10 nm
		780 nm	
– Moisture Stress	Plant water content	850 nm	20 nm
		1650 nm	

4.3 *Hydrology*

Remote sensing data are being used presently in snow-cover measurement and seasonal run-off forecasting for reservoir management, soil-moisture assessment for irrigation practices, mapping of water bodies, flood mapping. Research endeavours are especially needed in precipitation run-off and forecasting of actual run-off, snow water equivalent and soil moisture measurements. All these parameters will lead to a better understanding of the hydrological cycle and its changes (Tables 11 & 12).

4.4 *Cartography*

Space images are extensively used for preparing thematic maps upto the scales of 1:50,000 with standard topographic map as a base map. However, they have limited use in the updating of map at 1:50,000 scale. The major problems encountered in topographic map updation are location and geometric accuracy of the information content. In the case of mountainous terrain digital elevation models need to be either generated from maps or from stereo pairs obtained by space sensors. Today's systems like SPOT and IRS 1C do not provide ideal data for this as the stereo data over a given area are acquired from observations on two different dates. A sensor system should have aft and fore looking cameras to obtain a stereo imagery. The 10m resolution available from SPOT is not fine enough to identify the features of interest for mapping and is not suitable for 1:25,000 scale of mapping. The cartographic needs today are – map compilation at 1:50,000 scale, updation at 1:25,000 scale, detection of changes in cultural features, production of DEMs and image maps. Table 13 presents the needs and requirements of sensors for cartography (INCA study group, 1994). From Table 13 it is clear that most of the application requirements are met by spatial resolution of 1-2m and a vertical resolution of 1m. SAR interferometry may be used for getting DEMs of high accuracy.

Table 8. Satellite sensor requirements for agrometeorology.

Priority-wise Basic parameters	*Required Accuracy*	*Spatial Resolution (km)*	*Temporal Resolution*	*Spectral Bands for Data/Sensor*	*Present Status (Global)*	*Application Areas*
1. Rainfall	> 95%	10 to 50	Daily	Thermal (Split ch.)	RD	Crop yield, Soil moisture
2. Veg. Index	> 95%	1 to 5	Days	Visible & NIR	QO	Crop growth monitoring, Yield modelling drought
3. Canopy temp.	± 0.5°	1	Daily	Thermal (Split ch.)	QO	Crop stress, Drought, Crop yield, ET
4. Albedo	> 90%	50	Daily	Visible, NIR, MIR, ERBS	QO	Absorbed solar radiation, Photo-synthesis crop yield
5. Insolation	> 85%	100	3 hrs.	Visible, NIR, MIR, ERBS	RD	Absorbed solar radiation, Photo-synthesis crop yield
6. Tmin/Tmax (air)	± 0.5°	10	12 hrs.	HIRS (TOVS)	QO	Crop stress, GDD, Crop yield, ET
7. Land surface temp.	± 0.5°	1	Daily	Thermal (Split ch.) AVHRR (day/night)	QO	Soil moisture, ET
8. Soil moisture (surface/root zone)	> 95%	3	2 days	Thermal (MSU/TOVS)	RD	Crop stress, crop water requirement, ET
9. Humidity	± 0.5 gm/cm^2	5-10	12 hrs.	Thermal AVHRR (MSU/TOVS)	QO	ET, Pest occurrence

Note: RD: R&D level; QO: Quasi Operational; Tmin: Minimum temperature; Tmax: Maximum Temperature

Table 9. Sensor requirements for agriculture, landuse and soils.

Sr. No.	*Application objective*	*Information needs*	*Observation requirements*	*Remarks*
1.a)	Landuse/cover mapping	Admn. unit wise maps and statistical data	70-80m, VIS, NIR, MIR MW	
		Level I & II (1:250,000)		
		Level II & III (1:50,000)	20-40m, VIS, NIR, MIR	
		Level III (1:10,000)	5-10m, VIS, NIR, MIR	
b)	Cadastral level and updating	Map showing field boundaries	< 5m PAN	
c)	Land transformation studies			
d)	Urban landuse - Demography - Housing quality - Traffic modelling - Planning utilities	1:25,000 1:10,000 1:4000	10-20m, MS 5m vertical resolution 5-10m, MS 2m vertical resolution 2m PAN, 1m vertical resolution	
2.	Agricultural Landuse	Area under Crops at 1:250,000 Plantations 1:50,000 Orchards Fallow Lands Waste Lands	80m, VIS, NIR, MIR 20-40m VIS, NIR, MIR 1:10,000-1:25,000 5-10m VIS(2), NIR, MIR with ~ 95% accuracy, stereo, 20 d	
3.	Soil			
a)	Reconnaissance soil map	Soil sub-group association at 1:50,000		To be extensively supported by soil profile studies
	Semi-detailed map	Soil series association at 1:50,000		
	Detailed & Reconnaissance map	Phases of soil series at 1:10,000-1:25,000 (Sub-watershed level)	5-10m, multispectral 5m contours	
	Land capability and soil suitability	1:25,000 class level Sub-class level soil suitability for a crop		

