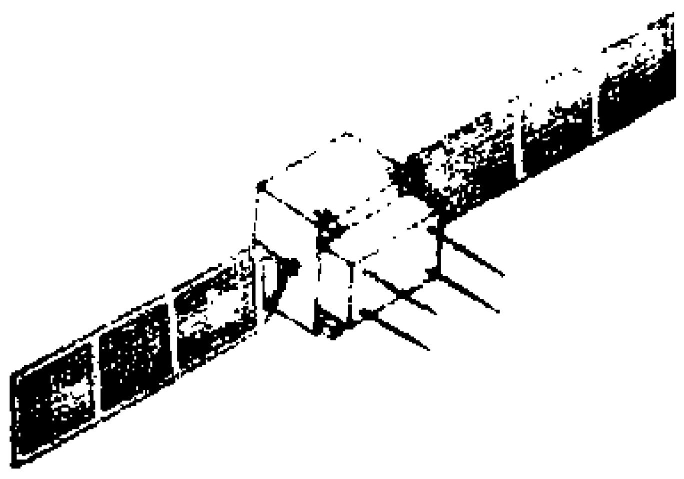

Special Issue on:
Remote Sensing for National Development

IRS Mission

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ABSTRACT: *Recognising the importance of satellite-based remote sensing systems for harnessing the natural resources of India, ISRO has undertaken the design and development of a series of Indian Remote Sensing Satellites (IRS) to provide remotely sensed data for applications in the areas of agriculture, hydrology, geology, drought and flood monitoring, marine studies, snow studies and land use. As a first step to this, IRS-1A, launched in 1988 has been operationalised and has become the central element in the national natural resources management system. This paper highlights the various considerations, that have gone into, in deciding the mission parameters, sensors choice, spacecraft main-frame system and ground segment. Further, it gives a brief account of the performance of IRS-1A system and the follow-on satellites in the IRS series.*

Introduction

Timely and accurate information on various natural resources, both renewable and non-renewable, is very important for the planned development of any country. For a country of India's size and population, the necessity of generating continuous and updated information on terrestrial resources and environment needs hardly any emphasis in this context. Such an information, among other things, should include aspects pertaining to meteorological, geological, geographical and ecological conditions. In this connection, a space-based earth observation system offers unique possibilities in its ability for synoptic and systematic acquisition of the related data and making available the same, with very short turn-around times to resource managers and planners.

Recognising the above considerations in the long term planning of the Indian space programme, realisation of operational capabilities in remote sensing using space platforms for the monitoring of earth resources and environment ranks high on the priority. Evolution of the related efforts over the last two decades included conduct of aerial flights, development of a variety of remote sensors, setting up of ground based data processing and interpretation hardware and carrying out specific end-to-end application experiments using aerial and satellite imagery in close co-ordination with a number of user agencies.

One of the major landmarks in these efforts is the planning and implementation of Bhaskara I and II experimental satellite programmes in the time-frame of 1976–1982. The Bhaskara programmes provided valuable experience and insight into a number of aspects, such as sensor system definition and development, conceptualisation and implementation of a space platform, ground-based data reception and processing, data interpretation and utilisation as well as issues relating to the integration of the remotely sensed data with the conventional data systems for resource management.

Consolidating the experience and expertise gained in the country to utilise remote sensing data for resource management and to develop various technologies to realise a satellite based remote sensing system, ISRO has taken the next step to go in for a national operational space-based remote sensing programme. This involves launching of a series of state-of-the-art remote sensing satellites and developing associated ground support systems including utilisation methodologies. IRS-1A (Figure 1) is the first in the series of such satellites to provide data on natural resources on a regular basis.

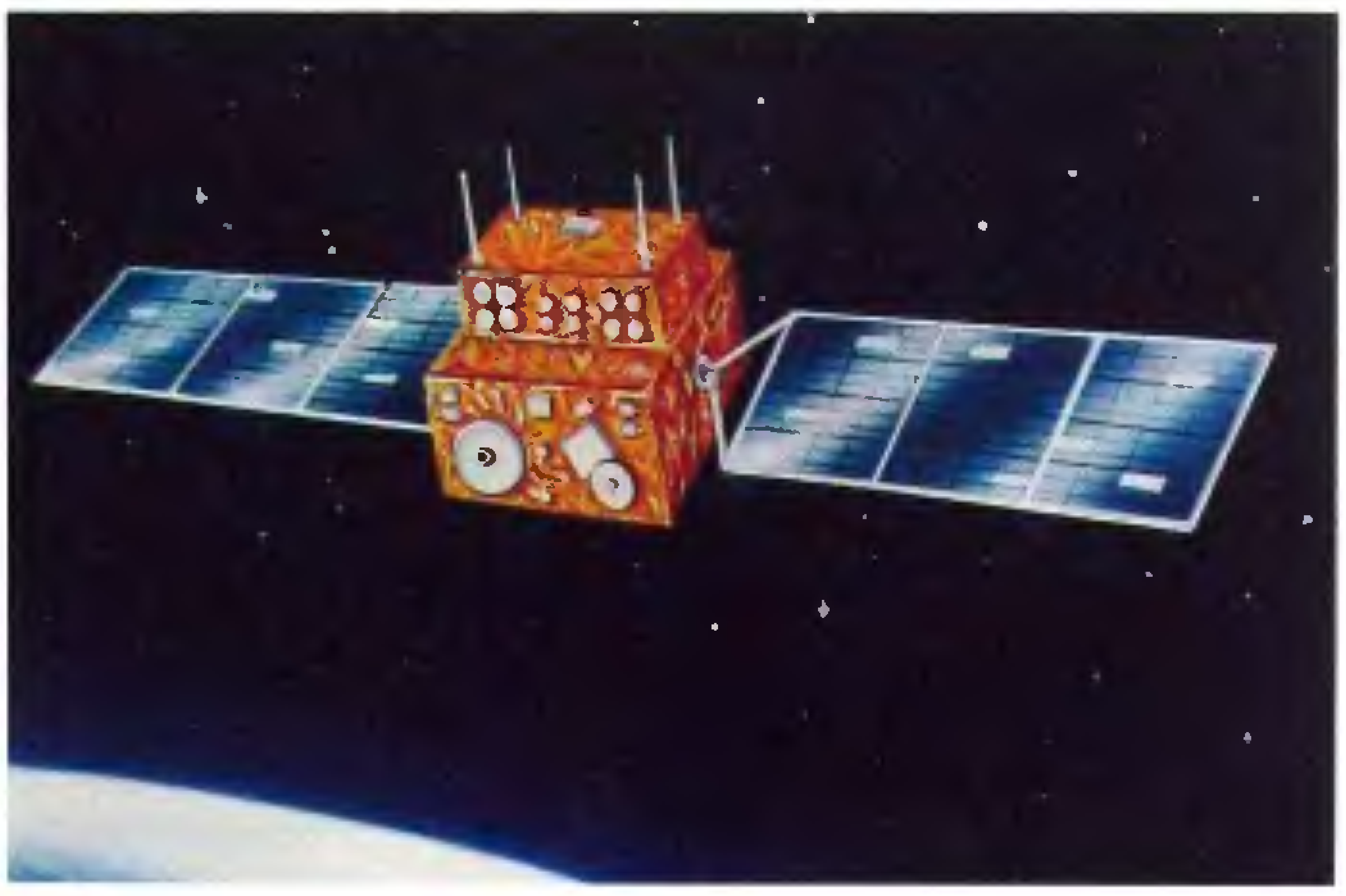

Figure 1. IRS-1A Spacecraft.

The principal components of IRS-1A mission are:

a) A three axis stabilised polar sun synchronous satellite with multi-spectral sensors.
b) Ground systems for the in-orbit satellite control including the tracking network with the associated supporting systems.
c) Data reception and processing system for the generation of user oriented data products and timely dissemination of the requisite type and quantum of data to the users.
d) Utilisation of the data in collaboration with user agencies in specific application disciplines.

Choice of key parameters for the mission

Any spacecraft mission can be broadly divided into two major segments, viz., Space segment and Ground segment. The objectives set forth for a remote sensing mission can be translated into a set of mission requirements which cover the areas related to the payload, orbit/attitude, satellite mainframe systems, launch vehicle, ground stations, spacecraft control centre, data reception, processing, archival and dissemination.

IRS mission envisages primarily to meet the specific Indian application needs in the areas of agriculture, hydrology and geology. Hence the basic mission characteristics like spectral bands and resolution, spatial and radiometric resolution, repetitivity and choice of local time have been arrived keeping these applications in view. Since only Indian needs are considered, a single data reception station in India has been planned to provide the required coverage. Maximum indigenisation in both hardware and software has been set as an important goal. The design life of the mission is set at three years. The data available from contemporary missions like SPOT and Landsat can additionally supplement that from IRS.

Selection of Payload and Sensor Parameters

It is well known that to increase the accuracy of interpretation, the information has to be collected in more than one spectral band. A number of studies and experience with Landsat data showed that 4 spectral bands covering visible and near infrared wavelength regions are adequate for most of the applications. Thus, the payload should have a multispectral imaging capability, with four spectral bands in the visible and near infrared region of the electro-magnetic spectrum. At the time of defining the IRS-1A Mission, opto-mechanical scanners like MSS/TM were the proven sensors for multispectral imaging from the spacecraft. Linear Imaging Self-scanning Sensor (LISS) using Charge Coupled Devices (CCDs) in the push-broom mode was flight tested in German Experimental Earth Observation Programme MOMS, flown onboard the shuttle, and LISS based camera was planned for the French operational satellite SPOT. Based on a careful comparative study between the opto-mechanical scanners and the LISS, it was decided to use solid state CCD cameras operating in the push-broom mode. This choice has the advantage of compact size, reduced data rate and higher reliability because of the absence of moving parts, lower power, higher geometric fidelity, etc. In addition, our study showed that future growth potential lies in LISS type of cameras. It was of course realised that the commercially available CCDs at that time had limited spectral response (0.4-1 micrometer) since the basic photon conversion takes place in a silicon photodiode. However, the decision was further dictated by the fact that the research and development programme was in an advanced stage to produce linear arrays operating in the different spectral wavelength regions of interest for Remote Sensing extending upto the Thermal Infrared. The various sensor parameters had to be chosen carefully to provide optimal information for various themes and the technical feasibility also had to be taken into account. Sensor parameters of importance include spatial resolution, spectral domain and bandwidth, radiometric sensitivity and temporal resolution.

Spatial Resolution

Spatial resolution is one of the most important parameters deciding the potential applications capability and the engineering complexity of the payload. A judicious choice of the resolution is essential, keeping both the above aspects. Experience of using Landsat data showed that 80 metre spatial resolution of MSS is adequate for agricultural applications in monocropped area. Such a resolution is adequate for many other applications, such as geology, hydrology, forestry and land use studies. However, an improved resolution has definite advantage for multiple cropped area and urban studies.

