

# PRASANTHA CHANDRA MAHALANOBIS MEDAL AWARD LECTURE—1987

## REMOTE SENSING FROM SPACE

U R RAO FNA

*Chairman, Space Commission & Secretary, Department of Space,  
Cauvery Bhavan, K G Road, Bangalore-560 009, India*

*(Delivered 6 January 1988)*

I AM extremely grateful to the Indian National Science Academy for the award of the coveted *Prasantha Chandra Mahalanobis Medal* for the year 1987.

It is indeed a great honour to join the list of illustrious names of scientists who have received this medal in the preceding years. I consider this Award a recognition of the work carried out by all of my colleagues and myself in the Indian Space Research Organisation which has been providing the main thrust in establishing a self-reliant technology base and promoting application of space technology for the developments of our nation. In this talk, I propose to restrict myself to the status and potential of application of space remote sensing technology in the management of natural resources and the resulting direct benefits that accrue to the nation.

### INTRODUCTION

In just about three decades, since the dawn of the space age, space sciences and technology have virtually revolutionised the global communication system, enabled us to keep a close weather watch and have provided a unique solution to the conservation, monitoring and management of our natural resources. The promise of space regarding its ability to both directly and indirectly contribute to the improvement of human life style, to make life fuller, wider, healthier and richer in comforts has, in this short period, become an achievable reality. The potential applications of space technology particularly for improving the conditions in developing countries, which are burdened with large population density, low yield, unchecked deforestation, increasing wasteland and desertification, over-dependence on unpredictable rainfall, combined with frequently recurring natural disasters such as drought and flood, is practically unmatched. A totally new dimension which space has opened up, for the first time, has in essence reduced the world into a single global village with instantaneous communications and its ability to monitor and shape the global environment as a whole.

The unique advantages of space technology for obtaining systematic, rapid and repetitive coverage over large areas in a timely manner, for meeting growing communication and educational needs of even the remotest corners of the world in a

flexible and cost effective manner, and for carrying out material processing activities under the zero gravity space environment in suitable space platform have made it a prime catalyst for achieving dramatic transformation of human society.

### PRINCIPLES OF REMOTE SENSING

Remote sensing from space is fundamentally dependent on the reflected, scattered or emitted radiation received from different objects, areas or phenomena on the earth. While for most purposes sun is the prime source of radiation, in active remote sensing artificial sources such as lasers or radars housed in the spacecraft could also be employed in the spectral regions where signal to noise ratio using natural emission is marginal. The opacity of the atmosphere essentially restricts the remote sensing activity to a few transparent bands of the electromagnetic spectrum in the ultraviolet from  $0.35\mu\text{m}$  to  $0.5\mu\text{m}$ , in the visible  $0.4\mu$  to  $0.7\mu$ , in the infrared from  $0.7\mu\text{m}$  to  $2.5\mu\text{m}$ ,  $3$  to  $5\mu\text{m}$ ,  $8$ – $15\mu\text{m}$  and in the microwave region from  $1\text{mm}$  ( $1000\mu\text{m}$ ) to about  $1\text{m}$ . Information monitoring capability crucially depends on the spatial resolution that can be obtained in relation to the nature of information to be gathered. Whereas gross resolution of  $1\text{km}^2$  is good enough for looking at oceans, large water bodies, extended biomasses and meteorological phenomena, resolutions of  $30\text{m}$  or better are required for applications such as digital classification of forestry, agriculture crop monitoring, wasteland classification drought monitoring. Present day satellites are able to take imageries typically with a resolution of  $10$ – $30$  metres. Whereas ground measurements and limited aircraft surveys can provide imageries with a resolution of a metre or better, the cost per square km of coverage with a satellite is only about 16 paise as against Rs. 13 for aerial remote sensing. Further, an entire country like India can be covered by a satellite in just a period of  $15$ – $20$  days using a satellite, whereas it will require years to cover the same area with aerial remote sensing. Coverage cycle time obviously depends on the swath width of imaging scenery during each pass which decreases with higher resolution. It is evident that each system needs to be optimised for particular applications, since swath width and resolution requirements are contradictory requiring a compromise between these two parameters to obtain maximal benefit from space remote sensing.

Multispectral imaging provides a new dimension in resource monitoring through its ability for unique identification of targets by intercomparison of reflectivity in different spectral bands and using techniques such as band rationing. The reflectivity from water, for example, in infrared is practically nonexistent unlike in the visible thus permitting unique identification of water resources from other land-based canopy through a comparison of their reflectivities in visible and infrared. Whereas frequent repetitive measurements of reflectivity are essential particularly for monitoring transient or short duration phenomena such as agricultural crops, flood mapping, snow features and drought monitoring, semipermanent features such as mineral exploration, soil classification and gross monitoring of forestry need to be sensed at less frequent intervals characteristically once in about two years. The advent of active microwave remote sensing has provided another

quantum jump in remote sensing capability due to its ability to critically look at ocean resources and more importantly due to its imperviousness to cloud cover thus adding all weather capability to remote sensing.

Rapid advances in computer technology and computing power has played a crucial role in the development of remote sensing as a whole. The data rates which were hardly a few mega bits/second a few years ago are now being stretched to almost 100m bits/second and beyond thus providing the basic capability to go in for improved resolution through sophisticated and fast onboard processors. The enormous computing power on the ground, likewise, can now process the space derived information quickly and obtain requisite data products for enabling remote sensing scientists to interpret with a quick turn around time, essential for many important applications dealing with short time phenomena such as agricultural monitoring, disaster forecast and disaster management situations. Onboard processing to further cut down the turn around time is right round the corner. Space remote sensing combined with aerial, ground and sea truths has thus already become an invaluable tool in resource survey, providing for the first time, a powerful new technique for not only resource planning and monitoring but also for effective management including disaster management.