Contd. ...

Contd. ... **Table 9**

Sr. No.	*Application objective*	*Information needs*	*Observation requirements*	*Remarks*
4.	Soil and land degradation	Extent and spatial distribution of degraded lands	80m, VIS, NIR, MIR	
	- Water logging - Salinity - Erosion - Desertification	Severity level Changes At three scales (1:250,000, 1:50,000 & 1:10,000-1:25,000)	20-40m, VIS, NIR, MIR 5-10m, VIS, NIR, MIR stereo 5m, 20 d	
5.	Agricultural hydrology			
	- Surface water body/storage	Extent, Change detection at 1:50,000 (> 2.5 ha) 1:10,000 scale		
	- Soil moisture	Estimation of surface soil moisture and its spatial distribution	SAR L, C band 15-18° incidence angle, 3 d	Development of soil moisture profile models
		Root zone	I, C SAR data TIR 20-30m, 1km	
6.	Agricultural drought	Veg. status at district level crop status with 3-4 severity levels	200m, 80m, 20-40m 5-8 d	
		Taluka level crop status for major crops and its linkage with yield model		
		Early warning for moisture stress in command areas	TIR(2), 80-100 m 2-4 d	
	- Irrigation management	Irrigated crop inventory Crop water demand, Crop moisture status, Crop water use/ET Crop water budget	As in 6 and Agrometeorological parameters	

4.5 *Mineral exploration*

Indirect indictors like drainage, landform etc. and major rock type/structural mapping at 1:50,000 scale are at present being used as guides in mineral/petroleum exploration. The conventional geological exploration is based upon structural/ lithological mapping and detection of geological/geophysical anomalies. A list of geological parameters observable through remote sensing is given in Table 14. The large scale (1:10,000) mapping of lithofacies and structural features for more accurate targeting of mineral/petroleum occurrences needs to be done. Imaging spectrometers may be useful for the discrimination of various hydrothermally altered rocks. High resolution multichannel thermal IR data with a repeat cycle of twice a day is required for thermal inertia study. Active microwave data with multiple polarizations/frequencies may be useful for the extraction of geomorphological features. Imaging at low sun angles will also be beneficial for geological discrimination in hilly terrains. The observational requirements for mineral exploration are given in Table 14.

Table 10. Forestry: Sensor requirements.

Sr. No.	*Applications objective*	*Observational requirements GR (m)*	*Spectral bands*	*Repetivity*	*Remarks*
1.	Forest extent mapping	250-500	VIS, NIR, SWIR	3-7 d	
	Monitoring changes at global/regional level	(1:250,000) 1:1 M			
2.	Forest type & density mapping	20-30	VIS, NIR, SWIR,	15-20 d	Operational texture analysis programs
	Delineating areas of afforestation, deforestation, encroachment (national level)	(1:50,000)	MW (X,P)		
3.	Forest management at compartment level	5-10 (1:10,000 to 1:25,000)	VIS, NIR, SWIR	15-20 d	Mensuration parameters
	- Species composition and canopy structure		Narrow bands (VNIR) MW		
	- Site characteristics (DTM, Soil moisture)		STEREO (~ 1m height res.)		
	- Tree volume/biomass		INSAR		
4.	Monitoring, fire detection/ monitoring, fire proneness		3-4 μm & 10-12 μm	D&N	
5.	Monitoring disease and damage assessment		Specific narrow bands	15-20 d	
6.	Biodiversity				Species identification

Table 11. Hydrology Applications: Needs.

