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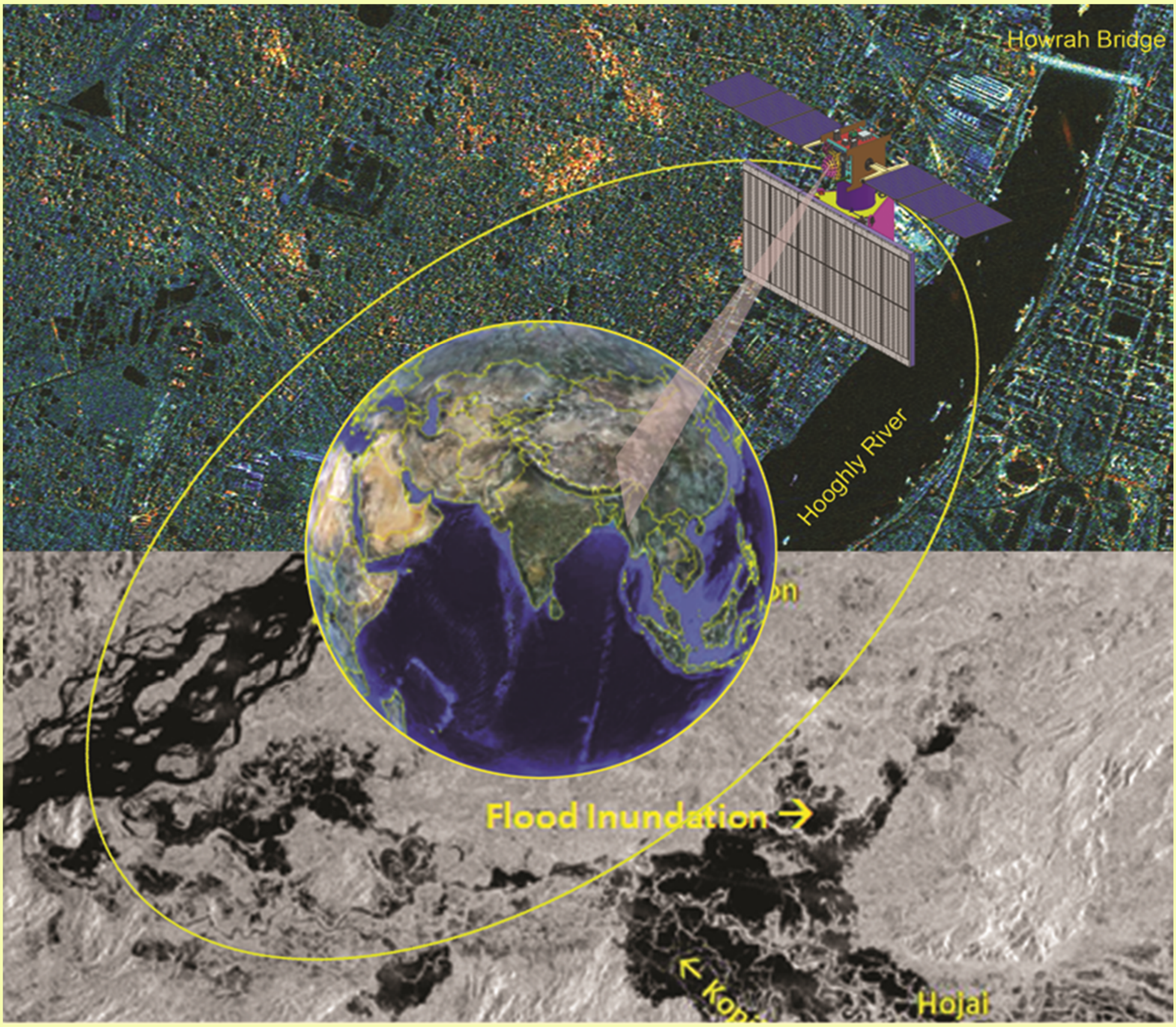
EOS-04
(RISAT-1A)
Hand Book



National Remote Sensing Centre
Indian Space Research Organisation

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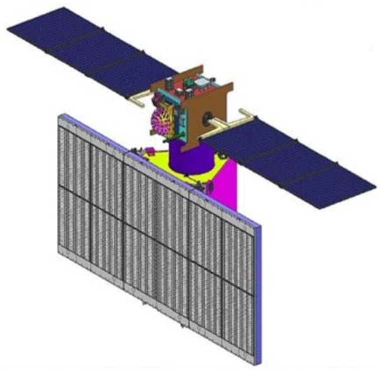

Hand Book

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NATIONAL REMOTE SENSING CENTRE

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ORGANISATION OF THE HANDBOOK

EOS-04 Data User's Handbook provides essential information to the users about the mission, satellite, sensors, orbit and coverage, referencing scheme, data acquisition, products and services.

Chapter 1 provides an insight to the Indian Earth Observation Program and mission objectives.

Chapter 2 provides an overview of the satellite system, sub-systems, satellite positioning system, payload and data handling systems and orbit, coverage and referencing scheme.

Chapter 3 covers various aspects of the ground segment such as TTC/Payload networks, data reception, base band systems, antenna control and Level-0 systems.

Chapter 4 provides details about various data processing levels, SAR data processing, data formats , data quality evaluation and value added products.

Chapter 5 gives an insight to the data access, distribution and payload programming services.

Chapter 6 provides information on different types of applications of the data.

Chapter-I

1. Introduction

1.1 Indian Earth Observation Program

Earth Observation Satellites of ISRO have successfully accomplished many operational applications in the country along with technology advancements. A large number of institutions belonging to Government, Academic and Private sectors have utilized space based inputs for various national and other application based projects. Different range and class of satellites have been launched by ISRO. The resolutions vary from 1 km to 30 cm. The IRS series of satellites which have contributed and enabled many unique applications of space based imaging are as mentioned below.

High resolution Cartosat series of satellites with a goal to serve earth resources management in general and to serve large scale cartographic application in particular. This series include Cartosat-1, Cartosat-2, 2A, 2B, 2C, 2D, 2E & 2F and Cartosat-3.

Resourcesat series of satellites include Resourecsat-1, 2, 2A satellites with a variety of spatial resolutions, spectral bands and swaths mainly provide data which is used for several applications covering the fields of agriculture, water resources, urban development, mineral prospecting, environment, forestry, drought & flood forecasting, ocean resources and disaster management.

Under Microwave class of satellites, Risat-1 with C band SAR was launched providing all-weather as well as the day-and-night observation capability and supported applications like agriculture, forestry, soil moisture, geology, sea ice, coastal monitoring, object identification, and flood monitoring. Risat-2 series of satellites are launched to support X band SAR data to cater to strategic requirements.

A series of satellites are dedicated to ocean related applications in documenting, Chlorophyll concentration, phytoplankton blooms, atmospheric aerosols and particulate matter besides providing weather forecast information to predict cyclones, etc. The satellites included in these series are Oceansat-1, 2, Megha - Tropiques, SARAL, Scatsat, INSAT series, and host of other satellites.

ISRO is in the verge of realising next generation of these satellites, as part of continuity of missions, to ensure that the user community is continuously benefitted from space inputs for sustainable development and good governance.

The hallmark of Indian space programme is the application-oriented focus and the benefits that have accrued to the country through these programmes. The societal services offered by Earth Observation, SATCOM and the recent NavIC constellation of satellites in various areas of national development, including tele-education and telemedicine, are standing examples of applications oriented space programme of Indian Remote Sensing applications projects at National, State and Local levels. The architecture of space programme in India emphasises on the applications, with active participation of user-community from Government, Academia and Industry. During past many years, Indian Remote Sensing Satellite constellation has taken giant strides in ensuring many areas of application to operational projects. Some of the most prominent ones are Agricultural Crops Inventory, Water Resources Information System, Ground Water Prospects, Forest Working Plans, Biodiversity and Coral Mapping, Potential Fishing Zones, Ocean State Forecasts, Rural Development, Urban Development, Inventory & Monitoring of Glacial Lakes / Water Bodies, Location based Services using NavIC constellation, Disaster Management Support Programme (Cyclone and Floods Mapping & Monitoring, Landslide Mapping & Monitoring, Agricultural Drought, Forest Fire, Earthquakes, Extreme Weather Monitoring and experimental Forecasts and so on).

Geospatial technologies, remote sensing, satellite communication and navigation systems are providing many new ways for effective management of natural resources. This has resulted in enabling variety of data and information products for societal benefits and also helping planners and decision-makers to embark upon unique citizen-centric services.

Web Geoportals like Bhoonidhi and Bhuvan with mobile friendly apps like Bhuvanlite are the other popular platforms, being used by Governments, to provide information services and solutions at all levels, which are proving to be effective. The Government system has successfully adopted to use such technologies for the benefit of people at large. ISRO works closely with Central & State Government departments/ ministries, Industry and Academia in ensuring best of solutions for optimal management of Natural Resources, support services for good governance and societal development. Through a well-coordinated effort, this system has been able to provide several important applications that are becoming citizen-centric.

The prime objective of Indian Space Programme is to enhance the space technology and use its applications to various national tasks in the areas of television broadcasting, telecommunications, meteorology applications and remote sensing applications for management of natural resources. The main capabilities are to design, build and launch satellites to a sun synchronous orbit, to establish and operate ground stations for spacecraft control, data transfer along with data processing and archival and to use the data obtained for various applications on the ground. Indigenously developed Indian Remote Sensing System is the largest civilian remote sensing satellite constellation in the world providing imageries in a variety of spatial resolutions, spectral bands and swaths and data is used for exploiting a new range of applications. The satellites were developed with the idea of applying space technologies for the benefit of humankind and the development of the country.

In this handbook, we discuss the details of EOS-04 which is a follow on mission of Risat-1 so as to provide continuity of the services. The overall configuration of the payload remains unaltered and it boasts of incorporating features which target to: (i) provide more to the user-community (ii) keep up with the technological strides, and (iii) Improve on the present data quality.

1.2 Mission Overview

EOS-04 was launched on 14-February 2022 by ISRO's own PSLV C-52. EOS-04 is a Low Earth Orbit (LEO) satellite to be operated in a Sun Synchronous Polar Orbit

(SSPO) with 6 AM-6 PM Equatorial Crossing Time (ECT) at an altitude of 524.87 km carrying a Synthetic Aperture Radar (SAR) payload. EOS-04 Spacecraft is configured using ISRO's RISAT-1 heritage bus and capabilities are fully exploited with respect to accommodation, power generation, thermal management etc.

EOS-04 SAR is capable of providing data in various resolution modes catering to a variety of applications as demonstrated in its precursor mission RISAT-1. The main objective of EOS-04 mission is to provide continuity of data to the users. To cater to the applications, the SAR payload of EOS-04 shall operate in C-Band frequency range (5.4G Hz) and in Side-Looking Radar mode with performance parameters for different modes as specified in the following sections.

Initially, SAR payload of EOS-04 was configured in C-Band at a frequency of 5.35 GHz, similar to that of RISAT-1. However, in order to avoid WLAN interference, the centre frequency of payload is shifted from 5.35 GHz to 5.4 GHz. A polar sun synchronous orbit at 536.38 km altitude and inclination of 97.554 deg. with repetivity cycle of 377 orbits in 25 days was chosen for RISAT-1. In view of the proximity of 536 km orbit to Starlink's orbital shell at 550 km altitude and higher dimension of EOS-04, orbit of 524.87 km altitude with inclination of 97.5 deg with 8-beam MRS operation (for systematic mode of imaging) is selected to avoid frequent conjunction threats without compromising the payload goals or violate mission constraints. The payload specifications are summarized in Table-1.