The requirements of the spatial resolution and repetitivity for different applications primarily intended in IRS utilisation are given in table 1. A spatial resolution of 35 to 70 metres satisfies the basic utilisation needs. Also, 35 to 70 metres spatial resolution typically represents the average size of the agricultural fields in the country which is about half an acre to one acre. This would also provide continuity to users already familiar with Landsat data. Resolution of 35 metres is provided for improvement in the information.

Table 1. Spatial resolution and repetitivity considerations

Agriculture	: 40–70 metres resolution.
	: Weekly/monthly repetitivity.
	: Soil classification needs seasonal considerations also.
Hydrology	: 40–100 metres resolution.
	: Soil moisture study for penetration beyond surface prefers microwave.
Geology	: 100–150 metres resolution.
	: Repetitivity can be monthly and more.
Coastal studies	: 100–150 metres resolution; sea food study needs 70–100 metres resolution.
	: Weekly/monthly repetitivity, for coastline delineation, yearly repetitivity sufficient.
Land use planning	: 80 metres resolution.
	: Yearly repetitivity.

Two imaging systems, one providing 70 metres resolution and the other providing 35 metres, but with the same swath was considered essential.

Spectral Resolution

In the spectral regime the important parameters to be considered are the location of the spectral bands in the electromagnetic spectrum and their bandwidths. In choosing the spectral bands, we should also ensure least correlation between them so that redundant data is not collected. Further, the atmospheric effects should be taken into account so as to minimise the atmospheric perturbations on the measured data. Narrow bandwidth consistent with engineering feasibility is preferred to avoid atmospheric absorption bands, and to maximise contrast. Based on a series of applications projects carried out along with the Indian users of remote sensing data, it was found that the best spectral bands to discriminate different classes were similar to the first four spectral bands of Thematic Mapper. The spectral bands finally chosen were:

a) 0.45–0.52 micrometre: has strong relationship between spectral reflectance in this region and plant pigment and has comparatively higher penetration in water. This band is useful for mapping suspended sediments/water quality and various studies related to coastal region.
b) 0.52–0.59 micrometre: centered around the first local maxima of the vegetation reflectance, useful for vegetation discrimination and the study of senescence rate of leaves. Also sensitive to ferric iron oxides.
c) 0.62–0.68 micrometre: centered around the chlorophyll absorption band of vegetation and, useful for identification of plant species. Greater soil contrast is found in this region. The upper end is limited to 0.68 to avoid the atmospheric absorption at 0.69 micrometre.
d) 0.77–0.86 micrometre: shows high reflectance for healthy vegetation and is useful for green biomass estimation and crop vigour studies. Water absorption in this region clearly demarcates land water boundary. The upper end is limited to 0.86 micrometre to avoid the broad water vapour absorption band centred around 0.92 micrometre. In addition, this also helps to improve the Modulation Transfer Function (MTF) of this band since CCD MTF falls fast as wavelength increases in the near infrared region.

Various combinations of these bands provide information for specific themes.

Table 2 gives the central wavelength and bandwidths of MSS, TM, SPOT and IRS. As seen from the table, IRS cameras have the highest spectral resolution in the green and near infrared

Table 2. Central wavelength and bandwidths of MSS, TM, SPOT and IRS (Figures in nanometres)

MSS		TM		SPOT-HRV(XS)		IRS LISS-I and II	
Cent-ral	Band width	Cent-ral	Band width	Cent-ral	Band width	Cent-ral	Band width
–	–	485	70	–	–	485	70
550	100	560	80	545	90	555	70
650	100	660	60	645	70	650	60
750	100	–	–	–	–	–	–
950	300	830	140	840	100	815	90
–	–	1650	200	–	–	–	–
–	–	11450	2100	–	–	–	–
–	–	2215	270	–	–	–	–

region and are free from most of the atmospheric absorption band. This is depicted in figure 2.

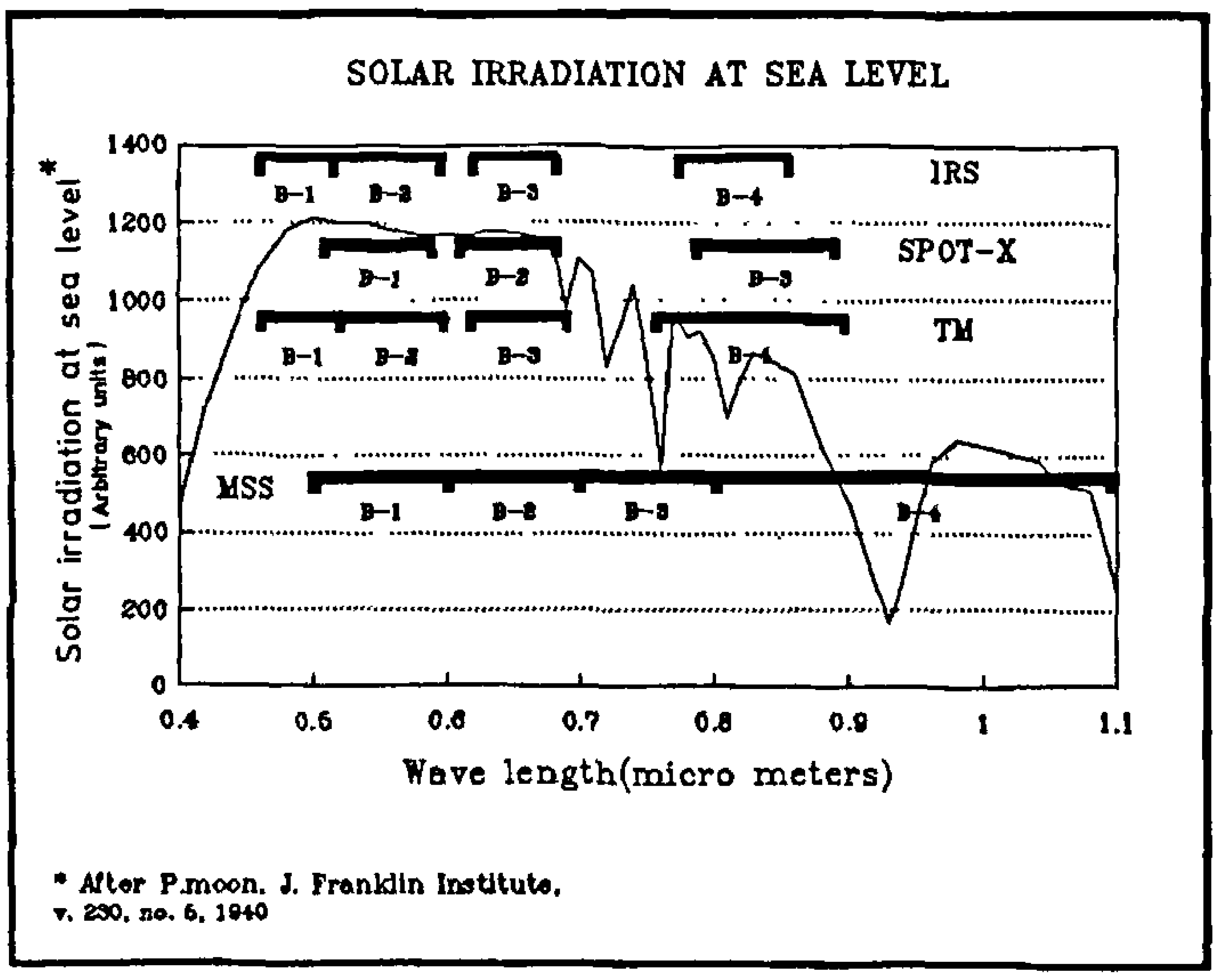

Figure 2. Spectral resolution of IRS cameras.

Temporal Resolution

The temporal resolution depends on the swath, the sidelap requirement and orbit characteristics. In the case of a LISS type camera, once the resolution is fixed, the swath is a product of the number of CCD elements and the pixel size. At the time of the initiation of the project, the arrays with maturity of production were limited to 2048 elements. Therefore in the case of LISS-I, the swath was limited to about 150 km. Since LISS-II has a better resolution, by a factor of two compared to LISS-I cameras, two LISS-II cameras were required to produce a swath similar to LISS-I. For IRS-1A the swath of 148 km, together with the suitable choice of orbit, enables repetitive coverage of the same area within a period of 22 days. Thus the two types of payloads employing LISS technique onboard IRS-1A have the following important features:

A camera (LISS-I) with a geometric resolution of 72.5 metres having spectral bands 0.45–0.52, 0.52–0.59, 0.62–0.68 and 0.77–0.86 micrometre and a swath of 148.48 km.

Two cameras (LISS-IIA & LISS-IIB) with a spatial resolution of 36.25 metres and operating in the same spectral bands as LISS-I with a swath of 74.24 km. The two LISS-II cameras provide a combined swath of 145.45 km allowing a 3 km overlap between them.

Radiometric Resolution

Radiometric resolution defines the least reflectance that should be measurable usually in digital form in the concerned spectral bands. The radiometric resolution requirement is primarily dictated by agricultural applications. A noise reflectance in the range of 0.25 per cent to 0.5 per cent is adequate for such applications. The number of quantisation levels to be adopted in the data conversion is decided by the maximum radiance value expected in the band and the noise equivalent reflectance. Under Joint Experiment Programme, the spectral limit of various crops under different irrigation conditions were observed during the corresponding crop cycle. It was found that 64 grey levels (6 bits quantisation data) cannot discriminate each of the crops under different irrigation conditions when compared to higher resolution data. Whereas, the potential improvement by going to higher resolution level like 256 levels (8 bit) adopted for Landsat-4, 5 and SPOT was not definitive owing to the effects of atmosphere and solar zenith angle variations. Hence, it is necessary to atleast provide 128 quantisation levels. Thus, 7 bit quantisation has been adopted for IRS missions for multi-spectral data.

Image Distortion and Registration

It will be necessary to provide requisite capabilities for registering the images as well as keeping those effects contributing to image distortion as minimal as possible. And it should be possible to overlay different band scenes taken from a particular camera over the same area at the same time in a repetitive cycle or over any two repetitive cycles. It should also be possible to overlay different band scenes taken from two different cameras on the same area at the same time. And it is required to correlate the band scenes with respect to the ground truth data, standard maps, etc., at various levels of application. In order to ensure that two image swaths corresponding to the same area, but taken over two different repetitivity cycles can be overlaid without any gaps, the across track drift between corresponding swaths of any repetitivity cycle should be less than 10 per cent of the swath width. This overlap should be maintained even under the presence of across track drifts arising from orbit decay as well as in the presence of attitude pointing errors.

Attitude Pointing Requirements

Pointing accuracies are derived from the basic requirement of improving the overall pixel registration capability as well as to ensure minimum swath displacement and thereby maintain the required overlap. The requirements are stringent to the effect that it should be possible to use the data quickly without applying detailed geometric corrections, if the need arises.