Sl. No.	*Applications*	*Observational requirements*	*Parameters amenable to RS*	*Primary spectral observables*
1.	Precipitation-extent and distribution	Cloud-top temperature, cloud growth, speed of storm	Cloud-top temperature cloud-top brightness	NIR radiances, visible radiances, microwave backscatter
2.	Rainfall surface run-off	Surface run-off	Cloud-cover index	NIR reflectance, microwave backscatter, reflectance in blue region
3.	Water bodies and flood mapping	Extent and volume of water in water bodies, channel flow/river discharge, Flood area delineation	Extent of the suspended sediments in water bodies & flooded area	NIR reflectance, microwave backscatter
4.	Snow and ice monitoring	Snow-cover-extent and water equivalent, snow melt run-off, topography	Wet snow areas	NIR reflectance, microwave backscatter (multi-frequency obs.)
5.	Groundwater recharge estimation	Rainfall, evapo-transpiration, infiltration	Landcover, soil types	VIS/NIR reflectances, thermal radiances

Table 12. Hydrology: Sensor requirements.

	Swath (km)	*Spatial resolution (m)*	*Repetivity*	*Spectral bands*	*Remarks*
Precipitation, flood mapping	1000	1000	Twice daily	VIS/NIR passive microwave	
Snow cover	1000	100-500	3-5 days	NIR, Ka, Ku, x bands	Sun-sync. orbit, constant illumination
Suspended sediments	150	20-30	Daily	VIS microwave	
Evapotranspiration	1000	250	Daily	VIS NIR Thermal	Equatorial crossing at 2 p.m.

Table 13. Cartography: Sensor requirements.

	Scale	*Grid spacing for DEM*	*Accuracy of DEM*	*Required Spatial Res.*	*Sensor type*
Large scale maps	≤ 1:10,000	10 m	< 1 m	1-2 m	Optical, with along track stereo, laser altimetry
Topographic maps	1:25,000 to 1:2,00,000	25 to 100 m	2.5 to 25 m	5-10 m	Optical, imaging, SAR
Global mapping	> 1:200,000	5 to 1 km	500 to 100 m	100-500 m	Optical, radar altimetry

Table 14. Geological and mineral resources development and management.

Applications	*Requirements*	*Parameters amenable to remote sensing*	*Primary spectral observables*
Geotechnical Study	Lithology	Broadscale rock-type discrimination	Narrow spectral bands (10 nm) in the range 0.4-2.5 μm
	Geological structures seismicity		Specific absorption channels
	Geotechnical properties of materials	Surface topographical change detection	SAR Interferometry
	Geological hazards	Lineaments	Use of optical/microwave/high resolution PAN
		Volcanocity	MIR, TIR bands, High repetivity (geostationary platforms)
Geomorphological Mapping	Landforms Drainage patterns Structures Catchments	Delineation of buried & surface drainage pattern	Microwave/Optical/TIR
	Flood prone areas	Digital terrain model	Optical stereo data/SAR Interferometry
Geological Mapping	Rocktype distri. Orientation of structures Natural hazards Thermal Inertia	Thermal inertia	TIR (day & night time)
Oil & Gas	Lithology Geologic structures Sediment thickness Reservoir rock Cap rock Geophysical anomaly Thermal Inertia	Off-shore gravity anomaly	Satellite altimetry

4.6 *Marine resources*

Sea-surface temperature charts generated from NOAA-AVHRR thermal data are being used for predicting potential fishing zones from dynamic features such as thermal fronts, eddies etc. Ocean colour is another parameter which has been studied for phytoplankton distribution. However, in absence of any colour sensor at present, extensive studies have not been possible. Besides this, fishery forecast models require information on winds, internal waves and other oceanic parameters which will require radars, altimeters and scatterometer measurements.

Inventory and monitoring of coastal features such as tidal wetlands, coastal land forms, mangroves, sea grass meadows, estuary dynamics, shoreline changes etc. have been done using space-borne data. However, improved spatial resolution with medium spectral resolution capabilities in a sensor are desirable for studying sediment transport and other coastal processes (Table 15 & 16).

4.7 *Climatology/global change*

To study global changes one has to study various processes such as hydrological cycle, earth radiation budget, atmospheric chemistry, ocean processes, land surface, sea level changes and biodiversity etc. (Table 17). As obvious monitoring of environment requires the measurement of a large number of parameters at different spatial and time scales which necessitate the use of various kinds of sensors. This includes a large variety of active and passive sensors which make measurements in the X-ray, ultra-violet, visible, infrared and microwave region of the electromagnetic spectrum as well as non-electromagnetic sensors like particle detectors, magnetometers, gravity gradiometers etc. The spatial and temporal sampling of measurement vary with the observed phenomena and in general sensors with different spatial resolution and coverage has to be employed. Simultaneous measurement of different parameters which may be a pre-requisite for monitoring many geophysical phenomena require different kinds of sensors boarded on the same observation platform. Also, frequent measurement of many quantities on global scale may require the simultaneous operation of many satellite platforms.