Modes of Operation :

The EOS-04 SAR will be operating in C-band at a frequency of 5.4 G Hz. The SAR system has been designed to provide constant swath for all elevation pointing for stripmap mode of imaging. Full-polarimetric mode has been introduced newly in EOS-04. Quad (Full) polarization will be operational for FRS-1, FRS-2 and for ScanSAR MRS and CRS modes. Quad (Full) polarization is not available for HRS mode. HRS mode configuration in EOS-04 is reconfigured with lower bandwidth (75 MHz) according to available WLAN frequency band. The salient features of these modes are summarized in the Table-2.

Payload Specifications:

Parameters	Specifications
Altitude	524.87 km
Orbit	Sun synchronous (6 AM -descending / 6 PM equatorial crossing)
Frequency	5.4 GHz ± 37.5 MHz
Polarization Combination	Single / Dual / Full-pol /Hybrid circular polarimetry (Transmit circular, receive linear)
Average DC Input Power	3.8 kW
Pulse width	5 μs to 25 μs
Antenna Roll Bias (deg)	± 36°
Range Coverage (km)	107-659 (either side of flight track)
Look Angle (deg)	11.5-49.6
Incidence Angle (deg)	12.4-55.5

Table-1 Payload Specifications

MODES	FRS-1 (FRS-1 FP)	FRS-2 (FRS-2 FP)	6-beam / 8-beam MRS / CRS	ScanSAR – FP (6/8/12 beam)	HRS
Chirp Bandwidth (MHz)	75	37.5	18.75	18.75	75
PRF (Hz)	2800-3200 (5600-6400)	2800-3200 (5600-6400)	2800-3200	5600-6400	3000-3700
Worst Sigma Naught (dB)	≤ -18	≤ -19	≤ -18	≤ -16	≤ -18
Swath (km)	25(20)	25(20)	115 / 160 / 223	87 / 115 / 168	15
Off-Nadir (km)	100-650 (100-400)	100-650 (100-400)	100-650	100-400	100-650
Slant range resolution (m)	2	4	8	8	2
Ground range resolution (m)	9.3-2.4	18.6-6.3	37.2-9.7	37.2-12.6	9.3-2.4
Azimuth Resolution (m)	3	3	23 / 33 / 50	23 / 33 / 50	1
Polarisation	Single/Dual/ Cirular/Full	Single/Dual/ Cirular/Full	Single/Dual/ Cirular/Full	Single/Dual/ Cirular/Full	Single/Dual/ Cirular

Table-2 Features of Modes of Operation

1.3 Mission elements

To meet the defined mission objectives, various components as required by the mission including SAR payload, satellite, orbit, satellite management in orbit and data handling on ground have been defined. This mission will be operational in nature. Mission specifications are similar to contemporary international missions. SAR payload has a multi-mode capability to cater the following:

- Continuous fine resolution strip mode for initial reconnaissance, infrastructure development applications, disaster management etc.
- Wide swath ScanSAR mode for agriculture, forestry, flood mapping, geological applications etc.
- High resolution spotlight mode for special applications.

The satellite is fabricated to have agility for maximizing the imaging in high-resolution mode with data transmission in real time as well as in storage mode. EOS-04 technology has been so chosen that the continuity is maintained with RISAT-1 mission. Mission Elements of EOS-04 which led to the development of user-friendly data products and data archival is presented in Figure-1.

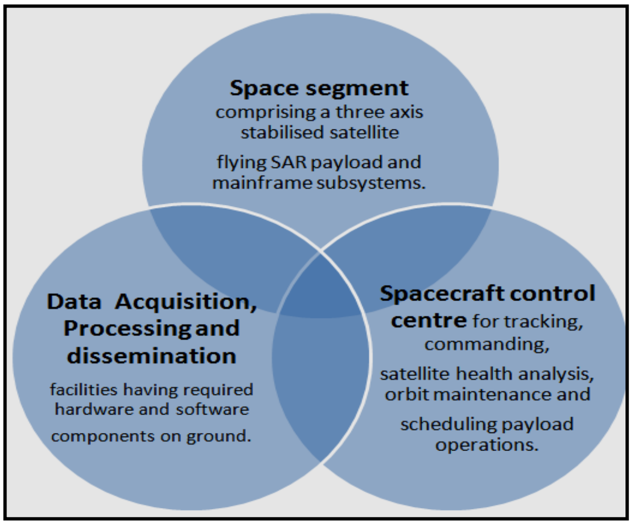


Figure-1 Mission elements of EOS-04

Chapter-II

2. EOS-04 Satellite Overview

2.1 System Overview

EOS-04 Synthetic Aperture Radar (SAR) payload is a multi-mode SAR which operates from a sun-synchronous orbit at a nominal altitude of 524.87 km. The satellite has the capability to store up to 1.4 Tb of data in the Solid State Recorder (SSR) on-board. The on-board data transmitter can transmit with a maximum data rate of 640 Mb/sec. in X-band, in two polarizations on the same X-band carrier. Based on the mission objectives, the basic imaging modes for this payload are as follows:

- Coarse Resolution scanSAR Mode (CRS): 50 m resolution, 223 km swath, Single, Dual, Circular/ Full-Pol.
- Medium Resolution scanSAR Mode (MRS): 33 m resolution, 160 km swath, Single, Dual, Circular/ Full-Pol.
- Fine Resolution Stripmap Mode-1 (FRS-1): 3 m resolution, 25 km swath, Single, Dual, Circular/ Full-Pol
- Fine Resolution Stripmap Mode-2 (FRS-2): 3 m resolution, 20 km swath, Single, Dual, Circular/ Full-Pol.
- High Resolution Spotlight Mode (HRS): 1 m resolution and 15 km swath, Single, Dual, Circular.

FRS-1 is a conventional stripmap mode of SAR operation. MRS and CRS are 8 and 12-beam ScanSAR configuration respectively. High Resolution Spotlight mode (HRS) has been added to provide a spotlight image of 10 km × 15 km with better than 2 m resolution in co and/or cross polarization. Provision is also made for an experimental capability to increase the azimuth extent up to 100 km in HRS mode which is called sliding Spotlight mode.

The Ground Segment consists of:

- A Telemetry Tracking and Command (TTC) segment comprising of a TTC network to provide optimum satellite operations and a Mission Control Centre for mission management, spacecraft operations and scheduling.

- An Image segment comprising of data reception, data processing and product generation systems along with centralized data dissemination centre.

2.1.1 Frequency and Polarization Selection

The selection of operational frequency and polarization are driven by the applications, demanding a wide range of resolution / swath / polarization combinations. From resolution considerations, resolution cell should be sufficiently large in comparison with the wavelength (about 10 times the wavelength). Hence, typically 3 m is the highest resolution in L-band, 1.5 to 2 m in S-band, 1m in C/X-bands and 10-20 cm in Ku/Ka band. Higher resolutions (1 m or better) are feasible for C-band frequencies and higher because of bandwidth allocation considerations. Total bandwidth allocation for radar applications is 1-2 GHz for L-band, 4-8 GHz for C-band, 8-12 GHz for X-band and 12-18 GHz for Ku-band.

For ground mapping and coastal applications like oil slick & ships detection, etc. C and X-band are preferred. For civilian applications like agriculture, soil moisture, forestry, flood mapping and ocean related studies, both C and L band with cross polarization are preferred. Ocean related studies are served best by VV-polarization and land related studies are aided by HH-polarization. Provision of both co and cross polar data aids significantly in discrimination of features. Co-polar return is mainly affected by surface or canopy scattering. Cross-polar return is mainly governed by volume scattering which depends on penetration through canopy/surface. So, higher the frequency poorer will be the return in cross-polarization. Hence, polarimetry is best suited in lower frequency bands like P, L and C. Polarimetry is not usually applicable for X band higher frequency bands.

These considerations have led to the choice of C-band frequency operation with single/dual/quad polarization capability to exploit the maximum gamut of applications.

2.1.2 Modes of Operation

The EOS-04 SAR operates in C-band at a frequency of 5.4 GHz. The spacecraft altitude has been fixed at 524.87 km from the 17 day repeat cycle considerations. The SAR system has been designed to provide constant swath for all elevation pointing and almost near constant minimum radar cross section performance. The proposed SAR will operate in the following basic modes.

- **Fine Resolution Strip map Mode (FRS-1 and FRS-2)** 25 km swath with 3m resolution. This mode (Figure-2) is based on strip map imaging, which is the conventional mode of SAR. In this, the orientation of the antenna beam is fixed with respect to flight path so that a strip of constant swath (here, 25 km) is illuminated along the flight direction. Slant Range resolution is 2 m and 4 m for FRS-1 and FRS-2 respectively due to variation in range bandwidth.

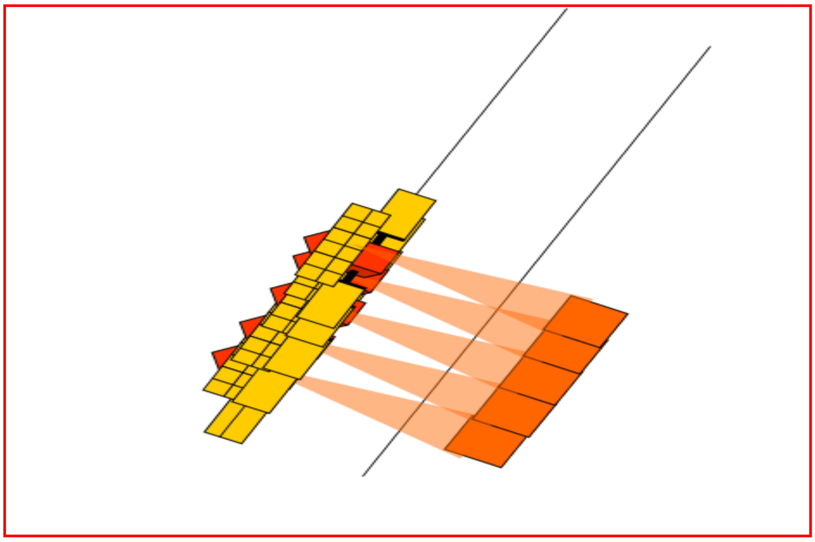


Figure-2 FRS 1 – Strip map mode

- **Coarse Resolution ScanSAR Mode (CRS)** 223 km swath with 50 m resolution. The ScanSAR mode allows for a multifold increase of the range swath dimension. This is achieved by periodically stepping the antenna beam to the neighboring sub-swaths (in the range direction). In this case, the radar is continuously ON, but only a portion of the full synthetic antenna length is available for each target in a sub-swath. This causes a degradation of the achievable azimuth resolution with respect to the strip map case. In other words, the range swath dimension increases at the expense of azimuth resolution. In the CRS-mode of EOS-04, the 12 beams cover each sub-swath of 20 km (either side of the intermediate sub-swaths will have an overlap of 10 km from the preceding and succeeding sub-swaths, thereby reducing the effective sub-swath width from 30 km to 20 km). Therefore, total swath in CRS mode would be 223 km.

- **Medium Resolution ScanSAR Mode (MRS)** 160 km swath with 33 m resolution. This is a 8-beam ScanSAR mode and is similar to the CRS mode.
- **Full-Polarimetry Mode** is a newly introduced mode and has wide field of applications. In this mode, receive path PRF is doubled and in transmit path alternate PRFs are used for transmitting H-pol and V-pol signal. Swath/Sub swath of 20 km over range coverage from 100 km to 400 km off-nadir by different look angles will be available with this mode. The mode is being implemented without any hardware change, neither on the payload nor on the spacecraft. This is available in imaging modes FRS-1, FRS-2, MRS and CRS with reduced swath with details provided in Table-3.
- **High Resolution Spotlight Mode (HRS)** with 1 m resolution. In the spotlight mode (Figure-3) the antenna beam is oriented continuously to illuminate a particular spot on the ground. This way, the target aperture time is increased which results in improved azimuth resolution (compared to that in the stripmap case). The improved resolution is obtained at the cost of azimuth coverage. The latter is partly improved by making use of sliding spotlight mode (hybrid spotlight-stripmap mode). This imaging would be done over a spot size of 10 km x 15 km. Azimuth extent can be extended to 100 km also.