The pointing accuracies are specified for the three defined axes of the spacecraft, namely pitch, roll and yaw. Their effects on the imagery are shown in figure 3. Detailed analysis of the worst case deviation conditions and assessment of technical feasibilities led to the conclusion that a maximum deviation of 0.4 deg. in both roll and pitch and 0.5 deg. in yaw can be allowed. The attitude determination accuracy *post facto* was specified to be 0.1 deg. in roll and pitch and 0.2 deg. in yaw. The allowable distortions in the picture requires the specification of 3.0 E-04 deg/sec for pitch and a jitter value of 3.0 E-04 deg. on all axes.

Orbit Selection

One of the critical elements in remote sensing missions is the orbit. The process of orbit selection is an iterative process and a trade-off exercise to meet conflicting requirements. However, the following factors are considered prime while selecting a suitable orbit:

- minimum variation in ground illumination
- sufficient overlap between adjacent scenes
- minimum variation in altitude
- maximum possible coverage from a single ground station
- less orbit decay and hence orbit manoeuvres once in 45-50 days
- compatibility with contemporary satellite systems
- sufficient solar energy incidence to generate the needed electric power

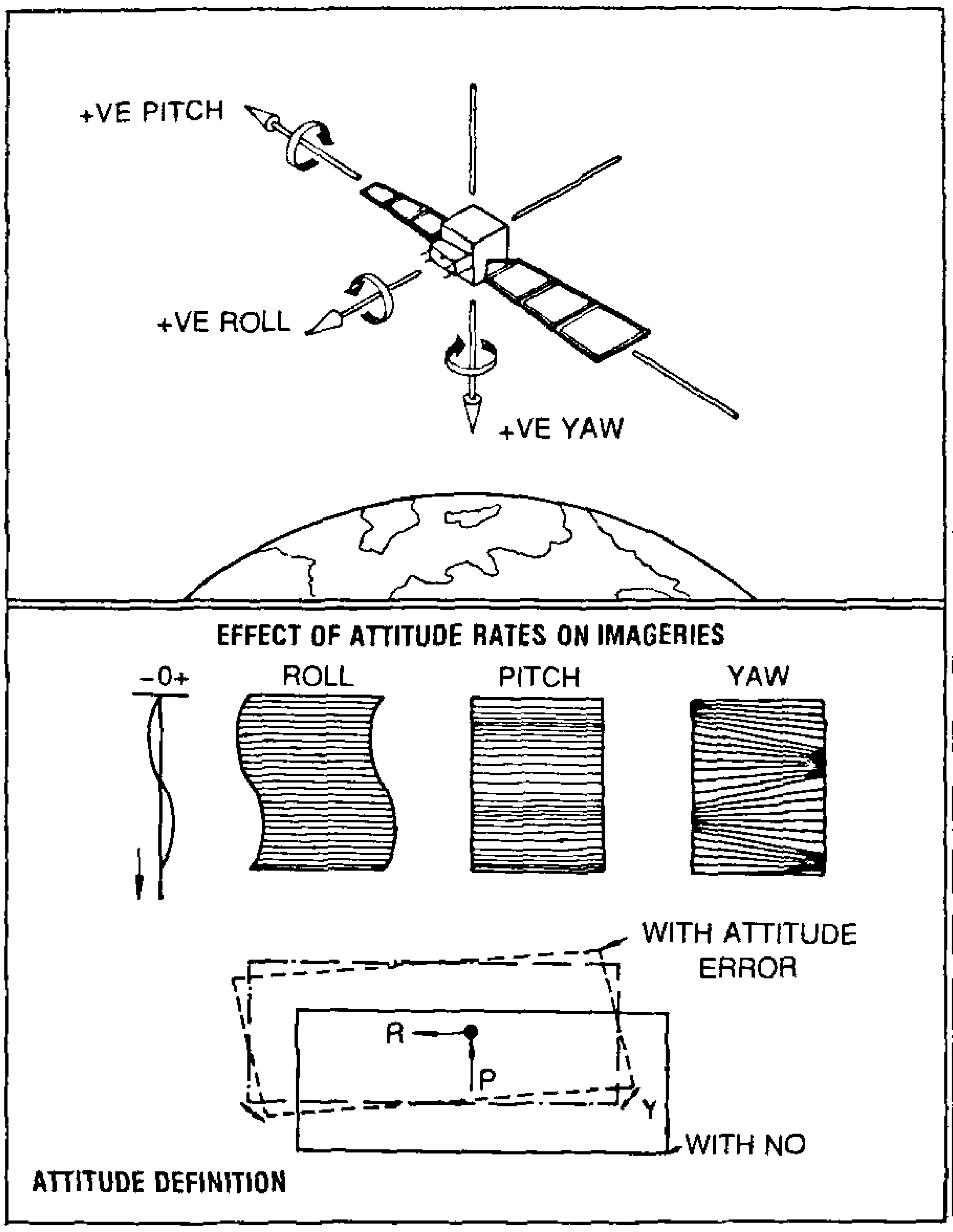

Figure 3. Pointing errors and their effect on imagery.

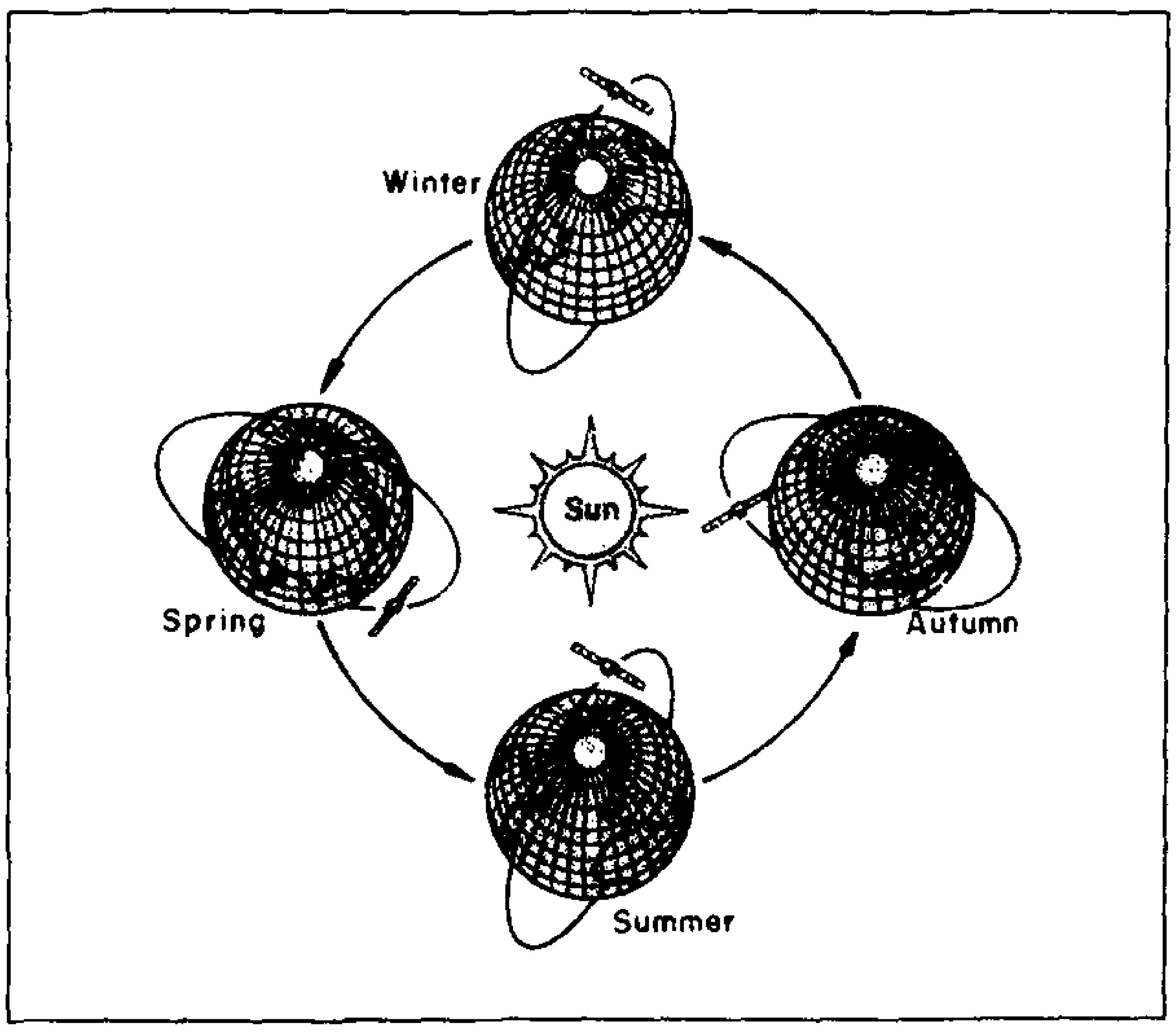

Figure 4. Sun-synchronous orbit.

- due weightage to satellite thermal system and attitude sensors' constraints

It is possible to meet the aforementioned constraints by selecting a sun-synchronous orbit, where the orbit plane will make almost a constant angle with the earth-sun line (Figure 4). This angle defines the so-called local time. An appropriate local time will also satisfy satellite power, thermal and attitude sensors' constraints. Trade-off studies covering requirements of users from different disciplines and the spacecraft constraints converged on to a local time of 10:25 hours at the descending node for IRS-1A. Requirements related to the swath, spatial resolution and camera optics design dictate the choice of altitude. These as well as consideration of low aerodynamic disturbance, contiguous imaging on consecutive days and the least altitude variation led to the selection of an orbit of 904 km altitude. In order to reduce the scale variations in the imagery, a near circular orbit is chosen. Sun-synchronism is maintained by choosing a retrograde orbit of inclination of 99.07 degrees. The details of final orbit selected for IRS-1A are given in table 3.

Table 3. Details of the final orbit selected for IRS-1A

Parameter	Value	Units
Semi-major axis	7282.277	km
Eccentricity	0.002	–
Inclination	99.028	Deg.
Nodal period	103.192	Minutes
Westward longitudinal shift between successive orbits	25.798045	Deg.
Westward longitudinal shift between n and n+14 orbits	1.17264 (130.54)	Deg (km)
Picture swath for LISS-I	148	km
Percentage overlap at equator for LISS-II	12	%
Repetition cycle	22	days
Number of orbits/cycle	307	orbits
Integer number of orbits per day	14	orbits

Local Time, Type of Node and Launch Window

In a sun-synchronous orbit, the local time of occurrence of passes remains the same except for the variations due to motion of the Sun. The local time remains the same for a given latitude. For the purposes of definition, local time is defined as the time at which the satellite crosses the equator on the equinox day. The choice of local time is mainly dictated by the application needs and it has significant effects on the spacecraft design also.

From the agricultural applications point of view, better illumination conditions are preferred and hence solar elevation angles better than 30 degrees is needed. For geological surveys and cartographic applications, shadow effects are preferred. It is necessary to consider the scene irradiance levels for the given local time against the available signal-to-noise ratio from the imaging system. The selected local time should also ensure that the data collection at the reception station is least affected due to clashes with other satellites.