#### EARLY EXPERIMENTS IN REMOTE SENSING

Remote sensing experiments in ISRO began in the late 60's with aerial survey using multi-data instrumented aircrafts carrying a variety of sensors including infrared scanners, multispectral scanners and radiometers, for selective monitoring of crops such as coconut plantation in Kerala, sugarcane in Mandya for crop yield and pest disease estimates. Extensive aerial surveys backed up by ground truth measurements were also carried out for soil studies including their salinity and alkalinity and for land-use studies in Ananthapur, Patiala and other selected areas. Water pollution studies of the Godavari river and a number of lakes caused by anthropogenic industrial activities, deforestation leading to silting of reservoirs are some of the other major studies conducted using aerial photography. The establishment of the LANDSAT receiving station at NRSA, Hyderabad in 1977 was a major step taken by ISRO in the use of satellite based remote sensing which provided scientists from ISRO and other user agencies an opportunity to gain valuable Experience in the interpretation and analysis of space based data. Envisaging the need for the parallel development of our own space segment and following the successful launch of Aryabhata in 1975, Bhaskara 1 and 2 satellites incorporating a two band TV camera system one in the visible and the other in the near infrared along with a 3 frequency passive microwave radiometer system were launched in 1979 and 1981 respectively to carry out remote sensing on an experimental basis. Whereas microwave data were primarily used for studying ocean related aspects, the TV imageries, in spite of their limited resolution of about 1km<sup>2</sup> were usefully employed for studying resources related to forestry, hydrology, large water and land masses. These imageries have been utilised to study the changing pattern of snow cover over the Himalayas and their run off with time. With imageries taken

over Beas and Sutlej valley, it was possible to identify snow cover, agricultural land and forested areas, Study of geological features in Bihar and Karnataka regions and in the Deccan trap region have assisted in delineating rock types and larger features of schist belts. Further, by suitable colour coding of the gray levels, it has been possible to distinguish fallow land from agricultural land and tropical moist deciduous forest from dry temperate forests. The imageries obtained over the Cambay region and the Sunderbans in Bengal provide significant information on the extent of silting in the coastal ocean area.

In order to achieve self-reliance and to establish the continued availability of space imageries for optimal applications in the Indian context, the Department of Space took the decision to design, fabricate and launch its own operational remote sensing satellites. IRS 1A is the first of the series of operational remote sensing satellites which is scheduled for launch in the beginning of 1988. IRS 1A carries two sets of cameras, one having a resolution of 72m and the other set of high resolution cameras having a resolution of 36m in four spectral bands. The spacecraft which will be launched into a polar sun synchronous orbit at an altitude of 904km will take continuous imageries using state of art Charge Coupled Device (CCD) cameras operating in a push broom mode with a swath width of 145km at the spacecraft passes over the Indian continent. The coverage of the entire country is accomplished in a 22day cycle, enabling us to take repetitive imageries over the same area with this turn around cycle time.

#### OPERATIONALISATION OF SPACE BASED REMOTE SENSING IN INDIA

In the meanwhile, utilising data from our own experimental satellites such as Bhaskara and the imageries taken by the Indian Cosmonaut, Rakesh Sharma along with the data being regularly received at the National Remote Sensing Agency of the Department of Space at Hyderabad from NOVA, LANDSAT and SPOT satellites, a large number of meaningful and important applications of relevance to the development of nation have already been operationalised on a nationwide scale. The first important application of remote sensing has been in the regular monitoring of the nation's forest wealth. Over the years 1972-75 to 1980-82, space remote sensing clearly indicates that the area under the closed forest has decreased from 14.12 to 10.88 per cent over this period, amounting to a decrease of about 1.1 million sq km of closed forest area. The aggregate of closed and open forest as existing today is only 19.5 per cent which needs to be systematically enhanced to at least 25 per cent of total area of the country. The forest mapping has now been fully operationalised along with the Department of Forests, to monitor the forest cover, on a biannual basis to enable us to monitor the status at regional and subregional levels.

Space imageries are now extensively being used, on a real time basis, for monitoring surface water resources including input to water budget from snow melt. Snow melt run off predictions using satellite imagery match the estimates based on the conventional measurements to better than 3 per cent. Flood mapping is being

effectively carried out, on a real time basis, using space imageries. More importantly monitoring of surface water as a function of time along with vegetation index is being used as an important input for drought monitoring and assessment. Realising that the surface water index is a convoluted product of rain precipitation and evaporation, the importance of surface water as an early warning indicator of drought is obvious.

Recognising the importance of efficient and optimal management of soil, space technology is being extensively used for soil mapping and soil classification. In order to support the large and growing population of the country, it is extremely important to monitor and check the alarming situation arising out of the increasing wasteland, which now covers over 20 per cent of our country, primarily due to ravines, gullies, degraded forests due to deforestation, increased salinity of the soil resulting from large scale use of fertilisers on irrigated land without adequate drainage. First task is clearly to identify the extent and type of wasteland at village level prior to adopting applicable reclamation measures. In cooperation with the National Wasteland Board, countrywide wasteland map is being prepared on 1 : 50,000 scale. As a first step, space imageries have been used to delineate 13 types of wasteland at village level for over 185 selected districts in the country, which are acutely affected by wasteland spread.

Another important area where space technology has been operationally used is in underground water targetting and in finding drinking water, the most essential ingredient of life. Using geomorphological features as seen from space as a guide, areas with high, medium and low potential of finding underground aquifers, capable of being tapped have been delineated in many drought prone States such as Rajasthan, Gujarat, Maharashtra, Karnataka, major parts of UP and Tamil Nadu. The experience indicates that the percentage success of water divining using space imageries together with ground based investigation have increased to about 90 per cent as against 40-50 per cent success obtained using ground measurements alone. Additionally the search time has been reduced by almost a factor of ten.

In the area of mineral exploration, along with the Department of Mines, survey of the entire South India has been taken up under the Vasundara Mission. The results already obtained have identified new areas of likely base metal deposits based on the comparison with the geomorphological features in known mineral deposit areas. Further detailed ground exploration in the new areas can lead to mineable deposits of mineralisation of such new minerals.

Detailed analysis and interpretation of space imageries are being extensively used for watershed management (Idduki, Narmada), environment monitoring (Kanha, Corbett National Parks), ocean resources monitoring, coast line survey including coastal erosion, water quality monitoring (sedimentation etc) and various other applications. An innovative use of space has been the identification and detailed characterisation of area around Bombay for rehabilitation of Dharavi slum carried out by the Department of Space at the request of Maharashtra Government. Likewise, space is being extensively used to monitor land usage and urban planning including growth of major cities.

In the field of agriculture, which is of crucial importance to a country like India, space remote sensing can provide unique inputs with its capability to identify different crops, distinguish between healthy and diseased crops and in providing reasonably accurate estimates of acreage and yield of various crops. It is only through extensive use of space imagery one can obtain timely inputs on all these crucial aspects needed for planning and distribution strategies. Agricultural mission in cooperation with the Department of Agriculture being taken up will hopefully enable us to derive basic quantitative information on major crops of the country in the next two to three years.