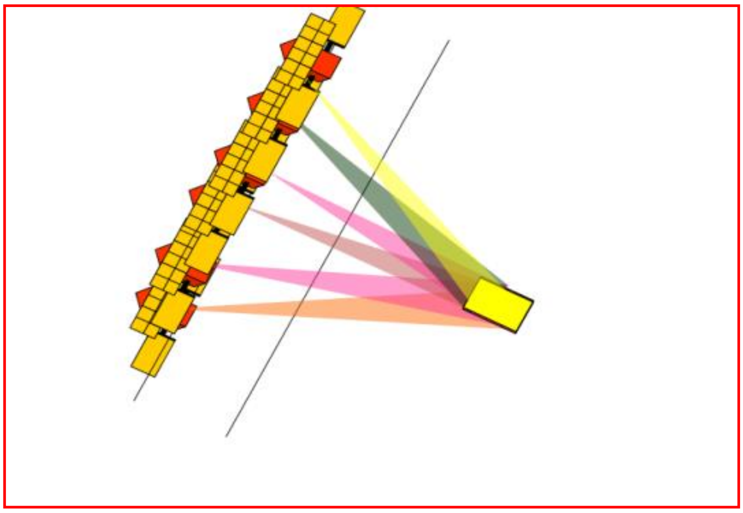


Figure- 3 HRS – Spot mode

2.1.3 Polarization:

EOS-04 can be operated in various polarizations namely linear, dual, full-pol, and circular. The details of the operable polarizations for different modes are provided in Table-3.

Imaging Modes	HRS	FRS-1	FRS-2	MRS	CRS
Swath (km)	15	25/20#	25/20#	160/115#	223/168#
Polarization	Single, Dual, Circular	Single, Dual, Circular/ Full-Pol	Single, Dual, Circular/Full-Pol	Single, Dual, Circular/Full-Pol	Single, Dual, Circular/Full-Pol

Table-3 Imaging Modes, Swaths and Polarizations #Full-Pol

An Electromagnetic (EM) plane wave has time-varying electric and magnetic field components in a plane perpendicular to the direction of travel. The two fields are orthogonal to one another, and are described by Maxwell's equations. Polarization refers to the alignment and regularity of the electric and magnetic field components of the wave, in a plane perpendicular to the direction of propagation. The electric field of plane wave can be represented as the vector sum of Horizontal and Vertical components and is characterized by their amplitude and relative phase. Figure-4 shows the polarization ellipse which is formed when we view the wave along the direction of propagation. The ellipse has a semi-major axis of length - a, and a semi-minor axis of length - b. The angle of the semi-major axis, measured counter-clockwise from the positive horizontal axis is the "orientation (ψ)" of the EM wave and can take on values between 0° and 180°. The degree to which the ellipse is oval is described by a shape parameter called "eccentricity" or "ellipticity", defined as $\chi=\arctan(b/a)$, which can take values between - 45° and +45°.

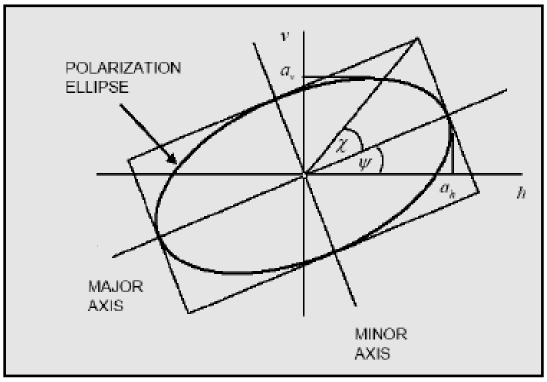


Figure-4 Polarization Ellipse

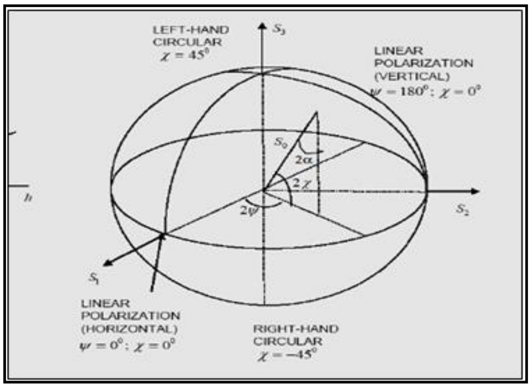


Figure-5 Poincare Sphere

The polarization state of a plane wave can be described by orientation and ellipticity, plus a parameter S_0 that is proportional to the total intensity of the wave. For a completely polarized wave, the polarization state can be described by a point on the Poincare sphere as shown in Figure-5. The latitude of a point on the sphere corresponds to 2x, i.e. two times the ellipticity of the wave. The longitude of a point on the sphere corresponds to 2ψ. We can see from this notation that linear polarizations lie on the equator, with Horizontal and Vertical polarizations opposite each other. Left-hand circular and right-hand circular polarizations lie on the north and south poles respectively. All other points on the sphere represent elliptical polarizations of various ellipticities (χ) and orientations (ψ). Points on the sphere that are directly opposite to one another represent polarizations those are orthogonal to one another and are referred to as cross polarizations.

SAR is a high resolution imaging RADAR, which transmits electro-magnetic waves, and receives the backscattered energy from the targets. A conventional SAR with any of single/dual polarization combinations (HH/HV/VV/VH) does not fully exploit the vector nature of scattered wave resulting in a loss of additional information about the target. Hybrid polarimetry caters significantly to address the same. In Hybrid polarimetry mode, transmission is in circular polarization and reception is simultaneous in both H and V polarizations. This hybrid polarimetric data provides more information compared to single/dual polarimetric data for analyzing the behavior of the various classes of targets. In EOS-04, hybrid polarimetric imaging can be done in all the modes - Spotlight, Stripmap and ScanSAR. In case of Full Polarimetric mode, the SAR alternates the polarization of each transmitted pulse (while effectively doubling the PRF) and receives in both H & V polarization simultaneously. All the target properties can be extracted from this mode, with an implication in terms of increased data rate and reduced swath.

The following are the significant advantages of Hybrid Polarimetry over Full Polarimetry

- Wider swath than full polarization
- Low PRF requirement resulting in less hardware constraints
- Higher incidence angle range coverage

Circular Polarimetric Modes (C-HRS, C-FRS-1, C-FRS-2, C-MRS, C-CRS):

All the modes of EOS-04 can be operated in hybrid-circular polarization. This is achieved by transmitting H & V polarized signals simultaneously but with a relative phase-shift of 90°. Hence, the transmit signal is in circular polarization and the receive signal is in linear (dual-polarization) – this makes it a hybrid-circular polarization operation. To keep the average power-requirements same as the original specifications, the pulse-width is reduced to half. Also it should be remembered that, as it is a side looking active sensor, around 107 km on either side of the sub-satellite track comes under non-imaging area for that orbit.

2.1.4 EOS-04 Imaging Geometry

In order to provide greater flexibility in the selection of the look angles for different applications and to increase the effective repeatability, a region on the ground may be accessed by different look angles ranging from 11° to 49° corresponding to off-nadir distances of 107 km and 659 km respectively. The repetivity for MRS mode will be 17 days cycle. This look angle variation is effected by electronic switching of the antenna beam in the elevation direction. This electronic switching of the beams is also necessary for ScanSAR modes of operation (MRS / CRS). SAR will operate with basic elevation beam width of 2.18° - 1.47°, over a total ground distance of 552 km, starting from an off nadir distance of 107 km and up to 659 km. Figures-6 & 7 show the basic system geometry of the SAR operation in all the above mentioned modes. The variation of the look angle and incidence angle for various off-nadir distances is also illustrated. The major mission parameters for space borne high resolution SAR are specified in Table-4.