For agricultural applications, the preferred local time is between 10:00 hours to 11:00 hours. The classification accuracy increases for all crop types upto 11:00 hours and then decreases. Near mid-day is preferred for higher scene irradiance and signal-to-noise ratio. However, atmospheric haze and afternoon clouds make the data quality to suffer and the data yield in a year will also be less. It is found that forenoon clouds are less debilitating than afternoon. For stereo imageries also, a local time of around 09:30 hours is preferred. With regard to clashes with other satellites' data reception, it was decided to have a dedicated data reception station for IRS and thus even though many satellites rise over the station, IRS will be assigned top priority. All passes will occur between 08:30 hours (IST) and 12:45 hours (IST).

Considering the above, a local time of near 10:30 hours was considered ideal for meeting the requirements of all application needs. Dispersions due to variations in launch time and seasonal variations can cause a change of + or – 20 minutes in the chosen local time.

The data collection opportunity during day time can be either during a south bound pass or a north bound pass, that is, at descending node or at ascending node. The descending node was preferred since it provides marginally better solar elevation angles for a given local time and also since it provides continuity to users who were already familiar with the data from Landsat and SPOT which had opted for descending node passes for data collection. The ascending node offers advantages in carrying out mission operations from Indian stations. However, the final choice of the node for imaging was descending node in view of the above mentioned over-riding advantage.

Coming to the selection of launch window, the launch of IRS should be possible on any day of the year and at a time decided by the chosen local time. Since the mission life is specified to be three years, no specification on season of launch exists. Descending node for imaging, 10:25 hours local time and day time launch from a Soviet Cosmodrome were selected for IRS-1A.

Space Segment

The space segment primarily consists of the camera system with the data handling system and the satellite platform comprising the main-frame sub-systems.

IRS-1A camera system: The satellite carries three push – broom scanners, based on charge-coupled devices, designated Linear Imaging Self Scanner (LISS)-I, II A & II B. LISS-I provides imageries at a spatial resolution of 72 m and a swath of 148 km, while LISS-II A & B provide a swath of 145 km combinedly at a resolution of 36 m. The data from LISS-I is transmitted at 5.2 Mbps (BPSK) on an S-Band carrier while LISS-II A & II B data is transmitted at 10.4 Mbps each (QPSK) on an X-Band carrier. The cameras provide data in three visible and one near infrared band. Refractive type of collecting optics with spectral selection by appropriate filter is used for each of the four spectral bands. The use of individual lens assembly for each spectral band allows performance optimisation in each band and effective utilisation of the full dynamic range of CCDs. Two LEDs per band are provided for in-flight calibration. LISS-II A and LISS-II B cameras have an overlap of nearly 3 km so that mosaicing of images from the two is possible. The technology adopted in IRS is similar to that adopted in contemporary missions like SPOT and MOS. All of them have push-broom scanners which utilise the satellite along track motion in orbit to image the earth with a linear CCD array (Figure 5).

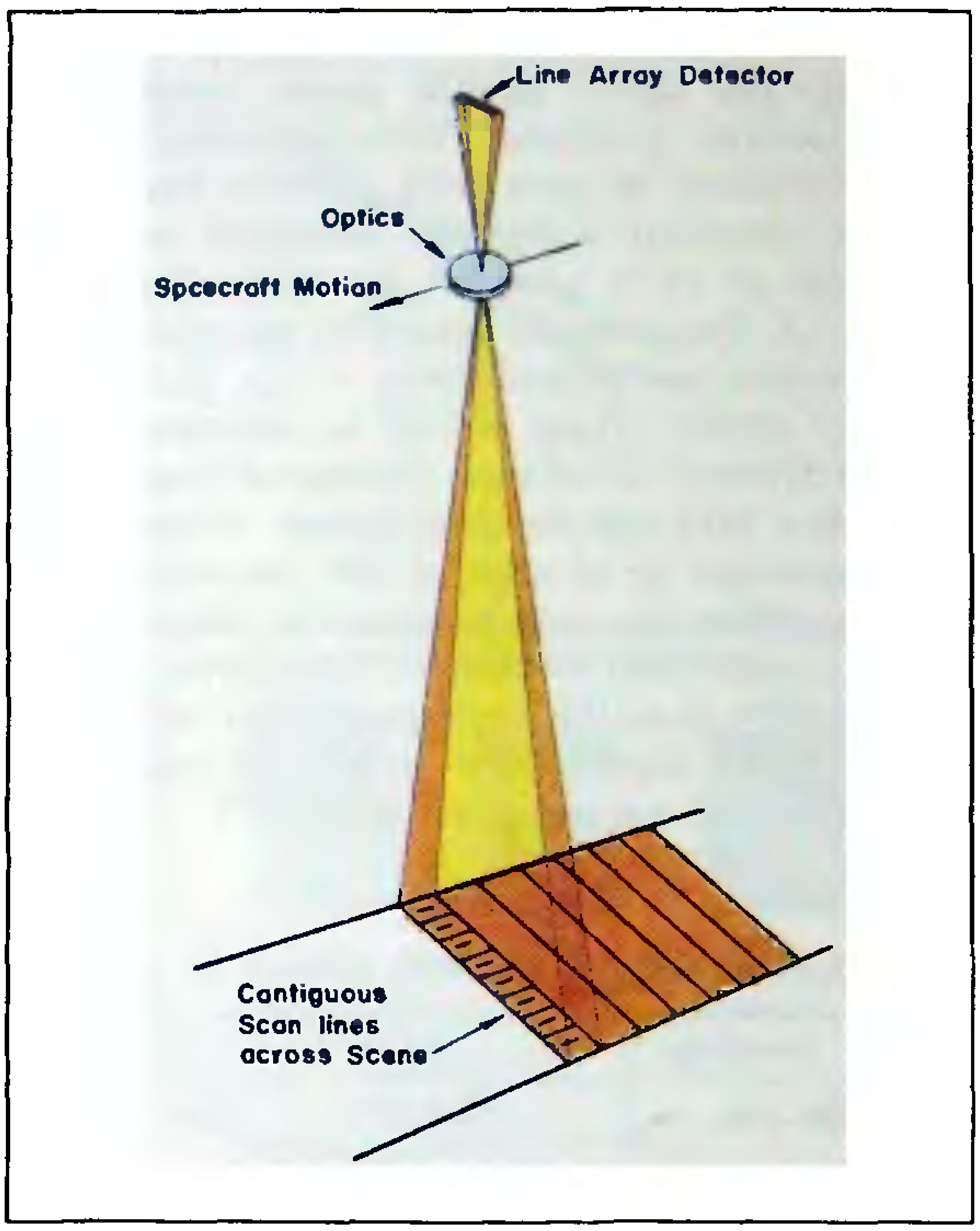

Figure 5. Push-broom concept.

IRS-1A Main-frame system: Commensurate with the mission requirements and specifications, IRS adopted a technology for the main-frame system which is comparable in performance with other operational remote sensing platforms in the world.

The telemetry, tracking and command system for IRS-1A operates in S-Band. This is an international standard system and thus provides capability for external agencies' ground stations also to track and provide the required mission support. The S-band transponder operates in coherent mode to provide range and two-way doppler data useful for orbit determination. VHF telecommand is provided as back-up.

The power system consists of two driven-deployable sun tracking panels producing power in excess of 620 Watts. Two nickel-cadmimum batteries of 40 AH capacity each, meet the peak load requirements and also the eclipse requirements.

The infrared earth sensors, conical and static, star sensors, sun sensors and dynamically tuned gyroscopes are the attitude sensors used during different phases of the mission, while the actuators are reaction wheels, magnetic torquers and hydrazine thrusters. For 3-axis attitude acquisition and orbit manoeuvres, monopropellant hydrazine based reaction control sytem equipped with 16 1-Newton thrusters are used. Thrusters are used for momentum dumping operations also. With 80 kg propellant loaded, it is possible to meet the designed mission life of three years including four contingency operations involving loss of earth lock.

The satellite structure is made of aluminium/aluminium honeycomb. The allup weight of the satellite at the time of launch was 974 kg. The thermal control system provides for passive control through tapes, paints, optical solar reflectors and multi-layer insulation blankets. Semi-active / active thermal control is provided through heaters and proportional temperature controllers for reaction control system, batteries and payload system. The imaging sensors are maintained between 15° C and 25° C, batteries are maintained between 0° C and 10° C, and other electronic packages are maintained within a range of 0 to 40° C.

The summary specifications of the spacecraft are given in table 4.

Table 4. Summary of specifications of IRS-1A

Type	Body stabilised remote sensing satellite.
Orbit	Sun-synchronous, 904 km orbit with equatorial crossing at 10.25 a.m., descending node.
Mission life	Three years.
Mechanical configuration	
Structure	Aluminium/Aluminium honeycomb structure.
Weight	974 kg.
Thermal control	
Thermal Components	Passive control using tapes, paint, OSR, MLI, blankets and semi-active/active control using proportionate temperature controller and heaters.
Thermal Range	20 +/– deg. C range for imaging sensors electro-optics, 5 +/–5 deg. C for chemical batteries, 0 to 40 deg. C for electronic packages.
Data handling	
Data rate	5.2 Mbps for LISS-I. 2 x 10.4 Mbps for LISS-II.
Modulation	PCM/BPSK for LISS-I in S-band. PCM/QPSK for LISS-II in X-band.
Attitude and orbit control	
Attitude Sensors	IR horizon sensors (conical and static), star sensor, sun sensors, Dynamically Tuned Gyros (DTGs).
Attitude Control	Reaction Wheels(4), magnetic torquers, hydrazine thrusters.
Orbit Control	Monopropellant hydrazine thrusters.
Orbit Determination	
Accuracy	1 km
Attitude determination	
Accuracy	0.1 degree
Telemetry, tracking and command (TTC)	
Telemetry	House Keeping (HK) information in S-band, PCM/PSK, Real time rate 256 bps and play-back rate 4 kbps onboard storage capacity of 98 minutes of HK data
Telecommand	S-band: PCM/PSK/FM/PM, and VHF: PCM/FSK/AM, Facility for ON/OFF and Data command
Tracking	S-band tone ranging and two way doppler, X-band beacon.
Power	
Solar Array	8.5 sq. metres area, deployable and sun-tracking panels, Generation of 620 Watts at EOL.
Battery	Two Ni-Cd batteries of 40 AH capacity each.

Scene Definition and Framing

Since the imaging in IRS is through line scanning, it is required to construct images with the help of a set of lines so that a meaningful scene can be provided to the user. This calls for defining a scene which will meet the user requirement, referencing scheme, compatibility with the photo-processing systems, scenes overlap along the track to enable mosaicing, etc. The width of the scene is fixed by the swath covered, and hence the number of detectors. In case of IRS-1A, the scene size for LISS-I is fixed to be 148 km across track and 174 km along track with scene centres separated by 2400 lines. The scene size of LISS-II is adjusted in such a way that 4 LISS-II scenes will cover the same area as covered by one LISS-I scene. The scene definition followed in IRS-1A is depicted in figure 6.