Early warning of drought, monitoring and management are of fundamental importance for a country like India, where on an average one in five years happens to be a severe drought year. When drought occurs in successive years, its impact on human life and livestock becomes almost catastrophic. It is clear that unless systematic and scientific short and long term measures are adopted as a part of national planning, recurring drought and flood situations will cause untold misery. Evolution of a meaningful integrated planning, integrating space-based information with conventional ground-based information and meteorological inputs can provide the best answer for dealing with drought situation. Whereas underground water potential is being continuously tapped both for irrigation and drinking water supply, the progressively sinking water table needs to be reinforced with adequate ground water charging mechanisms to ensure continuous supply of water. Space imageries can provide early warning of drought through the monitoring of vegetation and surface water index, the former indicative of agricultural drought and the latter of hydrological drought. Combined with actual meteorological inputs and space based information on land use, soil conservation, underground water potential, wasteland delineation and forest cover mapping, it is possible to evolve an integrated plan at each district level, identifying areas of ground water recharge and appropriate recharging mechanisms, type of crops to be grown in each area optimising the available resources, identification of areas which need upgradation of land by afforestation and fodder growth to arrest further soil erosion and wasteland reclamation measures. The integrated plan being of semi-permanent and long term nature, its actual implementation can be taken up in a progressive manner depending on the availability of resources to minimise the impact of severe drought on human life style.

Meteorological input being the basic input required for any agro-meteorological economy, accurate meteorological prediction becomes vital for a country like India. The unique multipurpose satellite system INSAT, for the first time, is able to provide real time global meteorological inputs over the entire Indian continent. In addition to the half-hourly meteorological imageries both in the visible and the infrared, our unique multipurpose geostationary satellite INSAT is also used as a data collection platform for receiving and retransmitting vital meteorological parameters from unattended ground-based meteorological platforms located in inaccessible areas. Over hundred data collection platforms have already been deployed and many more will be deployed in due course in critical areas such as

Yamuna catchment area which will also assist in flood level monitoring. Another novel feature of INSAT system has been the successful deployment of hundred disaster warning sets along the east coast of the country, which through INSAT selectively transmits locale specific early warning information on impending disasters such as cyclones and hurricanes to enable the planners to take appropriate remedial actions in a timely manner.

Extensive utilisation of remote sensing for resource survey requires trained manpower and availability of low cost interpretative systems. Through the efforts of the Department of Space, a large number specifically designed training courses for different disciplines such as agriculture, town planning, water resources, forestry, geology etc are being regularly given at the Indian Institute of Remote Sensing at Dehra Dun and other ISRO/DOS centres to train about 250 remote sensing specialists every year. Indian space effort has also consciously sought to involve Indian industry in its programme for manufacturing low cost image analysis equipment based on the technology developed by the Department of Space. The sale value of the products including the PC based digital analysis systems already exceeds Rs. 2 crores in less then 2-3 years.

#### FUTURE DIRECTIONS

IRS 1A is the first of the series of operational remote sensing satellites which will be followed by future remote sensing spacecrafts at an interval of 2-3 years to provide continuity and assured space services. The future IRS spacecrafts will have progressively improved resolution, possibly going to 10-20m and data handling capability in the range of  $\sim 100$ m bits/second. Establishment of the National Natural Resources Management System (NNRMS) in 1985 with five major Regional Remote Sensing Service Centres (RRSSC) is an important step in the operationalisation of remote sensing services in the country. RRSSC's at Bangalore and Dehra Dun have already become operational, and the remaining ones at Jodhpur, Nagpur and Kharagpur will become operational in the next few months. These service centres established in cooperation with other Departments such as Department of Science & Technology, Department of Mines and Department of Agriculture together with the associate centres being established at Lucknow and in Tamil Nadu, under the overall direction of the Department of Space as nodal agency, will provide a new dimension to our data handling and interpretation capability and ensure total utilisation of remote sensing services. The active involvement of various governmental departments and also State Remote Sensing Centres which have been established individually by a large number of States with medium computing power facilities is a significant development under NNRMS system, which will ensure full exploitation of this new science for national resource management.

Stereo images have a distinct advantage particularly in delineating geomorphological features of the earth's surface. A significant step in this direction has been taken by the Indian Space Research Organisation in deciding to fly a novel

experimental payload carrying the monocular electrooptical stereo scanner (MEOSS) in collaboration with DFVLR, the German Space Agency on the second SROSS satellite to be launched from India using ASLV, during March/April 1988. MEOSS, a single optical and single spectral band camera, employs CCD's working in push broom mode mounted perpendicular to the flight direction on a common focal plane. Near simultaneous images at an angle of 23° forward and backward along with the nadir images under constant illumination conditions, provide stereo capability. MEOSS, could well become a forerunner of stereo imaging system of the future.

Remote sensing in thermal infrared and microwave regions of the electromagnetic spectrum are particularly important for ocean survey studies, ocean temperature and wave height measurements. Passive microwave sensing using radiometers at 19, 23 and 31GHz were conducted on Bhaskara which were able to provide a significant information on ocean surface temperatures and turbulence. Active microwave sensing with powerful synthetic aperture radars show a great promise for both land and ocean based resource surveys and most importantly, being unaffected by cloud cover, can provide all weather capability for remote sensing. State-of-art technology does promise resolutions for these active devices comparable to optical remote sensing. Active microwave remote sensing being planned by ISRO for the mid 90's will include complementary payloads such as scatterometers, altimeters and passive radiometers in addition to the synthetic aperture radar enabling Indian scientists access to basic information related to both land and ocean resources. Parallely arrangements are being made to gain experience in this area through aerial flights and also to receive and experiment with data from ERS, the European microwave remote sensing satellite.

The future directions in remote sensing also include remote sensing in very narrow spectral bands in addition to improved resolution which will significantly aid in detection capability. The technology of optical instrumentation as well as the requirement of large volume of data transmission and considerable onboard processing requirement are some of the major hurdles which need to be solved for realising these objectives.