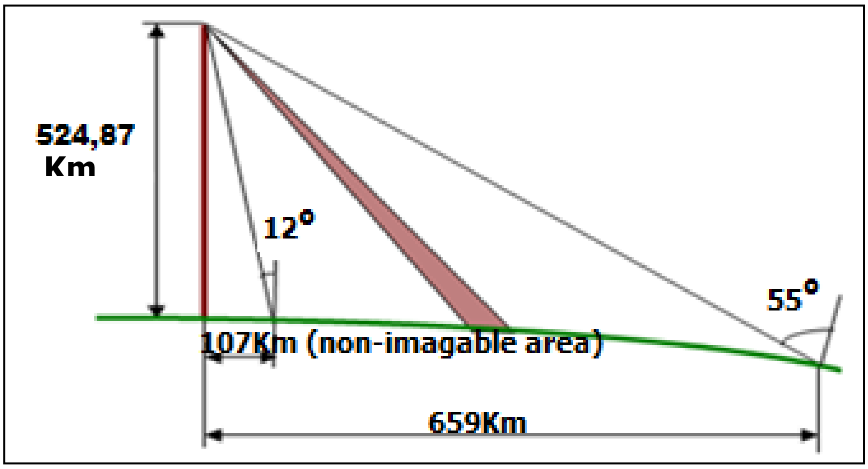


Figure-6 Basic system geometry

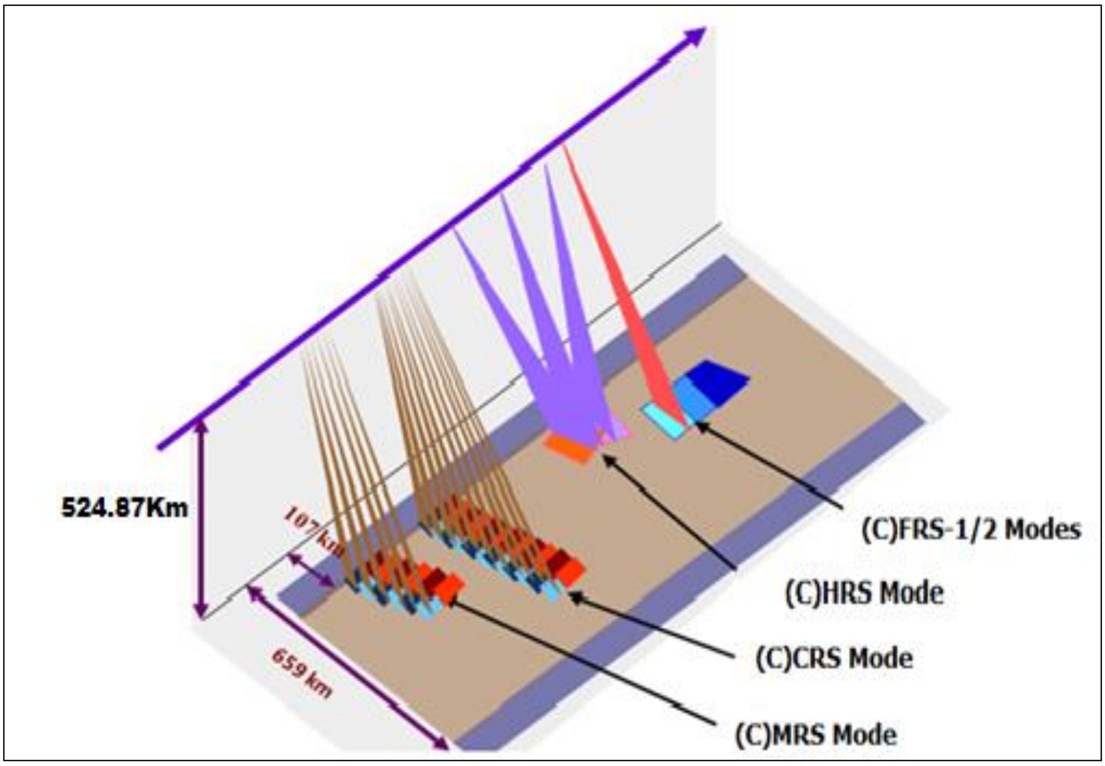


Figure-7 Operating modes of EOS-04 SAR

Altitude (km)	524.87	
Roll bias (deg)	36	
Spacecraft velocity(km/s)	7.6	
Look Angle (deg)	11.5-49.6	
Incidence Angle (deg)	12.4-55.5	
Range Coverage (km)	107-659	
Slant Range (km)	548-870	
Az Beamwidth (deg)	0.47	
EL Beamwidth (deg)	2.18-1.47	
Spacing between adjacent beams (in km)	9	
Swath for each beam (in km)	25	
Overlapping between alternate beams (each Side in km)	7	
Data Window (in microsec) @ 30 km Swath	62.98-184.32	
Doppler BW(Hz)	2532.23	
Mode	FRS-1/FRS-2/ MRS/CRS	HRS
Ground range resolution(m)	9.4-2.4 / 8.8-4.9 / 37.7- 9.8 / 37.7-9.8	3.3-0.85
Azimuth Resolution(m)	3/ 3/ 21-23/ 41-55	1
Swath (km)	25/25 /160/ 223	15
Slant range Resolution	2/ 4/ 8/ 8	0.7
Doppler BW (Hz)	2532.23	3000-3700
Nominal PRF (Hz)	3000	3500
Worst Sigma Naught (in dB) Considering both qualified and unqualified regions (100 km-700 km)	-18.22@22 km -16.81@25 km -13.33@30 km	-15.82@10 km
Worst-case Range Ambiguity(in dB) @ Nominal PRF	-16.94@22 km -15.6@25 km -13.4@30 km	-15.99@10 km
Worst case Azimuth Ambiguity (in dB) @ Nominal PRF	-21.47	-25.20
Data window (µs) @nominal earth radius of 6371 km	63-184 (@30 km swath)	80-165 (@10 km swath)
Worst-case Range Ambiguity (in dB)@ Nominal PRF	-16.94@22 km	

Table-4 SAR Mission Parameters

2.1.5 Antenna configuration in brief and Elevation beamwidth considerations

Area of the SAR antenna is dictated by the frequency band of operation, and is of the order of 12 sq m for C-band operation. Hence, EOS-04 active antenna is configured with 6 m (azimuth) x 2 m (elevation/range) dimensions, with 288 pairs (V & H) of TR-modules. The EOS-04 antenna consists of three panels each of 2 m×2 m size, as shown in Figure-8, to facilitate stowing during launch and later deployment in the space. The longer dimension of the antenna is aligned with azimuth direction and the width in the elevation/range direction. Each panel consists of 4 tiles of size 1 m×1 m, each consisting of 24×24 radiating elements. In the azimuth direction (antenna length) 24 elements are grouped together to be fed by a single TR-module pair (V/H polarization), hence we have 6 TR-module pairs in the antenna length direction. Each radiating element in the width direction is fed by a different TR-module pair, hence there are 48 (=24 x 2 m) TR-module pairs in the antenna width. The total number of TR-module pairs is therefore 288 (=6 m x 48). The inter-element spacing has been kept 0.7λ, where λ stands for wavelength which is 5.6 cm. If the spacing between the radiators is more than this, grating lobes will occur in the antenna patterns. At the junction of two tiles, the inter-element spacing is 1.4λ, therefore, one blank row of radiating elements may be assumed which is at a distance of 0.7λ from the nearest radiating elements from the adjacent tiles. In short, 49 rows of TR-modules may be assumed in the antenna width (for system analysis purposes), with the centre row as a hypothetical blank (inactive) one to attribute to the inter-tile spacing.

Elevation beam width will be made to vary with pointing angles in order to achieve pointing-independent swath of 25 km and constant minimum radar cross section performance. If the antenna beam width is kept constant, there will be varying footprint size in the range direction, due to change in slant ranges. At near off-nadir distances, the beam footprint will be smaller than the desired 25 km. Hence, in order to maintain the constant footprint of 25 km, the beam width is increased by switching off the TR-modules and in effect reducing the electrical width of the antenna (at near off-nadir distances). The TR-modules are switched off in the width direction, equally from outer edges of the adjacent two tiles, as shown in Figure-9.

Hence, elevation beam width is varied from 2.18° to 1.47° corresponding to off-nadir distances from 107 km to 659 km, respectively. The corresponding number of active TR-module rows in the elevation direction is illustrated in Figures -8 & 9

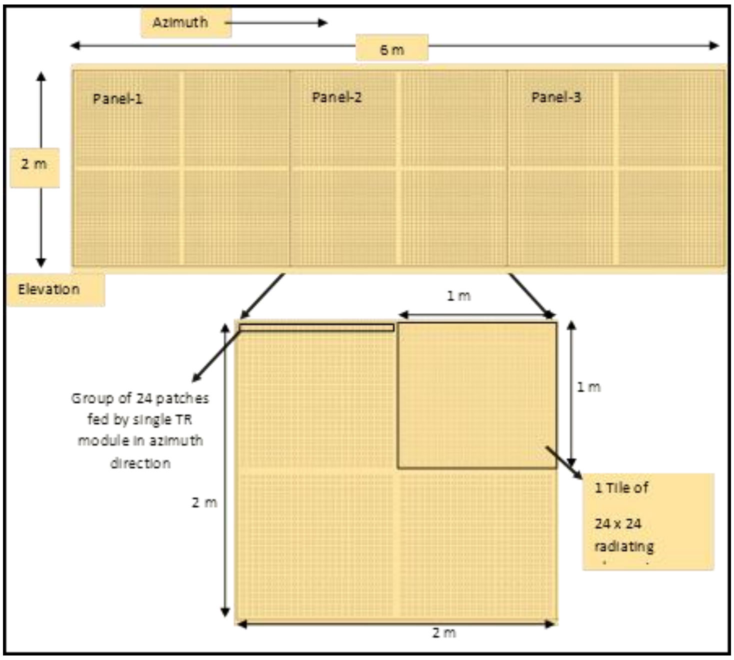


Figure-8 Distributed antenna for high resolution SAR

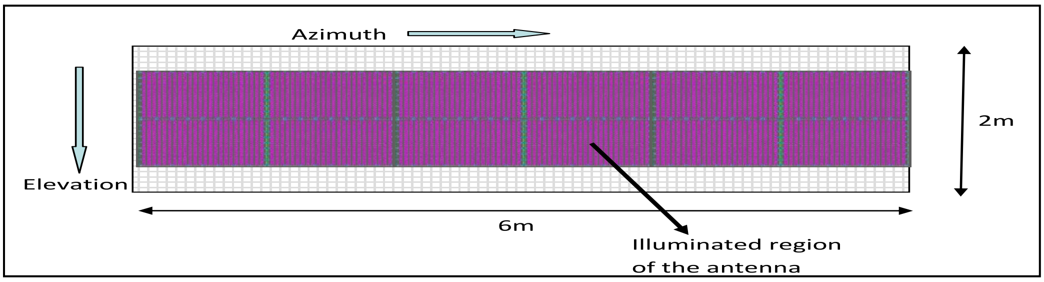


Figure-9 Change of antenna electrical width to cater to variable elevation

2.1.6 Selection of PRF for different Beam positions

The Doppler bandwidth corresponding to antenna length of 6 m and spacecraft velocity of 7.5 km/s will be 2500 Hz. Hence, the PRF should be greater than about 1.1 times the Doppler bandwidth, i.e. 2750 Hz. Changes in slant range corresponding to off-nadir distance change from 107 km to 659 km, lead to different echo start times and variable data windows. To accommodate the same, variable PRF is necessary. Therefore all the modes, except for HRS, have PRF between 2800–3200 Hz. Maximum PRF is limited by the minimum data window that has to be accommodated. In the case of HRS mode, Doppler centroid estimation (for different sub-apertures) requires additional 500 Hz (over the Doppler bandwidth of 2500 Hz), therefore PRF would lie between 3000 – 3700 Hz. This large range of PRF is required to satisfy the slant range change during pitch tilting of the satellite for azimuth coverage of 100 km, for each of the off-nadir distances. The slant range varies from ~548 km to 870 km for off-nadir positions of 107 km to 659 km respectively.

2.2 EOS-04 Space Segment

EOS-04 system configuration:

EOS-04 is built around a bus for ongoing IRS missions in the weight class of 2000 kg. The main structure of EOS-04 consists of one single cylinder of ~3.4 m height. The bottom side of the cylinder has a truncated triangular structure to hold the SAR antenna and major bus service elements. At the top side of the cylinder, a cuboid structure to accommodate the solar arrays, majority of the sensors and antennae is provided. The triangular structure with SAR antenna is identified as PAYLOAD module and the cuboid's structure with solar arrays is called as SOLAR PANEL module. Sufficient gap is available between the payload module and the solar panel module so that there is no interference between the solar array and the SAR antenna in launch configuration as well as on-orbit configuration. Synthetic Aperture Radar is an active planar array antenna. SAR antenna comprises of three panels. Each panel consists of four tiles. The 4 tiles are supported and held with a sandwich frame. The tile assembly with radiation patches and supporting electronics is bonded on to a sandwich panel, which has embedded heat pipes and OSR area to manage the heat generated by the tile assembly. The three panels of SAR antenna are held on to the triangular structure in launch and ground handling operations. The central panel of antenna is rigidly held to the triangular structure and the other two panels are deployable. The total mass of the satellite is 1715 kg in which the SAR antenna is of 854 kg approximately.

Coordinate System & Panel Nomenclature: The center of gravity (CG) of the satellite is taken as the origin of the co-ordinate system. This co-ordinate system is followed for the satellite attitude control and attitude determination purposes. Figure-10 describes the axes definition of EOS-04 mission.

Positive Yaw Axis from CG towards and perpendicular to SAR antenna in deployed configuration (towards center of earth).

Positive Pitch Axis from CG towards the bottom deck of the triangular structure supporting the SAR Antenna.

Positive Roll Axis Perpendicular to +ve Yaw and +ve Pitch axis completing the Right handed system. Roll axis is along the deployed SAR Antenna.