Path-row Referencing Scheme

The type of orbit chosen for IRS enables a predictable pattern for imaging, which can be used for referencing in relation to the geographic location by designing a grid pattern called "path-row referencing scheme". For this, the globe is divided into 307 segments each running from north to south and termed as a PATH. A set of 307 paths represents the total coverage cycle of IRS in 22 days. Each path is cut into ROWs by the lines running from east to west. Thus, any location on the earth may be referenced by the user with a unique path-row definition. For IRS mission, the zero degree visibility edge of Indian station on the east has been designated as path 1 which falls at 103° East. The row numbering starts from 81° North latitude and row 69 falls on the equator. The Indian region is covered between paths 9 and 35 and rows 41 and 63. The path-row definition scheme followed in IRS-1A mission is given in figure 7.

Since the orbit is very stable, it is possible to predict all dates on which a scene can be imaged. Orbit calendar is generated for the total mission duration indicating the date and the paths covered

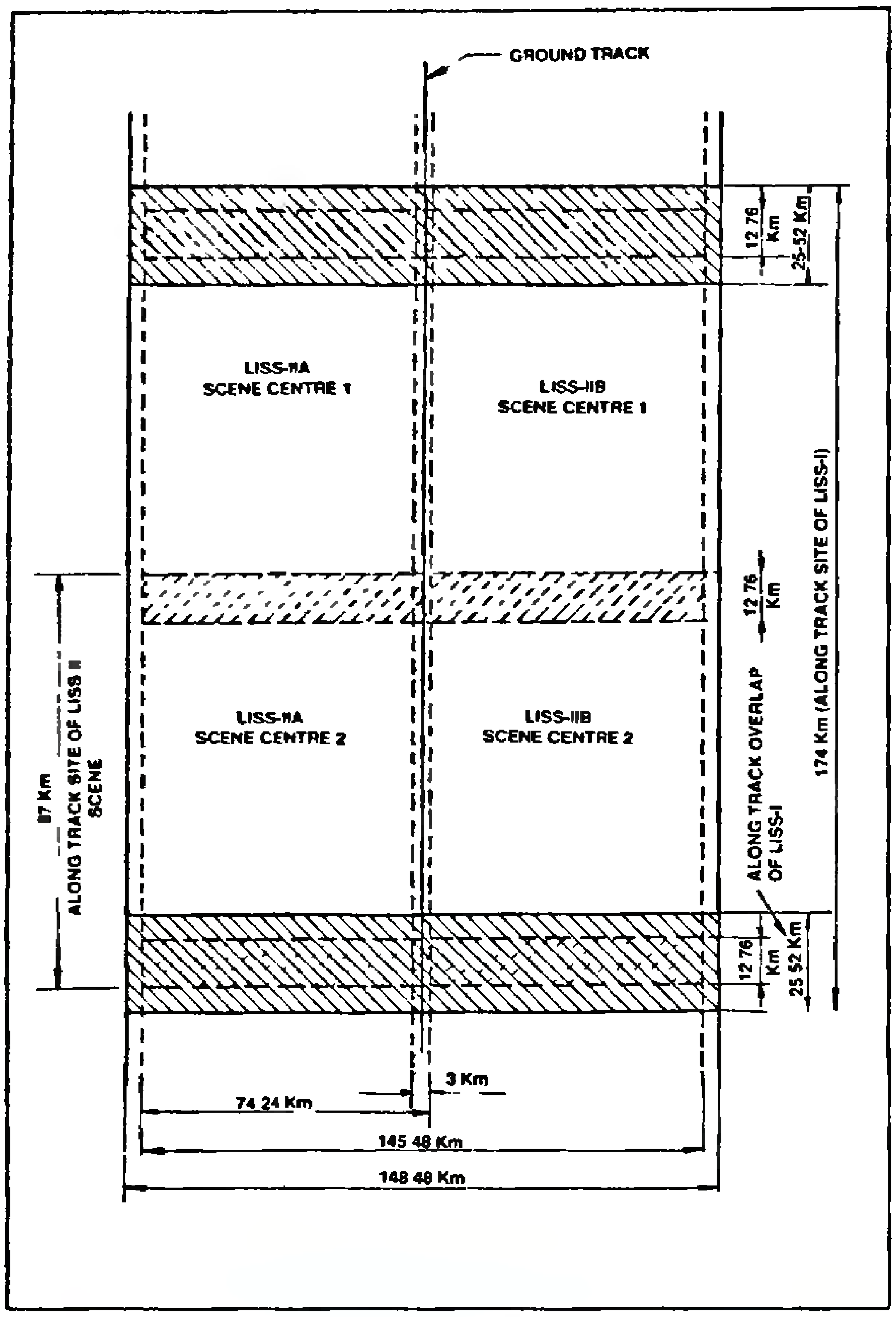

Figure 6. Scene definition in IRS imagery.

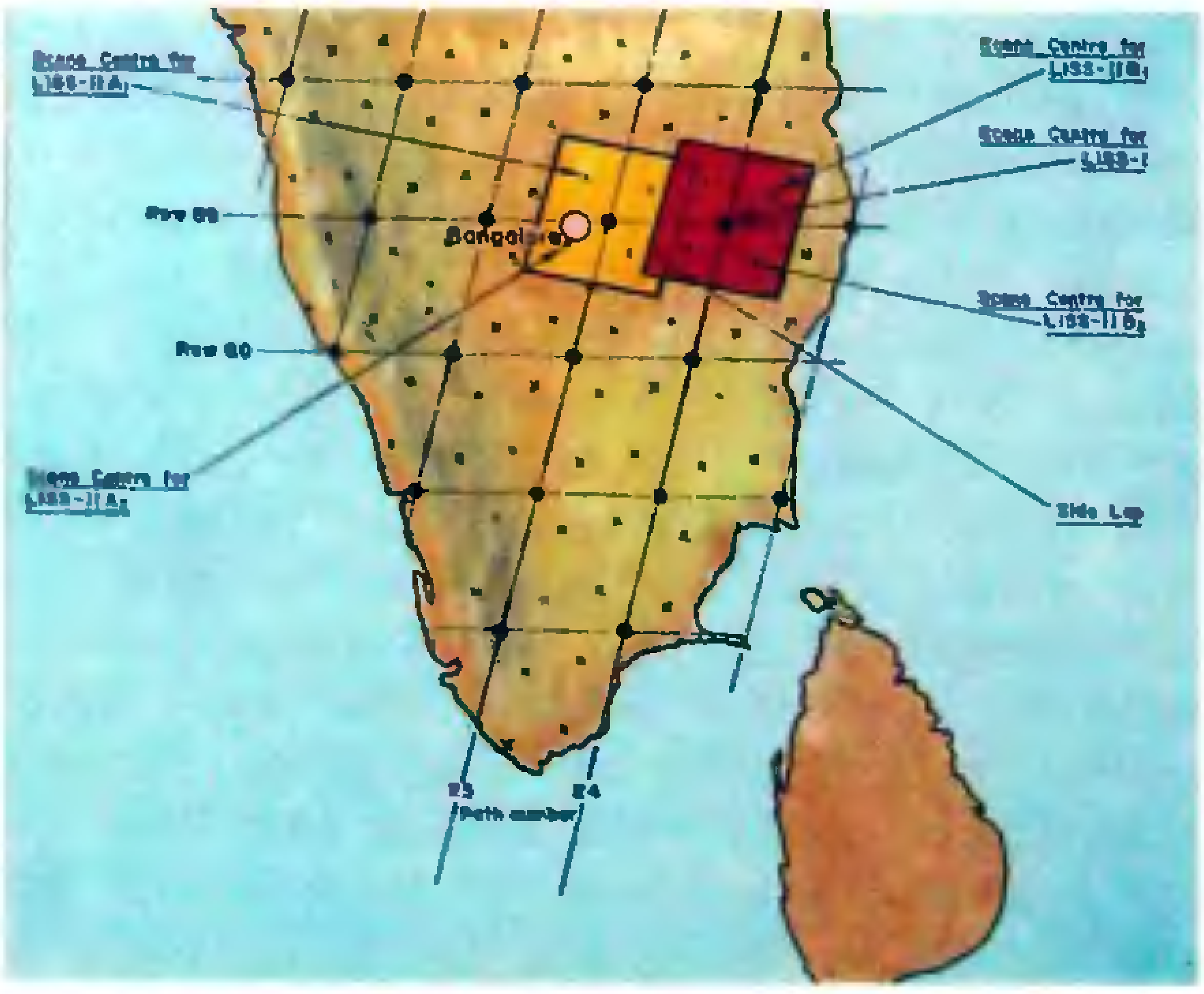

Figure 7. Path-row definition scheme.

on each day. So, a user can plan to acquire the data from IRS well in advance and also order the products based on the orbit calendar and path-row referencing scheme. However, since it is allowed to have a lateral shift in path by 28 km in East-West direction, the user who wishes to have data of the edge of a row or data pertaining to multi-date is advised to indicate his area of interest by name or latitude-longitude alongwith path-row number at the time of ordering.

IRS-1A Ground segment

The ground segment of IRS-1A (Figure 8) essentially caters to the following activities:

a) Planning of pre-launch, launch and post-launch operations.
b) Spacecraft operations.
c) Data reception and processing.
d) Data products generation.
e) Data archival and data dissemination.

TTC Network

Planning of network of ground stations: Being a low Earth orbit mission, the contact time with the satellite from the Indian ground stations, which are close to the equator, is limited. The ground stations located at Bangalore, Lucknow and Mauritius, which are operated by ISRO form the Indian part of the network for carrying out all operations related to satellite during the entire mission life. The satellite, soon after injection, called launch and early orbit phase, needs to be taken through a set of critical manoeuvres to make it ready for taking the pictures. For this purpose it is essential to have as many contacts with the satellite as possible, and also there are instances when the duration of contact in a visibility is not less than half an hour or so to accomplish a set of intended functions onboard. Also, in order to determine the orbit soon after injection and also to get good tracking geometry during the process of injection error removal, it is very much needed to get a set of stations which can provide the range, range rate and angles data. Taking into account the satellite operations' needs and the tracking data requirements for orbit determination, it was decided to avail the services of ground stations belonging to external agencies for telemetry, telecommand and tracking operations. The stations selected were Malindi (ESA), Weilheim (DFVLR), Fairbanks (NOAA) and Bearslake (LIT). These stations were meant for use during the initial phase of the mission. During the normal phase, the dependence on external stations was reduced. At present, Weilheim (DFVLR) alongwith the Indian stations has been supporting the satellite operations.