#### CONCLUSION

The potential of space remote sensing when combined with adequate ground and sea truths is practically unlimited for providing vital inputs into the various national resource sectors. The use of remote sensing for drought management is going to be the most important singular contribution to the developing world in addition to its inputs into both land and ocean based resources. Improved resolutions and techniques, as in any other branch of science, will enhance these capabilities considerably. Even though quantitative computation of cost benefit is difficult to compute due to the nature of its impact on a variety of sectors, the cost effectivity of using space remote sensing for the management of natural resources is firmly established.

TABLE I  
Resolution requirements for remote sensing

Resource	Spectral	Spatial	Temporal
<b>AGRICULTURE</b>			
● Crop	Visible/Near IR	30m	Fortnightly
● Soil Moisture	Microwave	500m	Fortnightly
● Drought	Visible/Near IR	1km	Weekly
<b>FORESTRY</b>			
● Forest Cover	Visible/Near IR	30-60m	2 Yearly
● Forest Types	Visible/Near IR	30m	Yearly
<b>GEOLOGY</b>			
● Ground Water	Visible/Thermal	30-60m	5 Yearly
<b>WATER RESOURCES</b>			
● Snow Cover	Visible	500m	Seasonal
● Flood	Visible/Microwave	30-60m	Near Real Time
<b>OCEAN</b>			
● Phytoplankton	Visible	500m	Daily
● Sea Surface Temperature	Thermal	500m	Daily
● Waves and Winds	Thermal/Microwave	500m	Daily

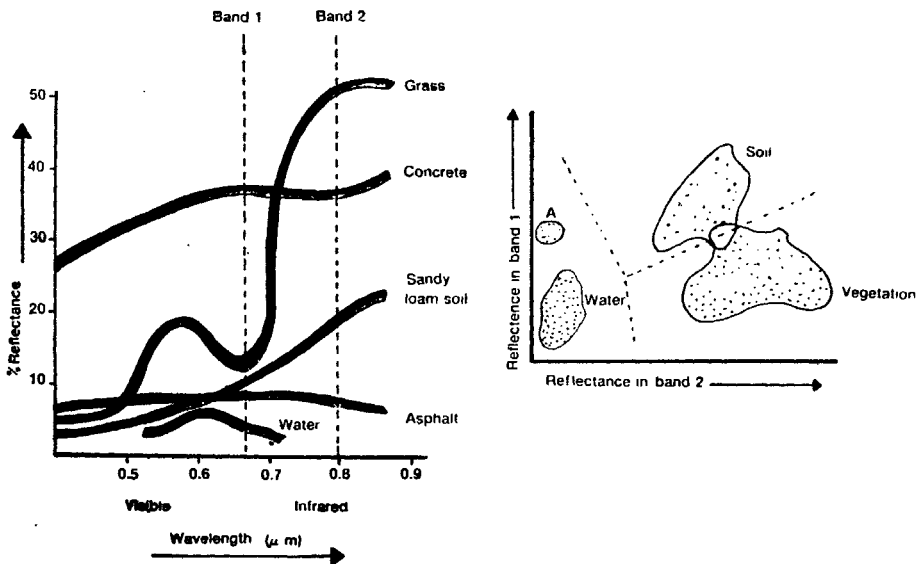


FIG 1 Spectral reflection/classification concept.

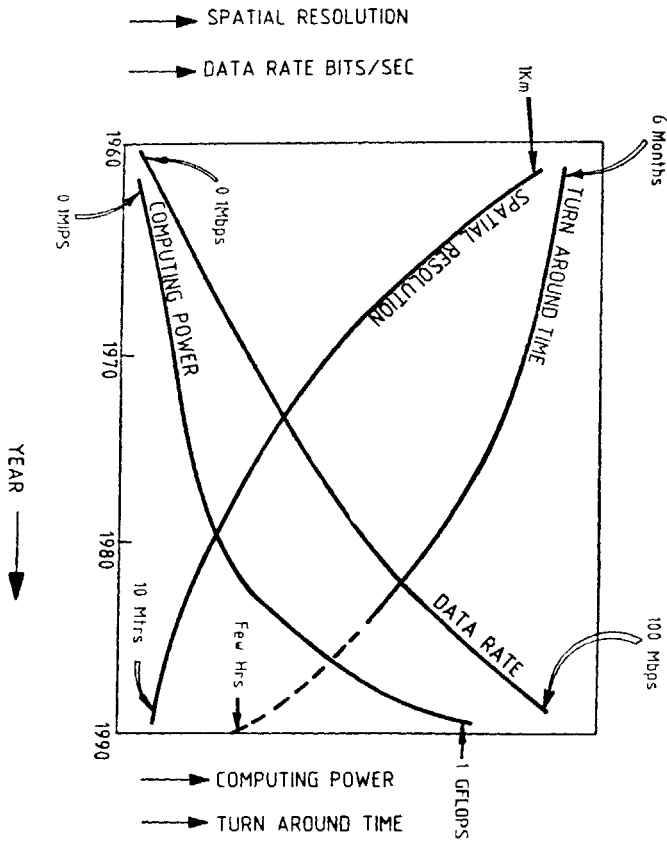


FIG 2 Evolution of data rates and spectral resolution in space remote sensing over the years.

TABLE II

*Spatial resolution for selected applications*

Object	Detection	Recognition	Identification
■ Bridge	6m	4.5m	1.5m
■ Vehicles	1.5m	0.6m	0.3m
■ Aircraft	4.5m	1.5m	0.9m
■ Ports	30m	15m	6m
■ Landing beaches	30m	4.5m	3m
■ Roads	9m	6m	1.8m
■ Town	60m	30m	3m
■ Village	40m	20m	3m
■ Agricultural plot	40m	20m	5m
■ Airfield	150m	90m	4.5m

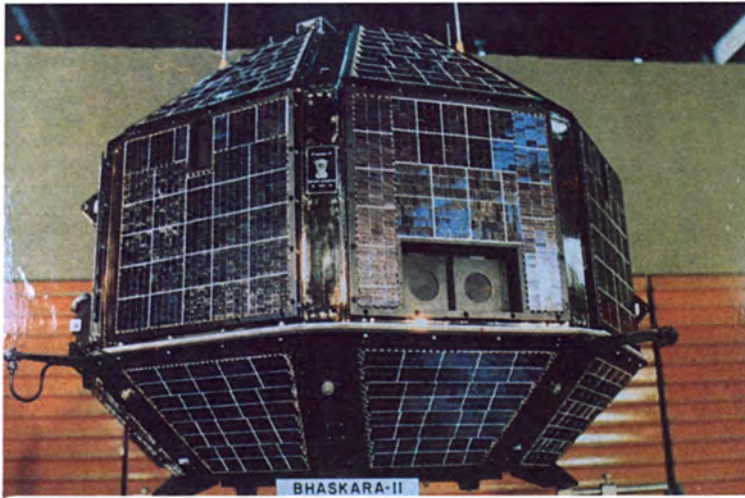


FIG 3 Bhaskara satellite launched in 1979, 1981.