Some of the derived parameters used for global-change studies are net radiation flux, precipitation, soil moisture, evaporation, etc. These are derived from various meteorological parameters like insolation, surface temperature, temperature and water profiles, cloud top temperatures, wind speed etc. Various sounders are presently used to derive temperature and humidity profiles. While temperature information is possible for 15 layers, humidity measurements are presently possible for only 3 layers. Precipitation and rain rates are being derived using visible/infrared and microwave data. Soil moisture can be detected in the surface layers by means of microwave absorption and emission. The total net radiation input to the land-surface determines the heat fluxes at the surface. Atmospheric structural parameters derived from sounders are used for determining it. While most of these measurements are possible from NOAA type sun-synchronous satellites there is a need for geo-stationary satellites also for certain parameters such as wind measurements, atmospheric convection/ instability and for improved high resolution sounding data.

Table 15. Marine Resources: Needs.

Application	*Requirements*	*Parameters Amenable to RS*	*Primary Spectral observables*
Primary productivity	Phytoplankton, yellow substance amount	Ocean colour, Chlorophyll fluorescence, Atm. correction	Reflectance in narrow spectral bands in blue region NIR reflectance, Reflectance at 685mm
Potential fishing grounds	Phytoplankton distribution, Identification of Oceanographic features, Thermal fronts	Chlorophyll, Sea surface temp., Atm. correction	Reflectance in blue region, Thermal reflectance, Microwave measurements
Coastal zone monitoring	Coastal wetlands, Shoreline changes, Water quality, Bathymetry	Extent & condition of wetlands Erosion & deposition Suspended sediments Topography & substrates	VIS/NIR reflectance Ocean colour VIS/NIR reflectance Reflectance in blue region
Coastal regulation zone	Coastal wetlands and shorelands	Extent	VIS/NIR reflectance

Table 16. Marine Resources: Sensor requirements.

Objectives	*Swath (km)*	*Spatial resolution (m)*	*Repetivity*	*Spectral bands*	*Remarks*
Open ocean studies, Ocean colour, Fluorescence, Atm. correction	1000	500-1000	Daily	6-8 bands (narrow band width region)	High radiometric sensitivity, tilt capability required to avoid sun glint
Coastal and beach processes	150-200	20-30	Daily	6-8 narrow spectral bands	For tidal motions and patterns studies, obs. is required at every 6 hrs.
Oceanographic parameters				Microwave measurements	

Table 17. Global change studies.

Phenomenon	*Objectives*	*Parameters required*
Climate change Ozone depletion Forest impacts	Earth radiation budget	Net solar radiation flux, amount, distribution and optical properties of clouds, cloud cover, oceanic prod. of trace gases.
Air/water pollution Biodiversity Sea level change	Carbon cycle	Carbon stocks and sinks, primary productivity of oceans, SST, salinity, forest cover, deforestation rate, biomass burning.
Desertification	Ocean processes	Ocean surface topography, ocean colour, SST, sea ice, wave heights, surface winds.
	Water cycle	Precipitation, energy fluxes, soil moisture, surface skin temperature, humidity, winds, clouds measurements, distribution of vegetation, soils and topography, snow cover.
	Atmospheric Chemistry	Ozone total content and vertical distribution, temperature, vertical distribution of source gases, (CH_4, N_2O, halocarbons) aerosols.