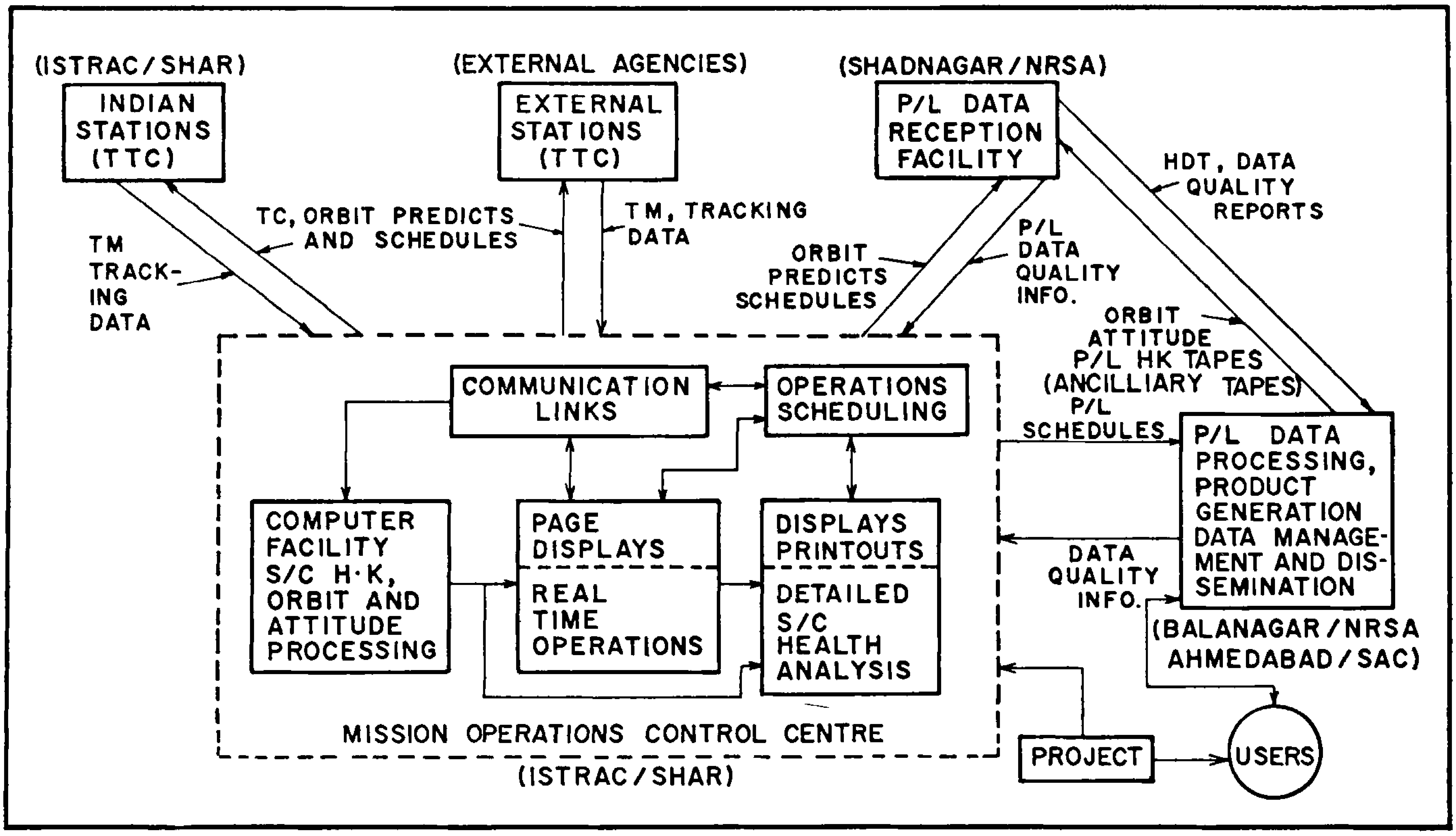

Figure 8. IRS ground segment organisation.

The Indian ground stations which support IRS mission are Bangalore, Lucknow and Mauritius (built and operated by ISRO). Bangalore ground station is the prime station for satellite operations. The Spacecraft Control Centre (SCC) is co-located with the prime ground station. SCC houses all facilities for satellite operations.

The functions of a TTC station are to receive the telemetry data from the satellite in real time, memory dump, dwell and star sensor data reception and also send commands to the satellite in both VHF and S-Band. The station also provides range, range rate and angles data for *post facto* orbit determination purposes. The standard TTC station provides a G/T of 20 dB/K in S-Band and the tracking system provides range data with an accuracy better than 10 metres and range rate at 10 cm/sec. The uplink transmitter power can be as high as 2 kW.

Payload Data Reception

In order to provide the entire Indian coverage from a single station an image data reception station was set up at Shadnagar, near Hyderabad.

The data reception station at Shadnagar receives the imagery data from the LISS cameras in S and X bands. A 10m-dish provides the necessary reception capability at a G/T of 19 dB/K and 31 dB/K. The station provides quick look display of one of the bands of any camera. The received data is recorded on High Density Tapes (HDTs). The station also produces Ancillary Computer Compatible Tapes (ACCTs), which include orbit, attitude and the camera's health and gain setting information. The ACCT alongwith HDT is used for data processing to produce higher level products.

Data products

The data products system is designed to produce IRS products of different types, formats, location accuracies and turn around times. The Quick Look Product (Level-0) generated at Shadnagar in real time is in 70 mm format. The browse products (Level-1) generated at Balanagar have earth rotation and radiometric corrections applied. The format will be in 63 x 65 mm with a location accuracy of 10 km. 9 chips are included in the browse photo format. The chips chosen are band 3 of LISS-I, bands 3 and 4 of LISS-II A and LISS-II B. The corrections applied in the case of standard products (Level-2) are, earth rotation, radiometric and geometric. They will be in 241 mm format with a location accuracy of 2.2 km. Standard products are generated based on users' requests. The Precision Products (Level-3) make use of Ground Control Points. They will be data. These products are in 241 mm format. In addition to the photo products, it is also possible to supply the IRS data in computer compatible tapes of 1600 bpi density (6250 bpi optional). It is also possible to generate geo-coded products at standard and precision accuracy levels.

Data Quality Evaluation

The quality of IRS imagery is evaluated on a routine basis. Towards this, the sensor, platform and orbit related parameters are analysed. The CAL data from onboard sensors is analysed to monitor the stability of sensor radiometry. The parameters which are routinely analysed are the dynamic range, signal-to-noise ratio, band-to-band registration, location accuracy, and scale variations.

Data Archival and Dissemination

The data dissemination, archival and user interface activities are handled by NRSA Data Centre -(NDC). Towards this, a full-fledged computerised Information Management System (IMS), capable of handling user enquiries, order processing, production monitoring, invoice preparation, archival data base maintenance and performance report generation has been operationalised. NDC maintains a browse facility to assist users in data selection. As a part of user interface, NDC has supplied IRS users' hand book; made timely announcements on launch, performance and data; supplied referencing scheme maps, price list, etc.

IRS-1A MISSION PROFILE

The satellite was launched on March 17, 1988 from a Cosmodrome at Baikonur in the Soviet Union. The operations on the satellite commenced immediately after injection into orbit. After a set of orientation manoeuvres the satellite's 3-axes were stabilised and the camera LISS-I was operated on the second day of the mission to get 72 metres resolution pictures. The second set of cameras, LISS-II A&B, were operated on 11th day of the mission to obtain 36.5 metres resolution pictures. All sub-systems of the satellite were checked for nominal performance. The orbit correction operations, to remove the injection errors from the launch vehicle, were carried out and the desired nominal orbit was reached on April 7, 1988 from when on the orbit calendar was started and the first cycle of imagery data collection was commenced. The routine operations on the satellite include camera operations in all day-time passes, calibration of cameras once in a repetitivity cycle, tracking data collection, satellite house-keeping and some special operations like orbit trim manoeuvres to maintain the ground track within a window of 28 km.

Table 5 provides the sequence of events which followed during the initial phase of IRS-1A mission and the same is depicted in the figure 9.

Table 5. IRS-1A mission sequence of events

Time	Event
MARCH 17, 1988	
T0 = 06:43:30(UT)	VOSTOK Lift-off
T0 + 2 min	First stage separation
T0 + 7 min 10 sec.	Second stage separation
T0 + 10 min 5 sec.	Nose cone jettisoning
T0 + 11 min 31 sec	IRS-1A injection and separation
T0 + 13 min 31 sec.	Solar panel deployment
T0 + 26 min 30 sec.	Sun acquisition
T0 + 1 hr 58 min 7 sec.	Earth acquisition
T0 + 3 hr 29 min 30 sec.	Three-axes stabilisation
T0 + 22 hr 44 min 47 sec.	LISS-I payload operation
March 28, 1988	
T0 + 10 d 22 hr 21 min 30 sec	LISS-II A & B Payload operation
April 7, 1988	
T0 + 21 d 1 hr 26 min 30 sec.	Completion of orbit Manoeuvres for attaining IRS Referenceing Scheme. In India in the coming years.

PERFORMANCE OF IRS-1A SYSTEM

The satellite IRS-1A has been functioning satisfactorily. Payloads LISS-I and LISS-II have been sending quality pictures daily during the morning passes over India. The payload calibration system operated once in a cycle has not indicated any significant degradation in the system. The radiometric correction tables cleared for operations at the end of the initial phase of the mission are applicable even now. The payload parameters evaluated through data quality evaluation exercises every repetitive cycle, have also revealed similar results. The payload operations are carried out in auto-mode through timers which are set prior to the intended operations by the Spacecraft Control Centre personnel. Payload data acquisition has been very regular, and data acquisition over the operations period is about 99 per cent. All special requests and events of