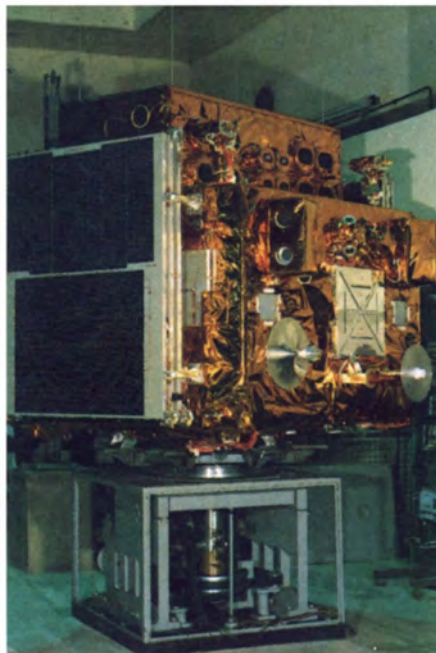


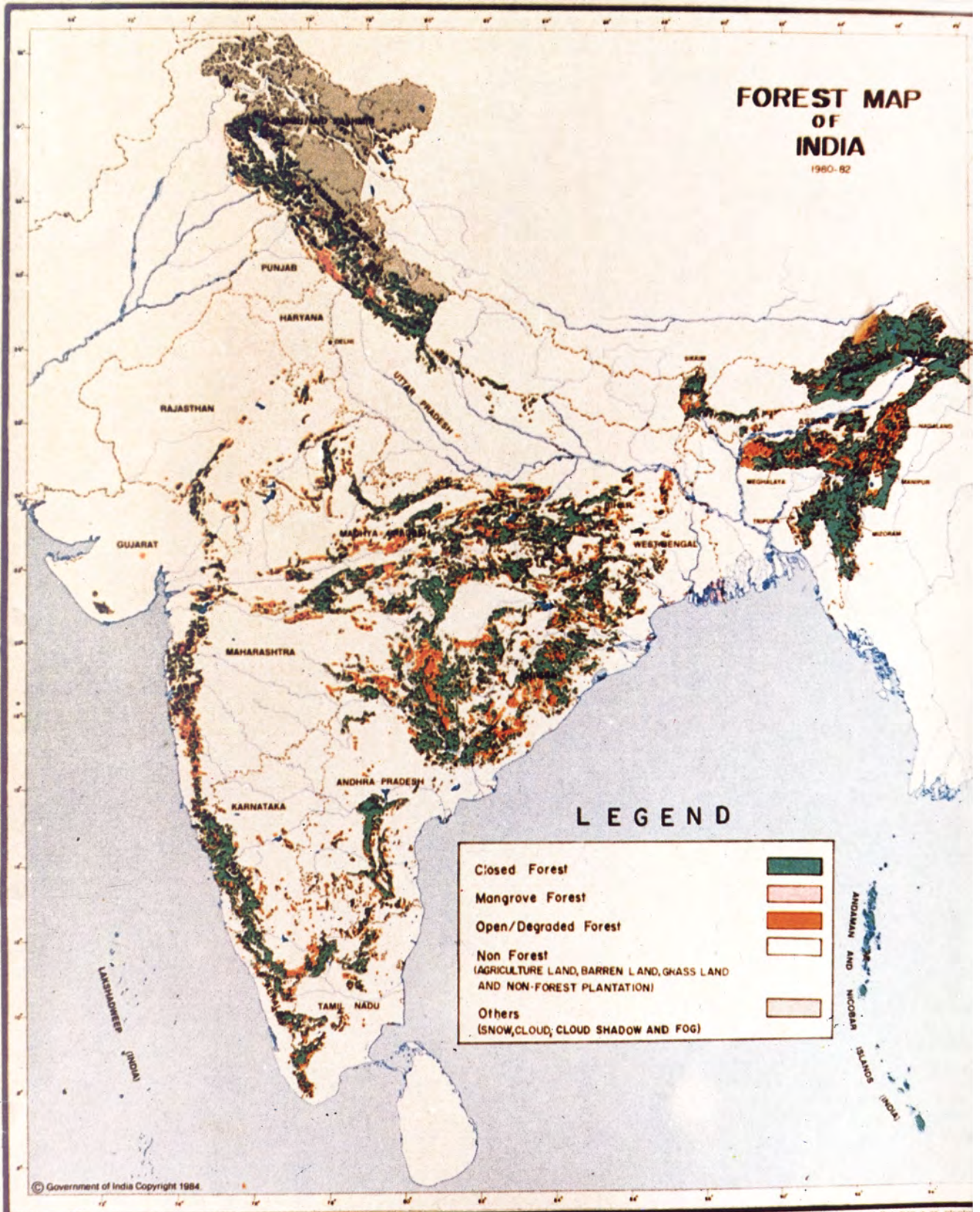
FIG 4 Indian Remote Sensing Satellite to be launched in 1988.








FIG 5 Forest cover over India during 1972-75.

# FOREST MAP OF INDIA

1980-82



**LEGEND**

Closed Forest	
Mangrove Forest	
Open/Degraded Forest	
Non Forest (AGRICULTURE LAND, BARREN LAND, GRASS LAND AND NON-FOREST PLANTATION)	
Others (SNOW, CLOUD, CLOUD SHADOW AND FOG)	

© Government of India Copyright 1984.

Based upon Survey of India map with the permission of the Surveyor General of India. The responsibility for the correctness of internal details rests with the publisher.

The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.

The boundary of Meghalaya shown on this map is as intended from the North Eastern Areas (Reorganisation) Act 1971 but yet to be verified.

Fig 6 Forest cover over India during 1980-82.