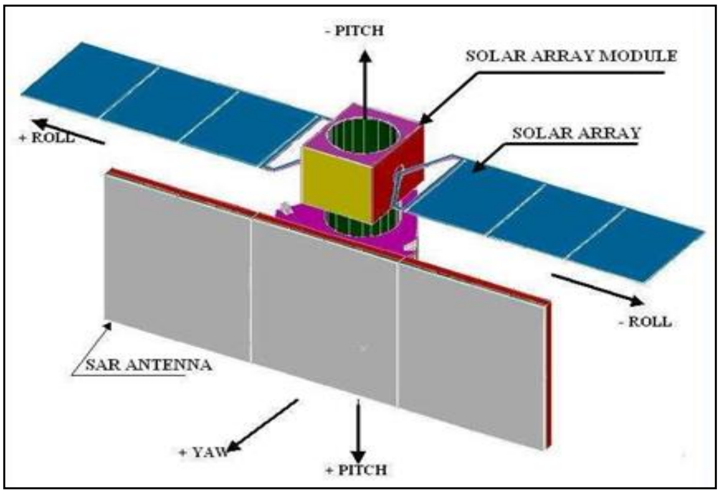


Figure-10 Deployed Configuration of EOS-04

2.3 EOS-04 Subsystems overview

2.3.1 Attitude and Orbit Control System (AOCS)

The EOS-04 orbit is a 6'O clock orbit. In the normal earth pointing mode, the negative pitch axis will be looking towards sun. By taking advantage of this orbit geometry, initial sun acquisition is carried out about negative pitch axis as against negative yaw axis. Once the negative pitch axis is made sun pointing further earth acquisition and yaw acquisition, became very easy and the entire three axis acquisition can be completed. The solar panel will be nominally in the yaw roll plane (orbit plane) perpendicular to the sunline. The SAR antenna will be in the roll pitch plane. To avoid the plume impingement in the solar panel and the SAR antenna, the thrusters are mounted along the negative pitch face of the spacecraft. The desired pointing stability and orbit requirements of the payload under normal operation are as follows:

Payload pointing accuracies

Yaw, Roll & Pitch = 0.05°

Drift rate = $3.0X10^{-4}$ °/sec.

The Attitude and Orbit Control system (AOCS) consists of various types of sensors for measuring attitude errors, control electronics implemented in On-Board Controller (OBC). Actuators such as reaction wheels, magnetic torques and thrusters impart thrust/torque to the space craft in the desired direction. The OBC generates control signals for the actuators, as a function of attitude errors, rates and depending on the operating modes, to provide the desired orientation and stability of the spacecraft despite various disturbance torques acting on the space craft. Three axis stabilization in EOS-04 is achieved by zero momentum system consisting of four reaction wheels mounted in tetrahedral configuration. The control applications of different attitude sensors are given below in Table-5.

Sl. No	Sensor	Output	Used For
1	Earth Sensor – 2Nos.	Observed Roll chord widths and pitch errors	Earth Acquisition, roll and pitch control during normal/thruster modes
2	IRU (Three DTG)	Yaw, roll and Pitch incremental angles	All modes of operation except safe mode and thruster control modes with back up controller
3	4 Pi Sun Sensor	Yaw, Roll and Pitch direction cosines	Sun Acquisition, 3-axis attitude determination on-ground
4	Magnetometer – 2Nos.	Earth's local Magnetic field components along yaw, roll and pitch axes	Momentum Dumping and 3-axes attitude determination on ground
5	DSS	Yaw Error, Roll Error	Yaw updates for DTG Yaw Acquisition
6	Star Sensor	Raw centroid data , Inertial quaternion's	Normal mode onboard AD
7	SPS	Spacecraft position measurements	Normal mode star sensor AD and SNS Imaging

Table-5 Control applications of different attitude sensors

The functional classifications of operational modes of AOCS are listed below:

- SSQ
- Sun Acquisition
- Rate Damp
- Yaw Acquisition–With DSS/DTG
- Orbit Maneuvering
- Normal mode– SSQ, SKFQ, ES-DTG, Dynamic observer
- Safe Mode–Hardware/Software
- Suspend mode

In addition to the above mentioned operational modes, AOCS incorporates the following features like:

- Auto Acquisition Sequencer
- Orbit Maneuver Sequencer
- Thruster Selection Logics
- Manual Thruster Firing
- Three axes momentum dumping
- Orbit position and rate computation from SPS
- Imaging Reference Computation
- Dynamic Friction Compensation
- Auto Reconfiguration of RW Control
- Over speed Protection
- Wheel spike Filter
- Earth sensor Spike Filter
- Gyro scale factor and misalignment correction

2.3.2 On Board Computer (OBC)

The following are the features of the system depicted in the Figure-11

- ASIC Based OBC for OBC 10&20 (Main and Redundant)
- OBC 30 for Hardware Based Sun for Safe Mode and Contingency TM

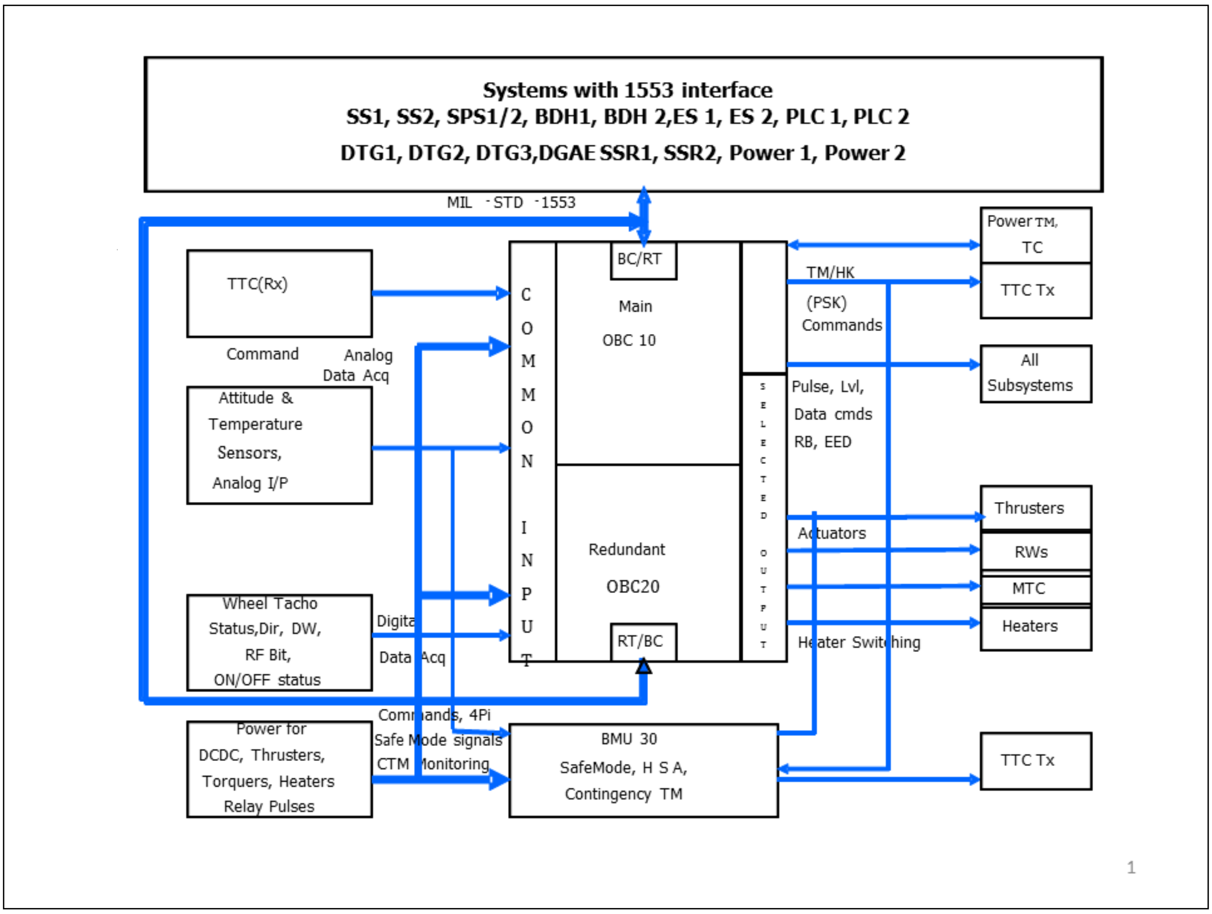


Figure-11 OBC Architecture

2.3.3 Power

EOS-04 Power System consists of Solar-array for power generation, chemical Battery for power storage and power electronics for power conditioning and distribution. The total peak power requirement is 4650 W. The solar array generates a worst case minimum of 2298 W (Summer Solstice and normal incidence at EOL with no string failure). The rest is supported by battery. The power system for EOS-04 is designed to meet the 6 AM/6 PM orbit illumination conditions, to cater to large power requirement of Synthetic Aperture Radar payload and eclipse conditions during summer solstice. The power system configuration is arrived to meet all the user requirements and interfaces. During the sunlit period the array is regulated to 70 V and battery gets charged. Battery Discharge Regulators (BDRs) supports the bus in eclipse condition and during sunlit condition when the load demand exceeds the array generation during payload operation by regulating the bus to 70 V. Table-6 below provides the specifications.

Parameters	Specifications
Single 70 V regulated bus	70+ 2 V
U-bus (M&R)	45-72 V
Maximum Power requirement	4650 W peak (for 12 minutes of payload operation per orbit)
Power generation	2298 W (Summer Solstice and normal incidence at EOL with no string failure)
Bus regulation	PS3R during sunlit, BDR during eclipse and payload
Number of BDR Modes	3+1(3 kW bus) hot redundancy
BDR output power capability	3000 W (with one module failure)
Ripple voltage	<300 mV
Max. Frequency	Free-running (Ripple regulated <15 kHz)
Maximum load current	66 Amps (in sunlit)
Battery	16 Cells, 135 AH, Li-ion Battery
Battery Voltage	45 V (With one cell failure) to 67.2 V
Maximum battery discharge current	58 Amps for battery discharge @50 V (during payload operation)
Total Bus Capacitance	5000 µF

Table-6 Power Parameter specifications

2.3.4 Thermal

Thermal control will be provided using space proven thermal control elements such as OSR, MLI, paints, thermal control tapes, quartz wool blanket, sink plates and heat pipes. Heaters will be provided to maintain temperatures during cold conditions.

The orbit and orientation of EOS-04 gives rise to the following factors that decide the thermal design approach of the main bus as well as payload.

- No eclipse during winter and equinox
- Eclipse only during summer (22 minutes maximum)
- Sun rays incident on SAR radiator with small incident angle resulting in high temperature

- More earthshine load on Earth viewing panel due to reduced altitude
- Reduced albedo load due to 6 AM/6 PM equatorial crossing time

2.3.5 Solar Array Deployment Antenna (SADA)

In EOS-04, due to the 6 AM geometry, the panels are in the orbit plane. In order to keep the panels normal to the sun, SADA is required to rotate the panels along the roll axis to make up the change in sun declination seasonally. The rotation requirement of SADA is as sinusoidal pattern over an orbit and the amplitude of the sinusoidal curve varies with season. Unified SADA electronics can be operated in two modes viz., autonomous mode and AOCE mode. In AOCE mode, SADA receives rate command from AOCE and the rotation rate and direction are determined by data command. In Auto mode, the rotation and the direction are determined by the Sun sensor error as well as the Sun Presence Signal (SPS). Micro stepping of the panel minimizes the periodic disturbance to the spacecraft. In a micro-stepping scheme, additional intermediate steps are created between the physical steps of the step per motor by properly modulating the excitation to two consecutive coils. On each Slew clock, the stepper motor is made to advance by one micro-step in clock-wise or counter clock-wise direction depending on the direction of rotation signal. All basic motor driving signals are stored in 2 PROMs for all types of driving modes. Since the operation of the solar array drive mechanism is critical to the mission, complete redundancy in all electrical circuits including motor coils, potentiometer tracks, electronics and DC/DC converters are provided.

2.3.6 Satellite Positioning System (SPS)

The Satellite positioning systems of EOS-04 comprises of 12 channel Multi GNSS Receiver (MGR-1) at L1 (1575.42 MHz) and L5 (1176.45 MHz) frequencies for receiving NAVIC, GAGAN and GPS constellation signals. SPS is designed for computing state vector of high dynamic platform.