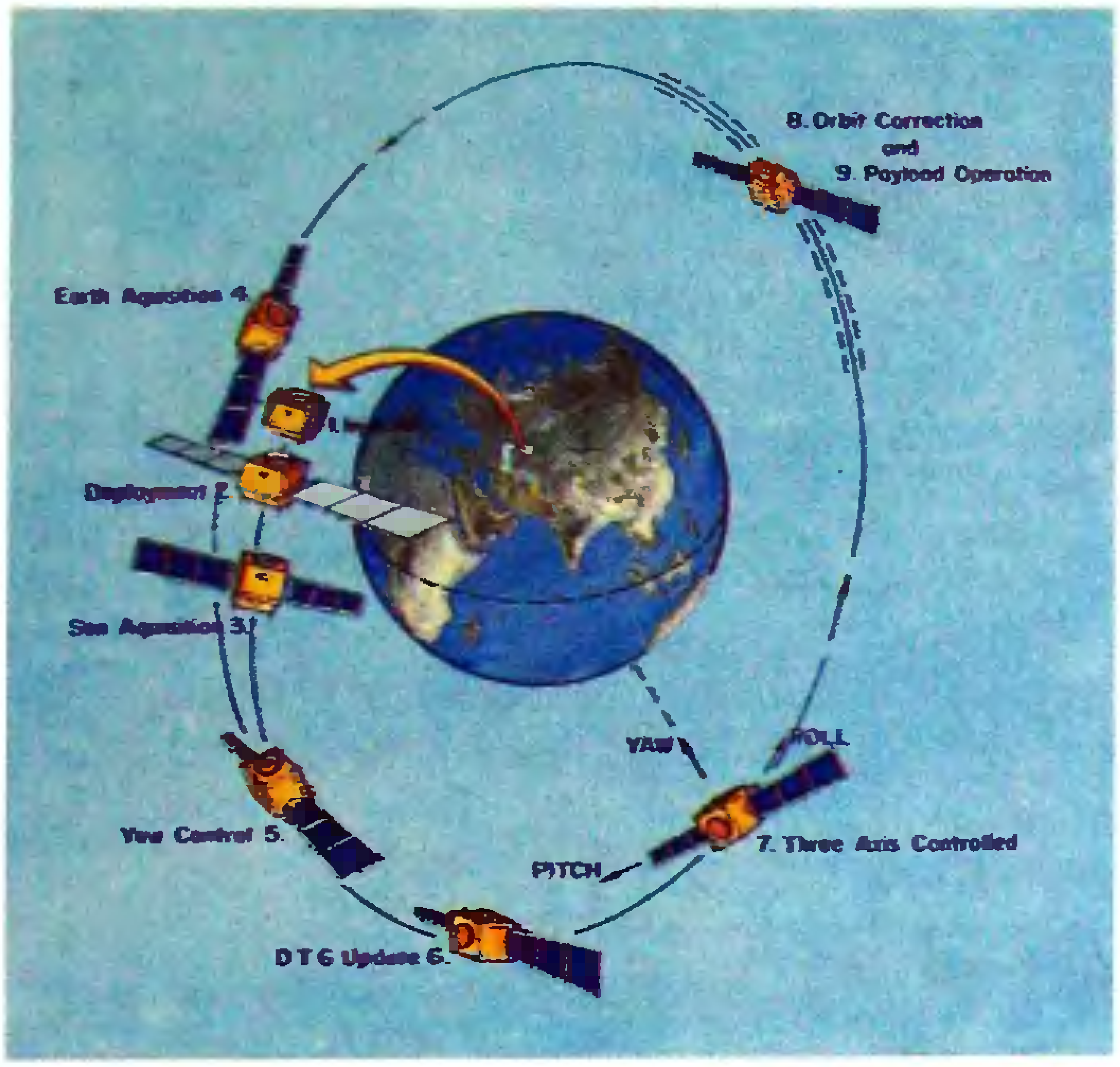

Figure 9. IRS-1A Mission sequence of events.

importance in and around India have been met through special scheduling and tracking paths upto 0.8 degrees elevation.

The main frame system has been supporting the payload operations very satisfactorily. Though attitude sensors had to be reconfigured during the early part of the mission, a firm configuration of the satellite has been set in the normal phase, and the same is valid even now. Only special operations like orbit manoeuvres, payload calibration, etc., call for S/C configuration changes which are carried out for the required duration in the specified orbit.

The telemetry, tracking and command system has been providing the health information, access to configuring the satellite for various routine operational requirements and range, range-rate data for orbit determination. Both VHF and S-Band command systems are being used depending on the need for operations. The systems selected for operations during launch pad are still being used. The telemetry data storage system is operated routinely in every orbit to assess the health of the satellite even outside the network visibility. The link margins on S-Band uplink and downlink are above 15 dB as observed from ISTRAC ground stations. The LISS-I and LISS-II data-links have provided link margins better than 6 dB over the Shadnagar ground station. The tracking system also has been performing satisfactorily with a margin better than 10 dB. The link margins established during the initial phase are still valid and satisfactory.

Power system has been generating, conditioning and supporting the various load requirements of the satellite systems. Solar arrays have not shown any appreciable power degradation since the start of the mission. At the beginning of mission, the power available for use was 616 Watts and at the end of the three years mission life, the power generated was less by 3 per cent. Batteries have been operating at 7–8 per cent depth of discharge and have been maintained between 2° C and 8° C. Since the depth of discharge is one-third the specified discharge and the temperature maintenance is within the specified limits, the life expectancy of battery has also improved, and it is no longer the life determining system. Power regulators selected during the initial phase have been working satisfactorily alongwith other power electronics systems. One side of the solar array drive assembly which helps in tracking the Sun for maximum power generation has been having intermittent tracking problems but has not affected the payload operations in any way. The excess power and battery over charge factors are 75 per cent and 1.15, respectively.

Attitude and orbit control system has been performing satisfactorily in the 3-axes stabilised mode. Three reaction wheels, one gyro with precision yaw sensor, two magnetic torquers and one conical sensor with corresponding control electronics have been maintaining the attitude of the satellite within the specified limits. Star sensor, though not used during payload operations, has been giving good data for satellite yaw angle determination. The satellite attitude got disturbed temporarily twice during the normal phase which was corrected subsequently within a few orbits.

The attitude pointing during payload passes has been within limits of + or − 0.1 degree. The drift rates achieved are 10 E-04 degrees/sec in yaw and 10 E-03 degrees/sec in pitch and roll. A typical attitude pointing plot is given in figure 10.

The fuel available onboard is estimated to be in excess of 25 kg. Considering all aspects of fuel consumption, the IRS-1A can be expected to have a useful life of more than a year from now.

Thermal system has maintained all temperatures well within the specified limits. The payload detectors have been operating within 18° C and 24° C, most of the electronic packages are working at room temperature and the satellite average temperature has been around 19° C. The reaction control system has been maintained well above 10° C at all points. The temperature of the spacecraft at the beginning of the mission was 17° C and at the end of three years the rise in temperature was observed to be 2 to 3° C. This is attributable to change in the local time and degradation in the absorptive and emissive

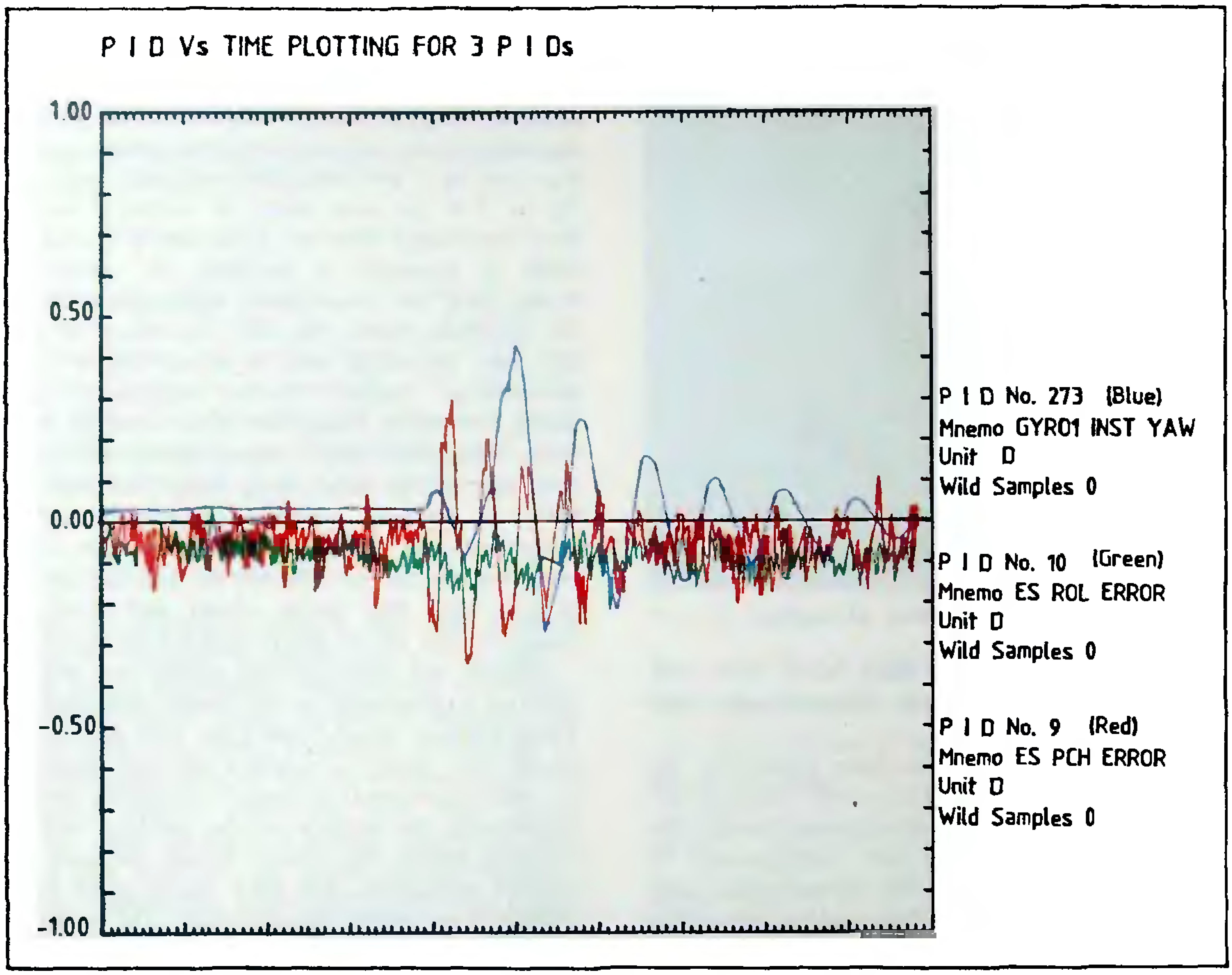

Figure 10. A typical attitude pointing plot of IRS-1A.

characteristics of various thermal control elements on the satellite.

The spacecraft operations are being conducted from the control centre located at Bangalore. The operations follow a set of well defined procedures and schedules. The computer support, network stations support and communication links have been satisfactory. The network of stations supporting the operations consists of Bangalore, Lucknow, Mauritius and Weilheim. Mauritius station is now augmented to become a full-fledged TTC station with a 10 m antenna and tracking system. The spacecraft health processing software and flight dynamics software have been operational at the control centre. Certain new developments and modifications needed to meet the operational requirements during the normal phase have been carried out in the software system. Significant among them are star sensor attitude determination through recorded data, roll-yaw coupling estimation, pitch roll bias estimation, graphic utilities and optimisation of software.

Orbit determination has been producing very consistent results and the accuracy achieved in most of the cases is better than 400 metres. The ground track maintenance is done through periodic orbit corrections; the periodicity being 45 days on an average. The local time of IRS-1A has not been maintained at launch local time of 10:25 hours as no periodic inclination corrections are attempted. The ground track is maintained to lie within 12 km from the standard path referencing scheme. The ground track control over the three years of mission life is depicted in figure 11. It could be seen that the orbit maintenance manoeuvres have been carried out at an average interval of 45 days. During some seasons the corrections were done in less than 45 days because of larger orbit decay due to very high solar activity.