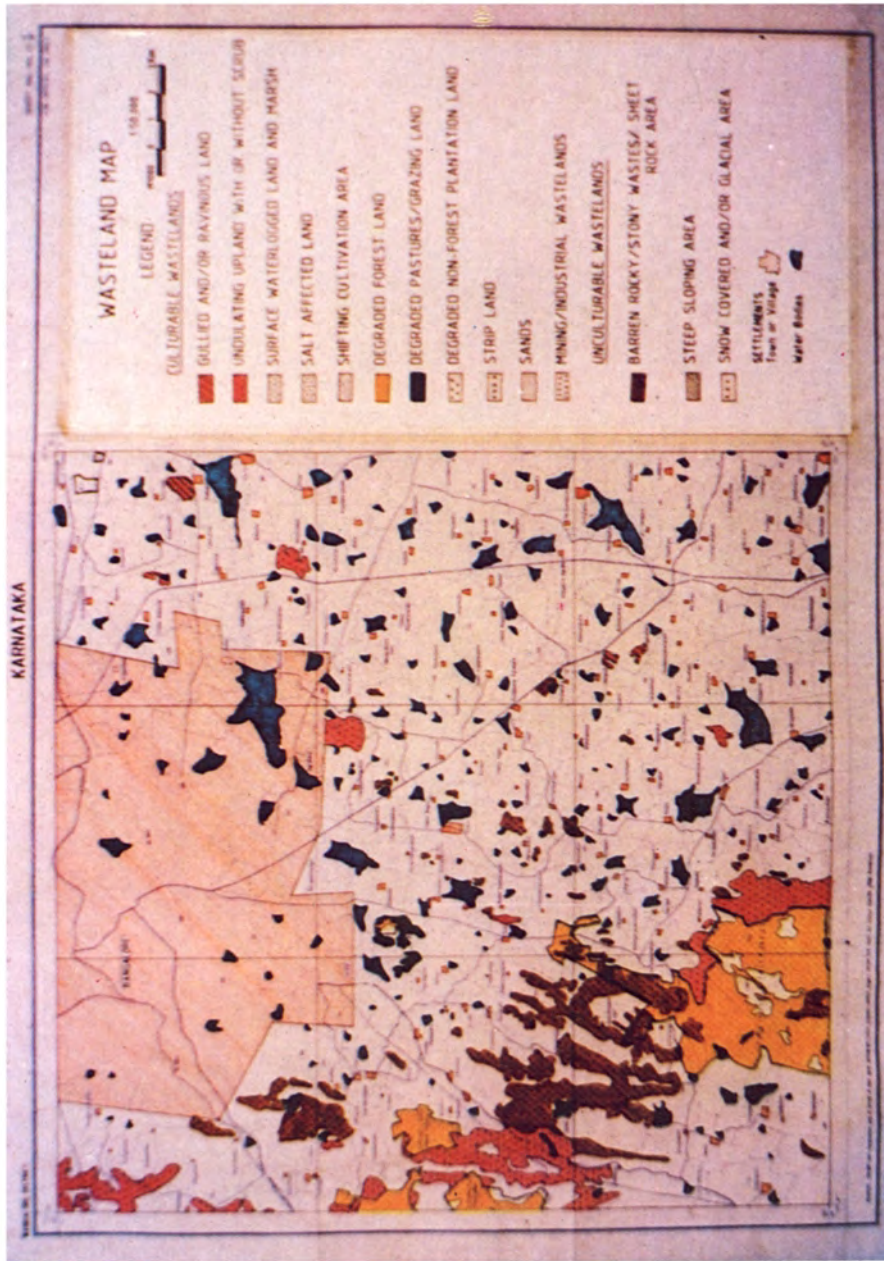


FIG 7 Thematic map showing wasteland classification in Bangalore district derived from LANDSAT imagery

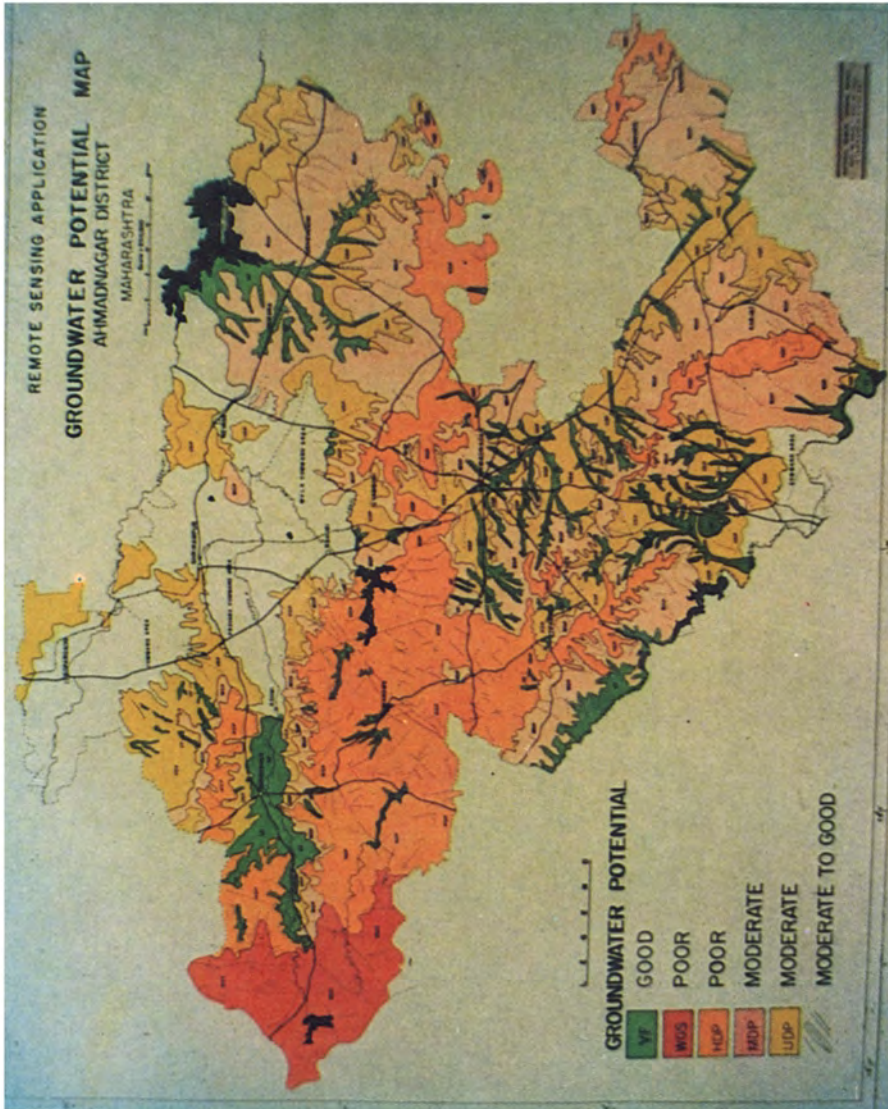


FIG 8 Thematic map showing underground water potential in Ahmednagar district, Maharashtra derived from LANDSAT imagery.