5. Summary requirements for future Earth Observation Systems

Besides the spatial, spectral and temporal resolution requirements discussed in the previous section, there are many other factors which need to be considered while designing a system. Non-availability of data from optical sensors during kharif season precludes the use of remote sensing data for operational agricultural information systems. Certain applications like surface energy budget and other meteorological parameters which in turn affect the terrestrial processes require night time observations which are presently not possible. Geological applications shall be benefited if viewing of earth surface at varying sun angles is done. Due to sun-synchronous orbits chosen, the present satellites can view the surface only at fixed sun angle. Above all, highly transient phenomena are rarely observed by these satellites. High spatial resolution results in low temporal resolution. Presently only two types of data are available for land-surface monitoring and assessment. First, high-resolution data from sensors like LANDSAT, SPOT, IRS and ERS-1 SAR which image the earth at low repetivity. Second, data from meteorological satellites like NOAA, which observe the earth at high repetitive rates but have coarse spatial resolution. Medium resolution data have been very useful mainly for mapping and classification purposes in many applications such as crop production forecasting, crop stress detection, forest mapping and damage detection, coastal mapping, environmental impact studies etc. However, they have not been found to be useful for alarm, or monitoring purposes due to their low repetivity and high cost. A 5 or 10m resolution is still inadequate to achieve plant detection in case of orchards or vineyards. A 10m resolution (SPOT PAN) is also not fine enough to identify the features of interest for mapping though the geometric accuracy achieved is adequate for mapping at 1:50,000. On the basis of the above considerations, the requirements for the future earth observation systems can be summarized as follows:

- Moderate spatial resolution (150-300m), high repetivity (2 D), minimum set of spectral bands (VIS, NIR, MIR, TIR) full coverage.

- Moderate to high spatial resolution (20-40m), high repetivity (4-6 D), spectral bands (VIS, NIR, MIR, TIR), full coverage.

- High spatial resolution (5-10m) multi-spectral data with provision for selecting specific narrow bands (VIS, NIR, MIR), viewing from different angles.

- Synthetic aperture radar operating in at least two frequencies (C, X, Ku), two incidence angles polarizations, moderate to high spatial resolution (20-40m), high repetivity (4-6 D).

- Very high spatial resolution data (1-2m) in panchromatic band to provide terrain details at cadastral level (1:10,000).

- Stereo capability (1-2m height resolution) to help planning/execution of development plans.

- Moderate resolution sensor operating in VIS, NIR, MIR on a geostationary platform for observations at different sun angles necessary for the development of canopy reflectance inversion models.

- Diurnal (at least two i.e. pre-dawn and noon) temperature measurements of the earth surface.

- Ocean colour monitor with daily coverage.

- Multifrequency microwave radiometer, scatterometer, altimeter, atmospheric sounder, etc.

6. Broad definition of future Earth Observation System

An earth observation system/mission and payloads on the space platform have to be carefully planned and designed keeping in view the user requirements and the technological constraints. Some of the broad considerations for a earth observation system (ESA report, 1991) are as follows:

- Observations of the earth surface
  - Repetitive monitoring at global scale
  - Selective observations of local areas
- Continuity of service for operational users (does not exclude innovations/ improvements)

- Calibration of sensors
- Synergy between sensors
- Atmospheric corrections: facilitates the use of data at different times/ observation conditions
- Timely access of data : ground acquisition / processing / distribution infrastructure
- Supporting activities : simulations, campaigns and modelling efforts.

Looking at the future thrust areas and application needs, the detailed mission design, in general, needs capabilities such as higher spatial resolution (optical), narrower spectral bands, higher repetivity, active microwave payloads with wider swaths and more frequencies, stereoscopic coverage, multisensor concept and viewing at different angles. The high spatial or spectral resolution of data naturally put stringent requirements on data handling capabilities of on-board and ground processing systems. So further improvements in these fields are closely related to progress in data handling (transmission, storage and processing) systems. The effect on data rates and volume by opting for higher spatial resolution data is given in Table 18. For instance, a daily coverage of India at 1m resolution requires simultaneous operation of about 186 satellites, while the same at 10m resolution could be acquired through only 19 polar orbiting satellites.

Table 18. System needed to cover India at higher spatial resolutions.

Payload			*Technology Issues*
IGFOV (metres)	10	1	Current level of technology permits realisation of such payloads
Swath (km)	150	15	
Spectral bands	3	3	
Quantisation levels	64	64	
No. of satellites needed			
To provide daily coverage	19	186	While it would be possible to manage a few satellites of this complexity in orbit the task of launching and managing such a mission would be prohibitive in cost
Data rate per satellite (mbits/sec)	178	1778	While 10 metre data can be transmitted 1 metre data calls for use of data compression techniques
Data volume per day (for a 10 minute pass) Million mega bits	2	200	Would require enormous storage and processing capabilities

A broad configuration of earth observation systems required for various applications is given in Table 19. A three tier configuration (A,B,C) would satisfy the needs of regional monitoring as well as locale-specific observations, if grouped optimally on a platform. The cartographic requirements can be met by a PAN sensor with stereo capability and a resolution of 1 to 2m (D). A payload combining an optical and a SAR sensor (E) could provide operational capability with the optical sensor yielding information about the spectral behaviour of the phenomena, and the radar giving the indispensable information on relief, soil moisture, surface roughness and sub-surface information by penetration, besides, measurements over vegetation even during cloud cover. Constant monitoring of the land mass is provided by a suitable sensor on a geostationary platform (F). It provides unique opportunity for measurement at different sun angles and greatly increases probability of getting cloud-free images. Meteorological observations would require a different set of sensors (G).