At the data reception station, the payload data is received during day time passes. Ancillary CCT generation has been going on smoothly. A single ACCT concept was operationalised during the third

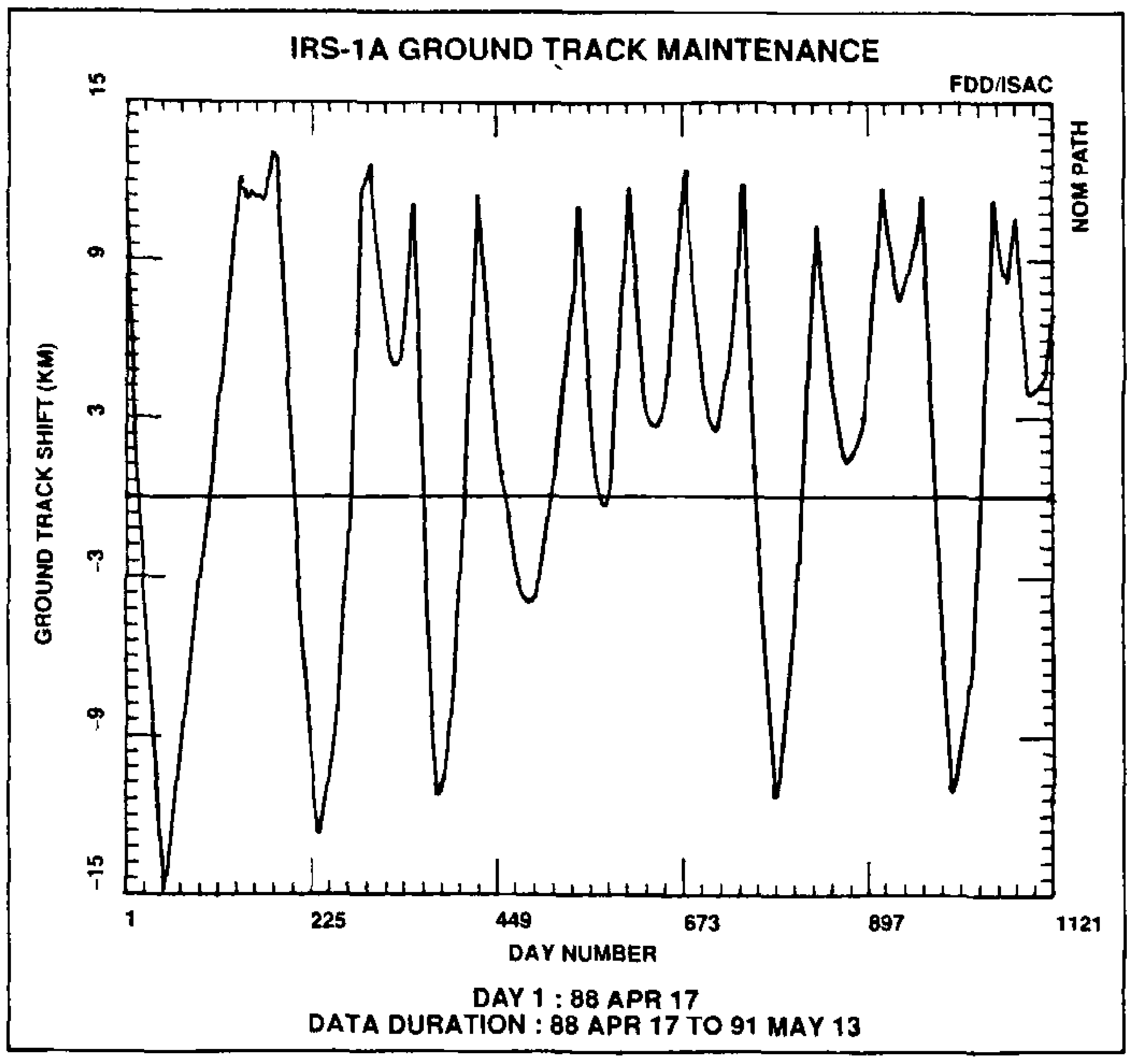

Figure 11. Ground track control over mission life.

year of the mission in contrast to *pre facto* and *post facto* ACCT generated during the first two years of the mission. ACCT concept has met all objectives set forth, level-0 system operates under a scheduler. Calibration data reception and analysis are also carried out on the same system under a different schedule.

The browse and the standard products generation at NRSA has been operational since the first payload operations. Geo-coded products are also being produced operationally. The location accuracy in standard product has met the specification of 2.2 km in most of the cases. Operationally, Information Management System and schedules are used for data products generation.

The precision and special products and the data quality evaluation are carried out at SAC. A GCP library consisting of nearly 2000 points has been built up for precision processing. Work on swath modelling has been initiated and the concept has been proved with a limited number of scenes. Special products have been generated for most of the Indian cities and as per user needs. Precision products have met a location accuracy in the range of 100–250 metres. Data quality is evaluated for every cycle. The payload parameters, platform parameters and mission parameters are evaluated for the specifications.

NRSA Data Centre has been managing the user queries, requests and data supply to the users. In addition, promotion related activities are also handled by the data centre.

The mission management structure evolved prior to the launch has been very effective in attending to the operational needs of the mission. The operations review boards and mission management boards hold periodic review meetings to assess the operational status of each area, problems and remedies for the problems faced and efforts are now on for improving the efficiency of the total system.

The data quality evaluation exercises are carried out throughout the mission life.

Data quality evaluation activity has been carried out once in every repetitivity cycle. The parameters evaluated are:

a) Radiometric parameters from calibration data and scene data.
b) Geometric parameters on standard, precision and geo-coded products.
c) Maximum and minimum attitude, altitude and velocity.

In addition to the above, following parameters are also evaluated, but less frequently:

a) Band-to-band misregistration.
b) Scale variation in the imagery.
c) Internal distortion.
d) Sidelap of scene for two consecutive days.
e) Sidelap and overlap of same scene from three cameras.
f) Modulation transfer function.

DQE Results

The saturation radiance achieved for LISS-I and Band 1 of LISS–II A and B, as seen for calibration data, is almost the same as that measured on ground before launch. Bands 2, 3 and 4 of LISS-II A and LISS-II B achieved 70 and 75 per cent, respectively of saturation radiance values measured on ground. Over the observed temperature variations of 18 – 24° C in orbit,. the variation in saturation radiance is observed to be less than 1.5 per cent and relative variation in all bands is identical.

The dark currents measured for individual detectors show that there is practically no variation in the dark current of LISS-II A and B, whereas a dark current variation of less than 1.5 per cent was observed in band 4 of LISS-I, which is also well within the specifications.

Scene based parameter evaluation was carried out for selected targets, and the saturation radiance values obtained from other satellites compare well with those obtained from IRS for most of the targets.

Location accuracy measured on standard products was well within 2.2 km in most of the cases, while the same for precision products was upto 500 metres or better. The average pixel size measured for LISS-I is 72 metres and the percentage scale variation is less than 0.5 per cent.

FUTURE PLANS

IRS-1B, the in-orbit replacement for IRS-1A, is scheduled for launch in August 1991 from a Soviet Cosmodrome. It carries payloads identical to those flown aboard IRS-1A. These two satellites will provide better repetitivity coverage when operated simultaneously, typically of the order of 14–15 days. For this, in-orbit phasing adjustments of IRS-1B with respect to IRS-1A has been planned. The main frame performance is expected to be better than that of IRS-1A, and hence better accuracies are expected for the products. Time-tagged command capability provided in IRS-1B will enable multiple payload operations anywhere in the world, thus making it a global mission to meet any other user's needs. Swath modelling concepts will be tried out during the mission and hence standard products of better accuracies will be available.

IRS-1C/1D (Figure 12), scheduled for launch in the time-frame of 1994–96, will have enhanced capabilities in the form of higher resolution cameras operating from 817 km polar sun-synchronous circular orbit. Three cameras – one operating in panchromatic band and the other two in multispectral bands – have been included in the configuration. The panchromatic camera will have off-nadir viewing capability which will help in revisiting a place within 5 days. Off-nadir viewing angle can be controlled from ground upto a maximum of + or – 26 degrees. Panchromatic camera provides imagery of better than 10 metres resolution covering a swath of 70 metres. One multi-spectral camera named LISS-III incorporates middle infrared band in addition to visible and near-infrared bands. LISS-III will provide imagery at a resolution of about 23 metres covering a swath of 140 km. The middle-infra red band will provide imagery at 70 metres resolution covering a swath of 148 km. The third camera, named Wide-Field Sensor (WIFS), will operate in two visible bands to provide imagery at

Figure 12. IRS-1C spacecraft.

metres covering a swath of 140 km. The middle-infra red band will provide imagery at 70 metres resolution covering a swath of 148 km. The third camera, named Wide-Field Sensor (WIFS), will operate in two visible bands to provide imagery at a resolution of 188 metres covering a swath of 770 km. WIFS camera will provide data with a repetitivity of five days and would be useful in generating vegetation index information. An on-board tape recorder will extend the data acquisition capability by 24 minutes. Power generation capability of IRS-1C will be enhanced to meet the extra power requirements compared to that with IRS-1A/1B. The three-axes attitude referencing system will be gyro based and area star tracker will provide precise attitude determination capability for the mission. Most of the other main-frame sub-systems will be derived from the proven IRS-1A/1B bus. IRS-1D, identical to IRS-1C will be the in-orbit replacement to IRS-1C to ensure data continuity beyond the mid '90s.

Conclusions

With the launching and operationalisation of IRS-1A, India has emerged as one of a few countries in the world with a capability of using satellite-based remotely sensed data for various resource applications on an operational basis. The capabilities of IRS-1A are comparable with other contemporary satellite missions. IRS-1A has thus laid a strong foundation for the future of remote sensing activities in the country. Planned launch of IRS-1B in the immediate future, to be followed by the more advanced versions of IRS like IRS-1C/1D, will provide the assured services of the space remote sensing data to the user community in India in the comming years.

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DATA RECEPTION FROM SATELLITE

There are several frequency bands that can be used for satellite to ground station link like VHF, S-band and X-band. Presently VHF is used mainly for the telemetry and the telecommand because the data rates are within a few kHz width.

As the data rate increases the carrier frequency has also to be increased to accommodate the higher band spread.

There is an international body which allocates the various frequencies for different purposes of communications. They have allocated S-band and X-band frequency bands for the purpose of data transmission for remote sensing satellite down-link operations.

S-band is used for a lower bit rates data transmission like MSS (15.06 Mb), LISS-I (5.2 Mb), etc.

X-band is used for higher bit rates like TM (84.9 Mb), SPOT (49.686 Mb), LISS-II (20.8 Mb).

IRS (LISS-II) uses X-band although it can be operated in S-band. This is to gain experience in X-band equipment, which will be very useful in planning and executing the future missions.

The received data is demodulated in mission specific demods and recorded on High Density Tapes.

In case of Landsat/SPOT station the data is transmitted to the recorded room through fibre optic link or through cable Mod/Demod System to the recording room which is situated at a distance of about 100 metres from the station.

Source : NNRMS Bulletin, **12**, 1990, ISRO HQ, Bangalore.