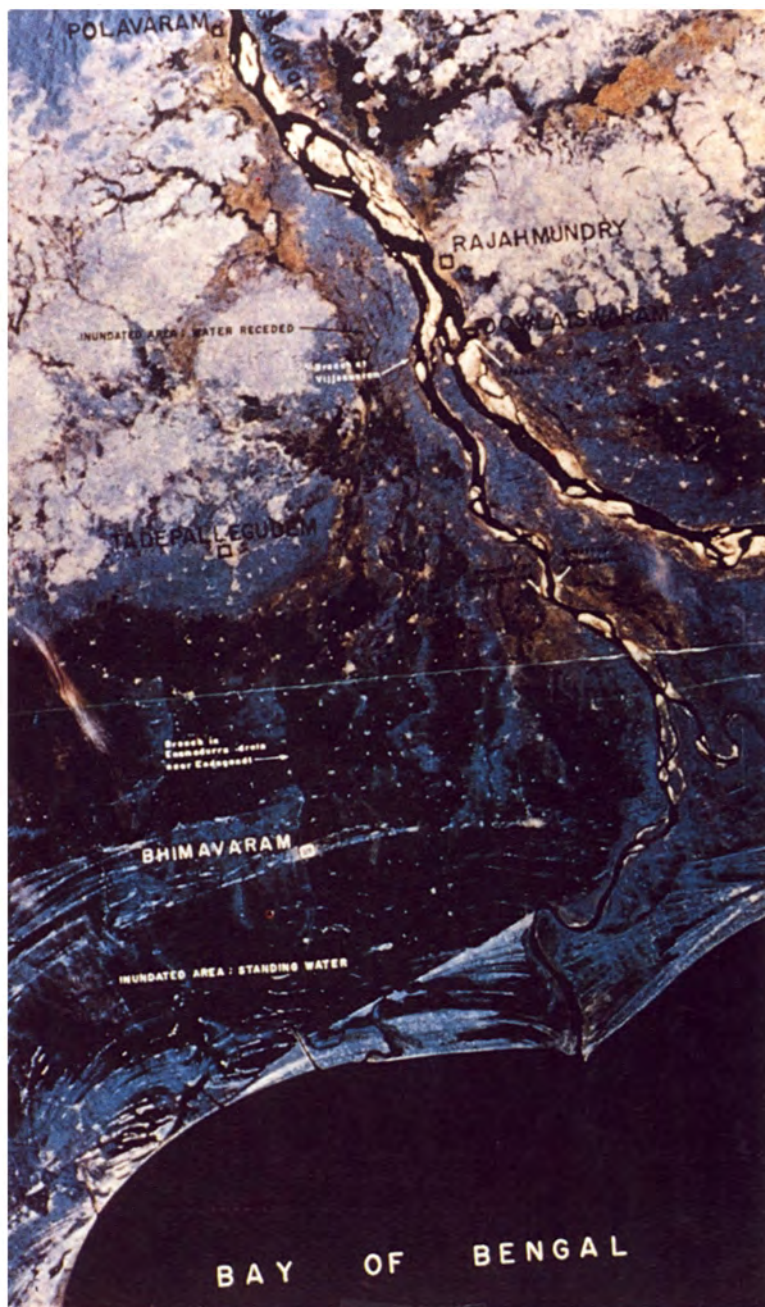


FIG 9 LANDSAT imagery over Godavari delta under flooded conditions. Blue and dark blue are inundated areas, containing marooned villages seen as white dots. Brown indicates the areas which were under flood, but where the water has receded after the floods at the time of taking imagery which was almost 10 days after the flood.

## AN INTEGRATED PLAN FOR DROUGHT MITIGATION

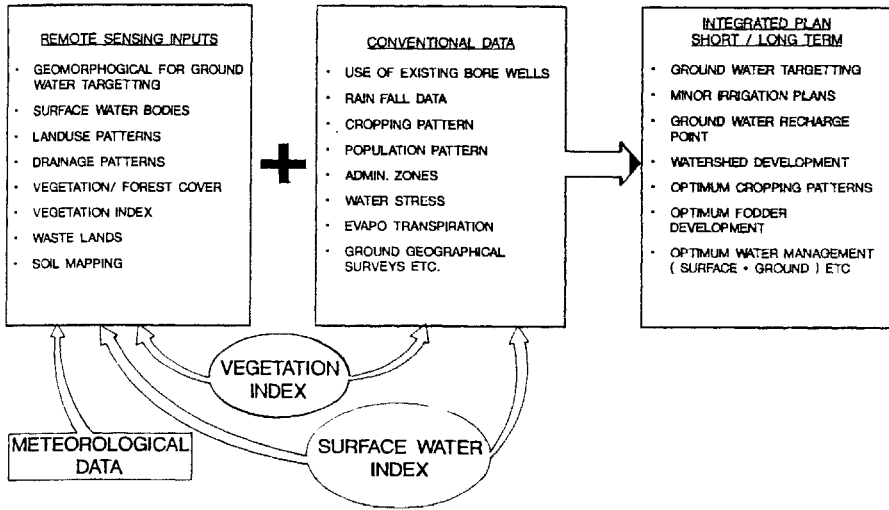


FIG 10 Concept of an integrated plan for drought management using space based remote sensing data and other information.