Table 19. A possible earth observation system configuration.

	A	*B*	*C*	*D*	*E*	*F*	*G*
Coverage/ Swath	1000-2500km	150-750km	25-75km	25-75km	150-300km	–	Multifrequency microwave radiometer, Altimeter, Scatterometer, Atmospheric Sounders. Sensor package+
Spatial Res.	150-250m	15-25m	5-8m	1-2m	20-40m	500m	
Repetivity	2 days	4-6 days	8-12 days viewing from diff-erent angles	Fore-aft stereo		Geo-stationary platform	
Spectral bands	VIS (3) NIR (2) MIR (2) TIR (2) 3-4 μm Narrow bands. Selectable gain settings	VIS (3) NIR (2) MIR (2)	Specific narrow bands	Panchro-matic	C, X, Ku HH, VV 45°, 20°	VIS, NIR, MIR and TIR, sensor package+	
Radiometric resolution	7/10	7	8		1 db		

+ sensors for characterisation of the atmosphere

Besides the systems suggested in Table 19, there are some additional requirements. While utility of P-band SAR data is recognized there are certain stringent requirements on the kind of platform required. Synthetic aperture altimeter for elevation determination may also be examined and considered. In order to get minimum of 0.5 per cent reflectance changes seen in the images, it is necessary to have 8 bit radiometric resolution. Radiometric resolution vis-a-vis spatial resolution needs to be examined from the applications point of view both at very fine spatial resolution of a couple of metres and at moderate resolution. Simulation studies in this respect need to be taken up. Depending upon the dynamic range as seen in the scene, adaptive quantisation should be incorporated in the onboard processor. For attaining better geometric accuracies GPS receiver onboard with a network of GPS stations at precisely known ground points will be required.

Regional monitoring of crops, detection of crop stress, crop discrimination, forest mapping, detection of forest fires etc. can be operationalized with WiFS having high repetivity. However, a sensor system for mapping soils at various categoric level is a issue of concern for many application scientists. Combination of sensors and the repetivity requirements may call for using orbits other than polar. An imaging spectrometer will be required for applications which include identification of species composition and canopy structure in forests, crop species identification, crop disease and nutrient stress etc. Such sensors may use array detectors. Besides these requirements, the need for absolute calibration of sensors and a sensor package for atmospheric correction is acutely felt. It needs to be defined in greater detail in terms of spectral channels etc. It should be integrated into the sensor system. Onboard processing should become an essential component.

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ANNEXURE-I

QUESTIONNAIRE FOR USERS' FEEDBACK TO ASSESS OPTIMUM SENSOR PARAMETER NEEDS SURVEY AND ANALYSIS

Purpose

Satellite remote sensing for resource survey initiated with the launch of LANDSAT-1 in the year 1972, has witnessed many changes, in the last two decades, in terms of availability of data of different resolutions, spectral bands, repeat cycles etc. There are many missions planned in the near future offering data of different dimensions. Large number of users in the country have used LANDSAT, SPOT and IRS data to meet their application needs. At this juncture, it is worth-while to assess the data needs existing, gaps and operational constraints in meeting all data needs for resource exploration. One way to obtain this information was to ask the Indian remote sensing community to spell out their application needs realized/realizable vis-a-vis sensor parameter(s) in a quantitative fashion. A survey was conducted on behalf of the Indian Society of Remote Sensing (ISRS) in September, 1994 to realize this. The broad objectives of this exercise were (a) to obtain feedback from Indian remote sensing community on effectiveness of presently available remote sensing data in meeting various application needs, (b) to assess the shortcomings in remote sensing data parameters to meet challenges, current and near future, in remote sensing applications and (c) to translate feed-back received from remote sensing data users, towards definition and design of future remote sensing missions.

Structure of the questionnaire

The questionnaire was designed keeping in view that a) it should involve minimum effort on part of the respondent