2.3.7 Reaction Wheels

There are four 50 Nms reaction wheels mounted in a tetrahedral configuration. The Wheel Drive Electronics has interface with Power and OBC. The reaction wheel operates in Torque Control Mode. Apart from the friction compensator there is a dynamic friction compensator, over limit check at wheel end.

Specifications for Wheel:

Angular momentum: 50 Nms at 4400 rpm, 68 Nms at 6000 rpm

Speed: ±4400 rpm

Reaction Torque: 0.3 Nm

Bias Torque: without DFC – 0.01 Nm, With DFC – 0.0005 Nm

2.3.8 IRU

EOS-04 carries three miniature gyros having the following specifications:

Maximum input range: ± 20°/sec.

Normal mode input range: ±3°/sec.

Short term stability: 0.15°/Hr (max)

2.3.9 Mechanism

Solar panel deployment takes place after 80 secs. from SNAP, where as the SAR Panel Deployment takes place 95 secs. from SNAP. The duration for SAR panel deployment is around 100 secs.

2.3.10 Dual Gimbal Antenna (DGA)

Dual Gimbal Antenna mechanism is required for downlinking of payload data to the ground stations. These mechanisms are meant to steer the antenna along the given profile to give a near hemispherical coverage for near real time data transfer.

2.3.11 Reaction Control System (RCS)

EOS-04 RCS system is a mono propellant hydrazine system operating in blow down mode. It employs eight 11N thrusters and a centrally mounted 11N thruster for orbit rising maneuvers. The thrust vector of the central thruster passes through the center of gravity of the satellite. There is no redundancy for the central 11N thruster and the fuel supply is from one block only. All the 11N thrusters are qualified to operate in pulse mode operation. The ON/OFF modulation is carried out from 0 to100%.The thrusters have been mounted with two axes canting within the available mounting space to achieve higher torque levels.

2.3.12 Solid State Recorder (SSR) salient features

BDH sends formatted data to SSR for recording and then forwards at RF downlink rate. The maximum output data rate from the BDH is of the order of 2.56 Gbps. To meet the BDH record bandwidth of 2.56 Gbps, four identical independent 12” x 12” advanced State-of-the-art NAND Flash Memory cards are used (two for main and two for redundant) with total capacity of 1.4 Tb for main and 1.4 Tb for redundant. The High Capacity single card configuration can support a total bandwidth of 1.28 Gbps. This bandwidth is shared across two record channels and a playback channel. Out of the high capacity, 700 Gb is usable for data storage and the remaining memory is reserved for parity storage and bad block management. Two independent record channels can handle continuous data rate of 640 Mbps per channel.

2.4 Payload and Data Handling System

For all modes of EOS-04, data rates are very high. Hence, data compression is a must for EOS-04. Therefore, flexible Block Adaptive Quantization is adopted to reduce the high data rates of the onboard raw data. The quantized 8-bit data is compressed into any of the 2/3/4/5/6 bits. The selection of BAQ bits can be commanded from ground.

Block Adaptive Quantization has the benefit of increasing the dynamic range of lower-bit data to that of the straight quantized data of same number of bits. The SQNR performance obtained with BAQ scheme is compared with that from conventional quantization. It is the only compression scheme that is suitable for compressing the SAR raw data, owing to its Gaussian characteristics. Other compression techniques like JPEG, LZW, etc. are suitable only for image data and not for Gaussian distributed SAR raw data.

In BAQ, a block of 128 range samples is averaged onboard and mapped to the scale factor given in the look-up-table. All the individual data samples within the given block are scaled down using this scale factor. This is repeated for all the blocks of the data window. Each 128 samples block will be encoded with 128 samples of lower-bit BAQ data along with one value of 8-bit averaged value of the block. The transmitted data consists of integer number of such blocks.

On ground, this BAQ encoded data is decoded using scale factor from inverse scale table corresponding to the transmitted block averaged value Figure-12 shows the comparison of impact of BAQ.

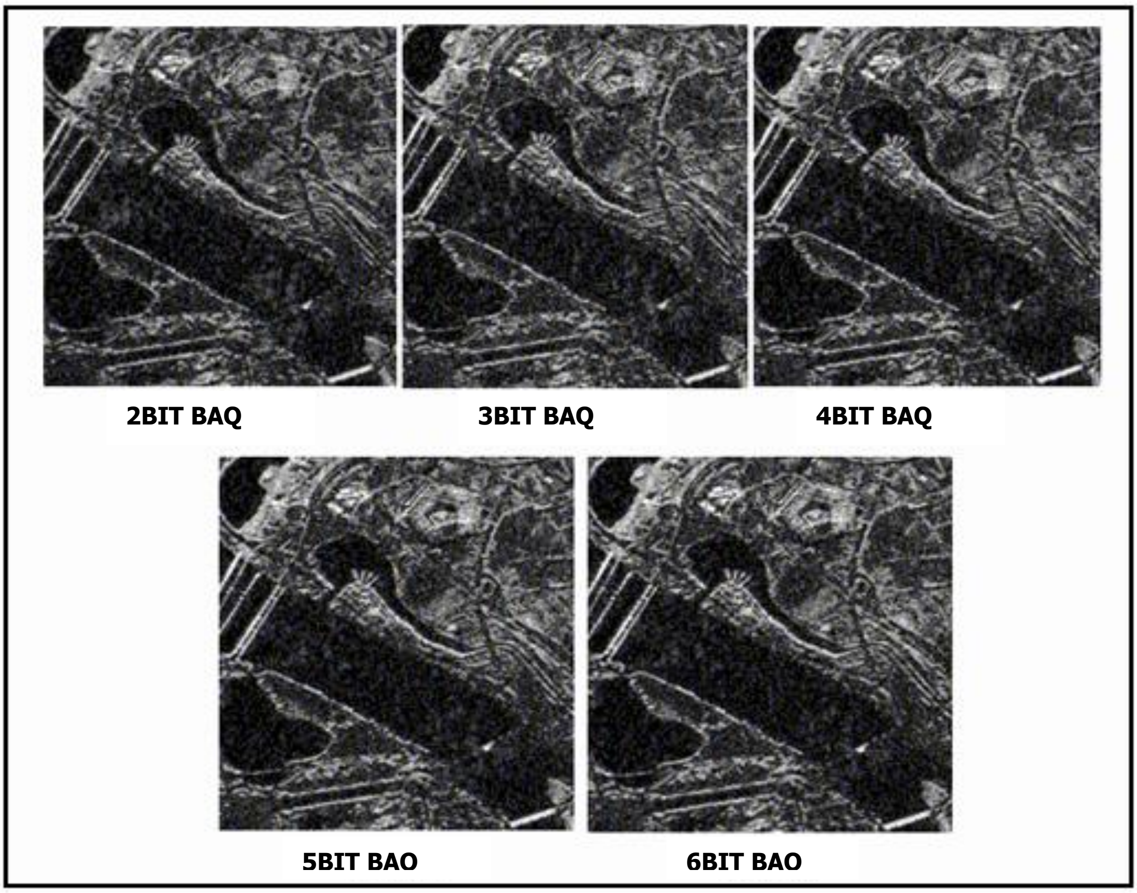


Figure-12 Images with 2/3/4/5/6/in compressions

2.4.1 Imaging with Real-Time Transmission

For EOS-04 SAR, maximum duration of imaging is 12 minutes per orbit. During this period, very large slant range changes would be encountered, thereby rendering single set of beam parameters inadequate. Hence, there is a necessity of periodic updation of beam parameters, if imaging duration exceeds particular limit.

As the beam parameters are highly dependent on satellite position (latitude), the lower and upper limits of these parameters are determined. Over the orbit, the minimum and maximum extent of RT duration is also derived with real-time transmission rate constraints (640 Mbps for Single-Polarization and 320 Mbps for Dual-Polarization).

In scanSAR operation, the total aperture time (corresponding to the azimuth footprint) is divided into different bursts. Each burst is used to illuminate different contiguous sub- swaths. For every beam, there will be some shift in the azimuth direction (w.r.t. the preceding beam), which corresponds to one burst duration. The shift in the azimuth direction depends on the number of beams (sub-swaths). For CRS mode, once the set of 12 beams is completed, the 13th beam will scan the area beside the first beam footprint in the azimuth direction, and the process is repeated. The same sub-swath position is repeated after every 12th beam. Hence, for N-beam scanSAR, the aperture time will be divided into (N+1) bursts. Each sub-swath coverage will be repeated after every N beams.

2.4.2 Scalloping Effect

Each target in the collected burst data undergoes amplitude modulation on account of the spectrum characteristic. Hence, targets at the burst ends have poorer intensity returns than those at the centre. Hence, the image after processing shows that targets at the centre of the burst are bright and those at the ends are dull, this image degradation is called scalloping effect. Figure-13 presents a simulated image with scalloping effect.

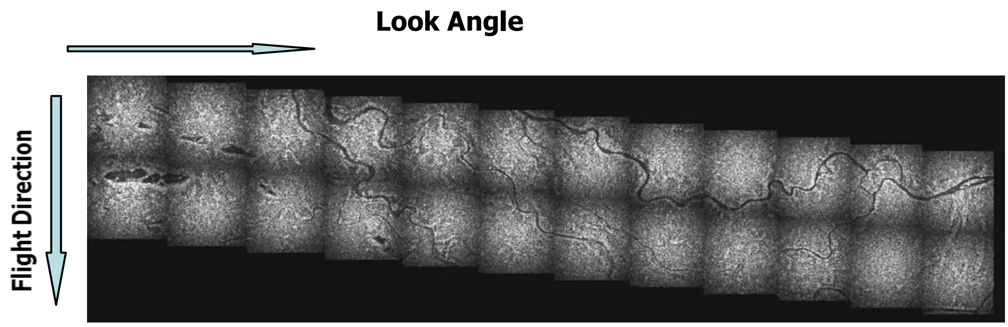


Figure-13 Illustration of Scalloping in a Simulated Image

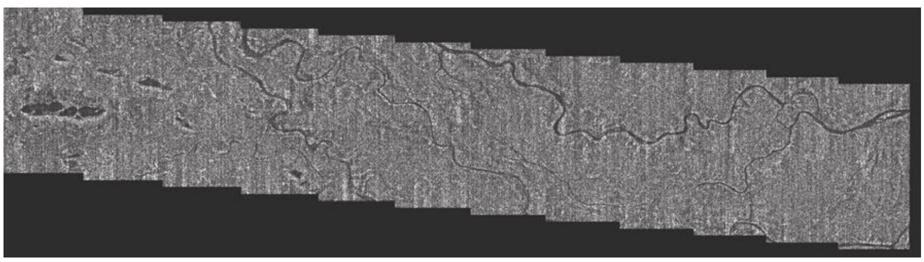


Figure-14 Image of the same area after Scalloping Correction

The scalloping effect is corrected by Doppler Centroid estimation and corresponding spectrum magnitude compensation. The scalloping corrected image is presented in Figure-14 above.

2.4.3 Key features of Sliding Spotlight Mode of Operation

In the spotlight mode, the antenna beam is oriented continuously to illuminate a particular spot on the ground. This way, the target aperture time is increased which results in improved azimuth resolution (compared to that from the strip map case). The improved resolution is obtained at the cost of coverage. The latter is partly improved by making use of sliding spotlight mode (hybrid spotlight-strip map mode). The simulation studies have been done for extended azimuth coverage up to 100 km in azimuth direction.

2.5 EOS-04 Orbit

The orbit is selected keeping in view the minimum number of days for systematic coverage in MRS and CRS mode. The orbit parameters are described in Table-7

Repeat cycle	257 orbits in 17 days
Altitude	524.87 km
Inclination	97.5 deg
Path-to-path distance	156 km
Mean Local Time	6 AM at descending node

Table-7 Orbit parameters

In the above orbit, it ideally takes 17 days for systematic global coverage with the same set of beams (i.e. with same incidence angle) in MRS mode. However this depends on the available resources (Mission and Ground segment).