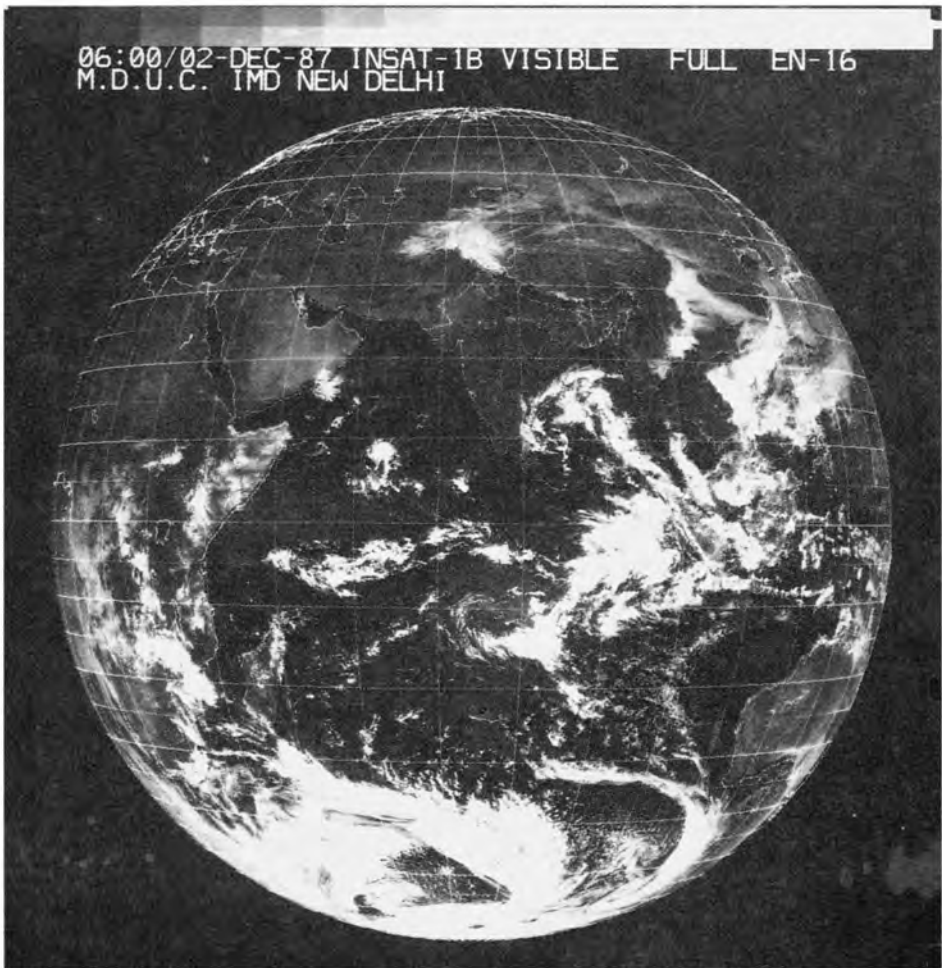


FIG 12 A typical full disc imagery of cloud cover over the Indian continent taken by the very high resolution radiometer onboard INSAT-1B.

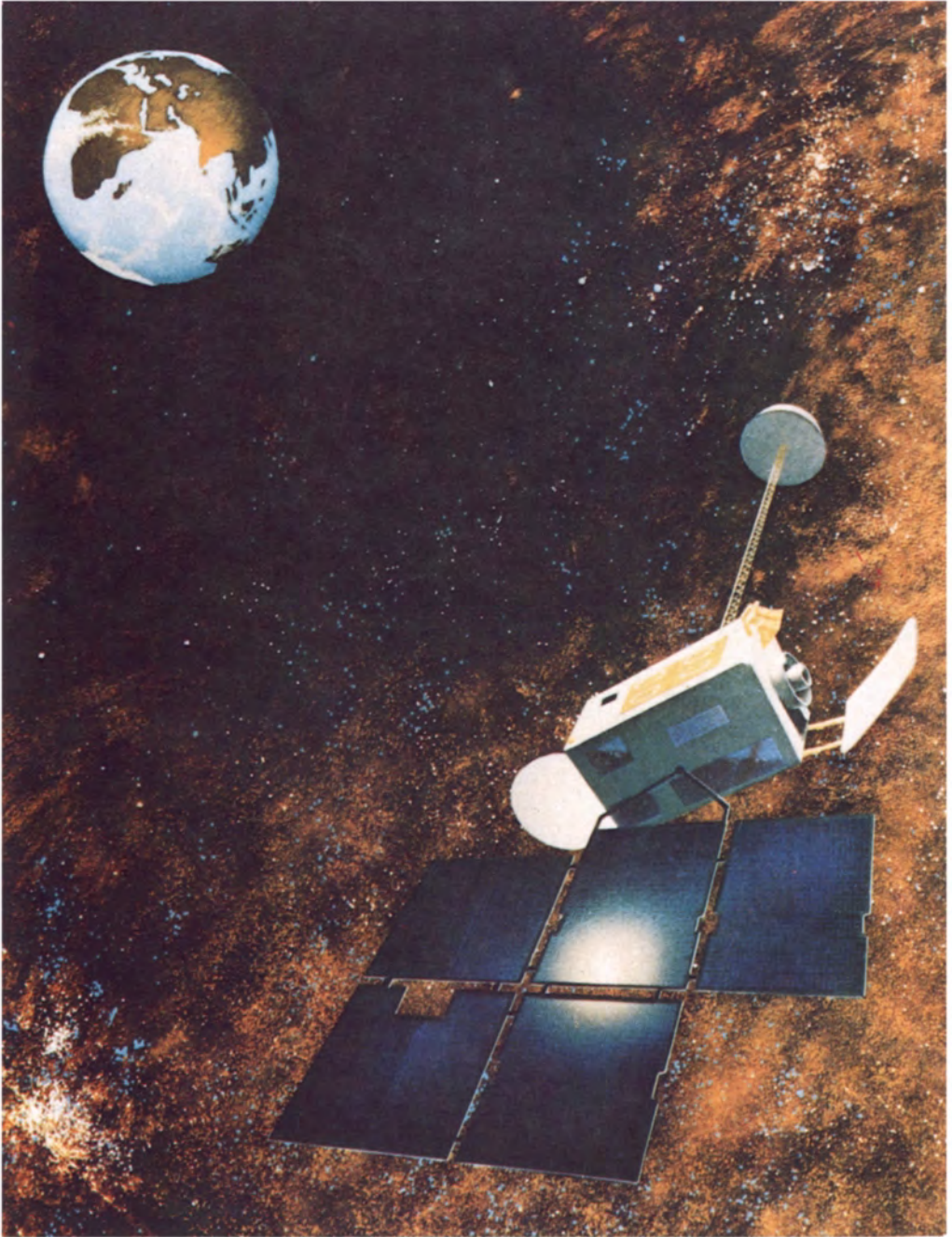


FIG 11 INSAT-1B Spacecraft.