2.5.1 EOS-04 Referencing Scheme

The referencing scheme implemented for EOS-04 is a generalized one due to the following factors.

- SAR operates in four different payload modes
- The swath for different payload modes can be placed anywhere within the range between 107 km and 659 km away from nadir

- Imaging is done in both ascending and descending passes
- Roll bias of ±36° are given to view on either side of the track
- SAR is always operated in off-nadir mode
- Hence the payload trace never coincides with the ground trace of the orbit from which it is operated
- The payload trace does not follow any one ground trace, but it crosses over many ground traces as shown in Figure-15

However to have ease of operations and for the user who use the same area for analysis again and again a pseudo reference scheme is formalized and implemented. Repeat cycle of spacecraft is 17 days. During systematic coverage or with same look angle geometry (with same orbital height and same view angle), same area can be viewed in multiple of 17 days. The primary requirement of referencing scheme is to use imaged area for Interferometric & FASAL like applications which require to super-impose scenes framed during one cycle to other cycle of imaging (Super-imposition of scenes provided by referencing scheme will be in latitude direction only, shift in longitude direction can be controlled by ground track maintenance).

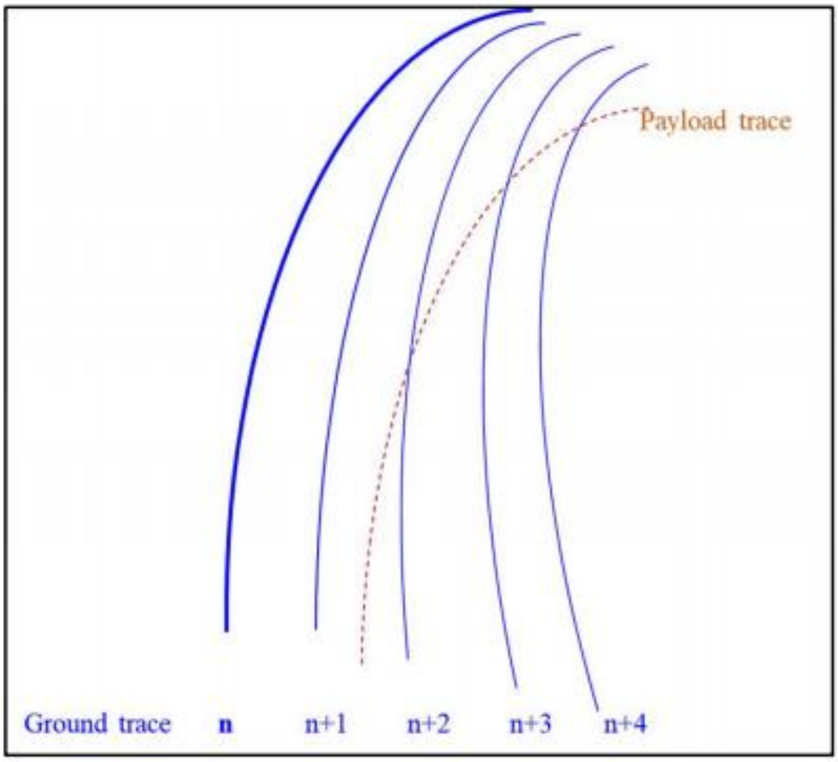


Figure-15 Payload trace with roll bias w.r.t ground trace

Design of Referencing scheme for FRS-1/FRS-2:

Latitude grid points are defined, which are used as scene centre latitudes. The scene sizes designed with scheme will be of length 20 km and swath varies as per beam width chosen. The scheme is designed in such a way that, same grid points are used as reference for descending as well as ascending imaging. Grid points are defined between ±70 deg latitude. Total no. of grid points is 888 within this range. Beyond ±70 deg, time-based scene framing is used. The grid designed and implemented ensures a consistent 10% along-track overlap between scenes. Scene framing with this referencing scheme will ensure superimpositions of a scene from one cycle to other cycle in the latitude direction.

Design of MRS based Referencing scheme (MREF):

MRS based referencing scheme is designed within ±70 deg latitude. The scene sizes designed with scheme will be of length 160 km and swath varies as per no. of beams chosen. Total no. of grid points is 111. With this scheme, 160 km x 160 km scenes can be generated with uniform overlap of 16 km for MRS-8 and 117 km x160 km for MRS-6. In this scheme also, same grid points are used as reference for descending as well as ascending imaging.

Design of CRS based Referencing scheme (CREF):

This scheme is also suited for interferometry and FASAL like applications and gives a non-square scene with uniform along-track overlap. Scene centre of CRS & MRS will exactly match, (Figure-16) if area is viewed with same geometry. The Scene Size considered is 223 km x 160 km with 10% Overlap in along track direction. The salient feature of this referencing scheme is that it can be generalized to any n-Beam Scansar Mode.

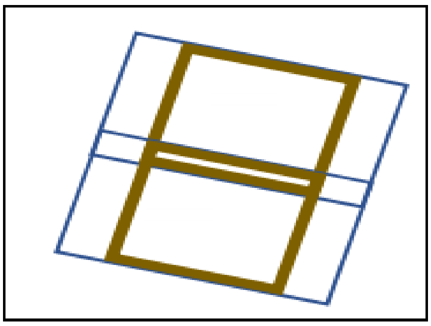


Figure-16 CREF referencing scheme

The sample diagram showing the graphical representation of the scenes acquired over the same area of interest in ascending and descending mode is given in Figure-17

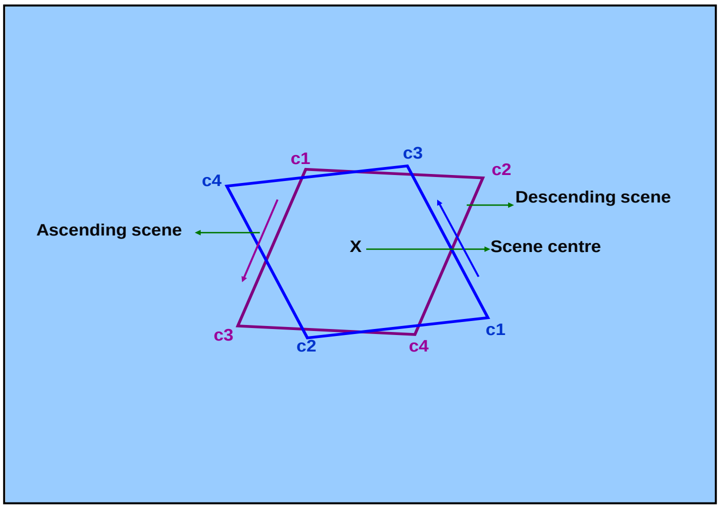


Figure-17 Ascending and Descending scene layout

Chapter-III

3. GROUND SEGMENT OVERVIEW

3.1 Introduction

The main functions of the Ground Segment are:

- Telemetry Tracking and Command
- Mission Control / Payload planning
- Data Reception
- Data Products Generation and Dissemination
- Data Analysis

Telemetry Tracking and Command (TTC) functions are carried out by ISRO Telemetry Tracking and Command Centre (ISTRAC) with its ground stations located at Bangalore, Lucknow and Mauritius, with selective support from external space agencies. The reception and Ingest of payload data is done at the earth stations of the National Remote Sensing Centre (NRSC), located at Shadnagar, Jodhpur & Antarctica. Mission Control support is provided from ISTRAC, Bangalore. The various elements of the EOS-04 Ground Segment are given in Table-8.

Element	Location	Functions
TTC	ISTRAC ground station at Bangalore, Lucknow, Biak and Mauritius.	1. Satellite housekeeping, data reception and recording. 2. Spacecraft commanding and tracking.
Mission Control	ISTRAC, Bangalore	1. Network coordination and control 2. Scheduling spacecraft operations 3. Spacecraft HK data logging 4. Communication links between concerned ground segment elements
Payload planning, Scheduling / Data Reception & Pre-processing	NRSC, Shadnagar, Jodhpur & Antarctica (AGEOS)	1. Planning of payload for user requests and other systematic collections. 2. Reception and Ingest of payload and SSR data and transfer to IMGEOS (at Jodhpur & AGEOS) 3. Generation of FRED, ADIF, OAT & Metadata for further Processing & Data Products Generation
Data products Generation, Dissemination and Analyses	NRSC, Shadnagar	1. Generation and distribution of different types of data products 2. Data quality evaluation, data and browse archival and management 3. Payload programming and request processing

Table-8 Various Elements and Functions of Ground Segment

3.2 TTC and Mission Operation Complex

3.2.1 Introduction

ISTRAC provides telemetry, tracking, telecommand, spacecraft operations and control support for EOS-04 mission through its network of ground stations, and Mission Operation Complex (MOX). MOX consists of mission control room, mission analysis room, simulation and training facilities, dedicated mission control room, computer facilities, flight dynamic operations and skyline communication facilities etc. TTC network comprises of a network of ground stations located at Bangalore (BLR), Lucknow (LCK), Mauritius (MAU), Sriharikota (SHAR), Trivandrum (TVM), Antarctica (ANT) and KSAT. A description of various facilities of ISTRAC and their functional responsibilities with specific reference to EOS-04 is provided in the following sections.

3.2.2 Spacecraft operations

The Spacecraft operations comprises of TTC network, Spacecraft Control centre, data links and the operations team for the essential elements of mission control. In order to fulfill EOS-04 mission goals, MOHA with the support of ISTRAC network, carries out continuous health monitoring and control of EOS-04 in the multi-mission operation environment. Along with this, MOHA also schedules and carries out payload operations (SAR Imaging), SSR record/dump operations and SPS data collection.

The spacecraft controllers at MOX interact through voice links with the TTC station to obtain telemetry and tracking support and uplink the scheduled commands during the radio visible segment of an orbit. MOX is equipped with the requisite mission software and display terminals to ensure error-free operations. These operations are carried out on a routine basis to keep the spacecraft in good health, intended orbit and orientation. Anomalies in spacecraft's health and deviation in spacecraft's attitude are tackled by spacecraft controllers by swift action, with the help of mission specific contingency operations management procedures.

Ground stations carry out ranging operations collecting range, Doppler and Angles data in order to determine precise orbit for tracking the spacecraft by TTC stations and payload data reception stations. ISTRAC ground stations are located at

Bangalore (BLR), Lucknow (LCK), Mauritius (MAU), Antarctica (ANT) and Biak provides the support during initial and normal phase operations.

The ISTRAC functional organization for EOS-04 mission support is shown in Figure-18

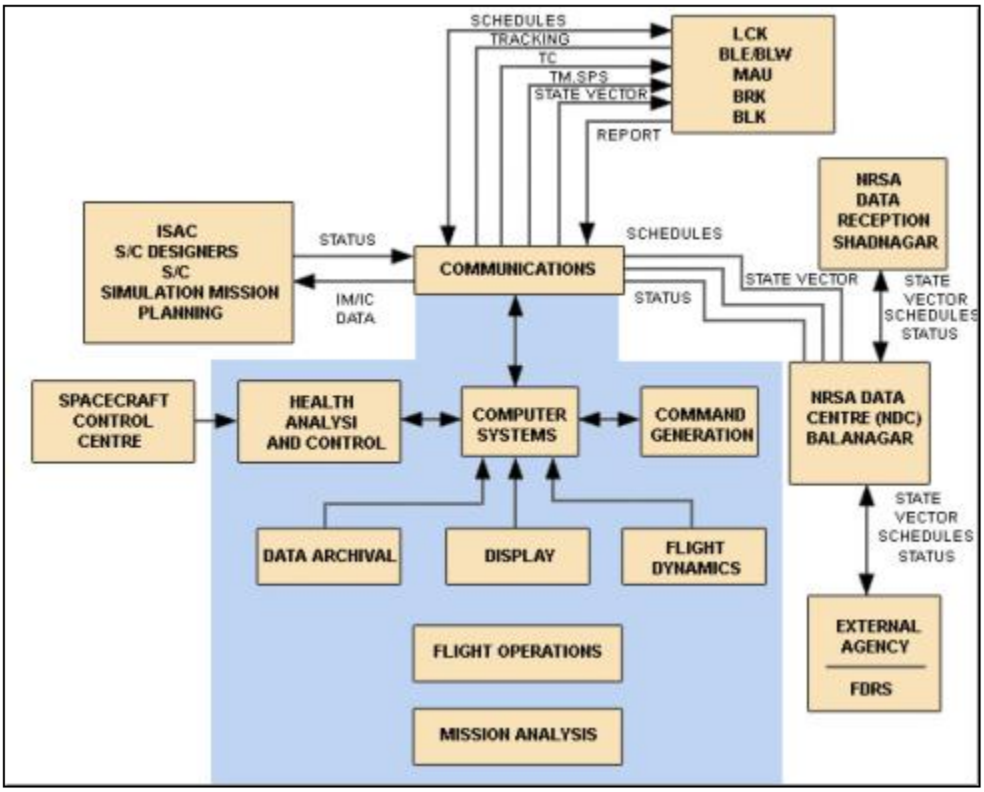


Figure-18 ISTRAC functional diagram for EOS-04 mission support

3.2.3 TTC Network

Spacecraft mission operations and control requires a suitable network of ground stations to plan and execute appropriate telecommand operations on the spacecraft, as per decided timeline. Ground station locations for EOS-04 have been chosen on the basis of mission's sequence of events, mission strategies and sufficient radio visibility requirements of important arcs of the orbit.

3.2.4 TTC ground station configuration

ISTRAC TTC stations are equipped with almost identical systems for telemetry (TM) reception, tracking and telecommanding. All ground stations are installed with 10/11 m antenna with a G/T of 20 dB/°K. An acquisition antenna equivalent of 1 m diameter, mounted on the main antenna system facilities initial acquisition of the satellite. Capability to receive 3 or 4 TM carriers with necessary recording, PCM demodulation and quick-look facilitates exist in all the stations.

Each station is provided with a complete telecommand system of 2 KW RF power and high precision range and range rate systems. Each station has almost complete redundancy at all levels.

Ground station computers send the data to mission computers at MOX for data processing. Important characteristics of ISTRAC network stations are given in Table-9

1.	**Operating Frequency**	
	Receive	2200-2300 MHz
	Transmit	2025-2120 MHz
2.	**Antenna**	
	Size	10/11 m
	Gain/Temp	20 dB/deg K
	Velocity	9.0 deg/sec.
	Acceleration	3.0 deg/sec^2
	Tracking Mode	▪ Auto ▪ Program ▪ CDM ▪ Manual
	Effective Isotopic Radiated Power	Greater than 70 dBW
3.	**Modulation**	
	Downlink	PCM/PSK/PM
	Uplink	PCM/PSK/PM
4.	Timing Accuracy	100 µs
5.	Transmitter Power	2 KW
6.	**Tracking Accuracy**	
	Angles	0.1 deg
	Range	10.0 m
	Range Rate	0.1 m/s
7.	Data Transfer	TCP/IP

Table-9 Characteristic Features of ISTRAC network stations

The salient features of the new TTC processor are:

- Station size has been reduced considerably by using compact systems
- Single receiver built in the processor handles different types of modulations
- Subcarrier frequency is tunable from 1 kHz to 1 MHz and data rate are also tunable to meet different mission requirement
- Remote monitoring and control facility is available

3.2.5 Functional requirement of TTC Network

The functions of the TTC ground stations are:

- Housekeeping data reception in real time mode, dwell mode and play back mode
- Receiving SPS, Raw-SS data and transmitting to MOX computers
- Formatting and transmitting the data to MOX computers
- Transmission of commands generated at MOX to spacecraft
- Tracking of the spacecraft
- Collecting range, Doppler and angles data and transmitting to MOX for orbit determination

The details of various support functions are given in the following sub-sections.

3.2.5.1 Telemetry

ISTRAC ground station(s) receives the down link signals from the spacecraft in real time and perform the following activities:

- Demodulate the signal
- Bit and Frame synchronization
- Time tagging
- Formatting into standard blocks for transmission
- Recording data for recalling

3.2.5.2 Telecommand

Telecommand supports remote commanding in real time during ground station visibility using PCDICE (Peripheral Component Digital Interconnect Command Encoder) located at the ground stations and transmitted to the spacecraft.

3.2.5.3 Tracking

Tracking support is provided during any segment of the orbit during the visibility. Tracking support is provided simultaneously with telecommand. The ground station also measures range, range rate (Doppler) and antenna angles of the spacecraft. This is essential for spacecraft orbit determination and ephemeris generation.

3.2.5.4 Data communication

Data communication links at ISTRAC establishes the required communication lines in coordination with the national and international agencies, to ensure transfer of telemetry, telecommand and tracking data using standard protocols. The TTC ground stations supporting EOS-04 and MOX systems are interlinked continuously through dedicated sky-links using INSAT and INTELSAT satellites and ISDN links as backup.

3.2.6 Mission Operation Complex

The Mission Operations Complex (MOX) located at Bangalore is the nerve centre of all TTC and spacecraft control operations.

Mission Analysis Room(MAR), Mission Control Room (MCR) , Dedicated Mission Operation Complex (DMCR), Flight Dynamics Operations (FDO), Scheduling System (SS) are various entities of MOX which comprises of several observation consoles and command terminals connected to the computer facility for providing spacecraft health data to mission experts and mission operations team from pre-launch to end of initial phase. MCR is augmented with an elegant projection system to monitor launch events display and spacecraft ground trace. MCR is large enough to accommodate 18 work stations with improved facilities to cater to the launch and initial phase operations. All mission activities for EOS-04 are carried out from (DMCR) in normal phase. DMCR has several dedicated consoles which are meant to handle many spacecraft missions simultaneously.

The major tasks carried out at MOX are:

- Scheduling and execution of EOS-04 mission operation tasks
- Planning and execution of orbit and attitude maneuvers as per mission requirements

- Orbit and attitude determination
- Scheduling of command operations as part of payload programming
- Housekeeping data monitoring in real time
- Spacecraft health data archival and database management
- Spacecraft health analysis and performance evaluation and reporting
- Co-ordination with various network stations, IGS, NDC and other related agencies to realize above tasks
- Anomaly identification and recovery action initiation in case of spacecraft emergencies along with mission experts

3.2.6.1 Flight dynamics operations

Flight dynamics operations at MOX consist of:

- Processing the tracking data received from ground stations and determining the orbit
- Generations of the orbital events for scheduling and spacecraft operations
- Look angles generation for ground stations
- Transmission of state vector to the users
- Attitude determination using various sensors data
- Orbit maintenance planning for stringent orbit control

3.2.6.2 Multi-Satellite Scheduling system

Effective TTC support is allocated to EOS-04 in the multi-mission environment by Multi-mission Scheduling Software (MSS). This MSS interfaces with Payload Programming System (PPS) in generating the operation schedules and command schedules for EOS-04 along with other existing missions. MSS generates schedule optimally by taking into account the following factors in the multi mission operations environment:

- Spacecraft specific requirements
- Spacecraft operations constraints
- Special operations requirements
- Network ground stations
- Ground stations configurations

- Visibility clashes

3.2.6.3 Payload Programming

Payload programming is a payload operation scheduling process which comprises of three major modules

- Web user interface at NDC
- Payload schedule generation at NDC
- Command schedule generation at MOX

The payload schedule received at MOX from NDC is input to generate command sequence to the space craft to cater the needs of payload user community. ISO 9001 Quality management system is in place at ISTRAC for conducting EOS-04 mission operations.

3.3 Data Reception Systems

EOS-04 satellite transmits SAR (Synthetic Aperture Radar) payload data through X-Band carrier using dual polarization. The data stream of each chain is at 320 Mbps data rate and modulated using QPSK modulation scheme. The bandwidth available for data reception in X-Band is being 375 Mbps, the two streams with a total data rate of 640 Mbps are transmitted to ground through RHC and LHC polarized signals at X-Band carrier frequency of 8212.5 MHz using the frequency re-use technique.

The ground station consists of a high efficient 7.5 m diameter antenna system with dual shaped reflectors in Cassegrain configuration. The station provides G/T of 31.5 dB/° K. All the RF and IF subsystems of the receive station handle higher bandwidth of 320 MHz. Design implementation of individual subsystems of ground station and the specifications of each unit are so drawn out that they will cater for the required over all ground station link margin.

Integrated **M**ulti mission **G**round segment for **E**arth **O**bservation **S**atellites (IMGEOS) has been established at NRSC Shadnagar with an objective to have a highly reliable and an easily adaptable system to cater for future mission requirements in order to achieve reduced turnaround time for the data product generation and dissemination. In IMGEOS scenario, four terminals with dual polarized S/X band feed and identical receive chain configuration are operational for Data reception from all ISRO & Foreign Earth Observation Satellites.

A new ground station is established and operational at Jodhpur which consists of a 7.5 m Tri Axis S/X Band Antenna system which will receive and ingest data in real-time and transfer the RAW data in near real-time to IMGEOS, Shadnagar for further processing.

The existing two Data Reception Stations at Antarctica Ground Station shall also receive and transfer the RAW data to IMGEOS, thus facilitating optimum utilization of EOS-04 payload imaging capabilities.

3.3.1 Data Reception Station Configuration

3.3.1.1 Station requirements to track and receive EOS-04 data

- Dual circularly polarized X/S-Band composite Feed
- Reception of high data rate (320 Mbps) modulated signals
- Additional LHCP chain for X-Band Auto Track
- Synthesized Up/Down Converter with additional channels
- X-Band Auto Track either through RHCP or LHCP carrier
- Auto diversity to facilitate tracking on either of three tracking Channels
- IF Fiber optic link for transfer of high data rate modulated IF spectrums
- High data rate Demodulators at 320 Mbps (I+Q) data rate
- High Data Rate RF Simulator for simulation of EOS-04 RF signals
- Digital Servo Control System for Tracking
- Station Automation Systems for Control, Configuration of DRS Systems
- Data Ingest, Timing & ADP Systems
- Multi Mission High Speed Front End Hardware (SPARC/FEH)

3.3.1.2 IMGEOS configuration

The configuration of centralized control room in IMGEOS architecture (Figure-19) is designed to meet the automation requirements of the data reception systems. In each of the four primary antenna systems, some of the Digital Servo control and RF subsystems are located in the concrete pedestal, all the IF/base band subsystems and Antenna control computer are located in centralized control room.

All the subsystems are designed with provision for remote monitoring and control capability through Ethernet interface. Thus all the subsystems are in a common network configuration, controlled and monitored through a central station control computer.

The Data and Tracking IF signals from each of the four primary antenna systems are driven from concrete pedestal to centralized control room through Fiber Optic links. The IF outputs from the Fiber optic receivers in control room are fed to the common Programmable F matrix, which routes these IF signals to the respective second down converter subsystems. The output of the second down converter is fed to the multi-mission programmable demodulators. The data and clock signals from each of the demodulators are routed to data ingest systems through a Data Path Controller Unit (DPC).

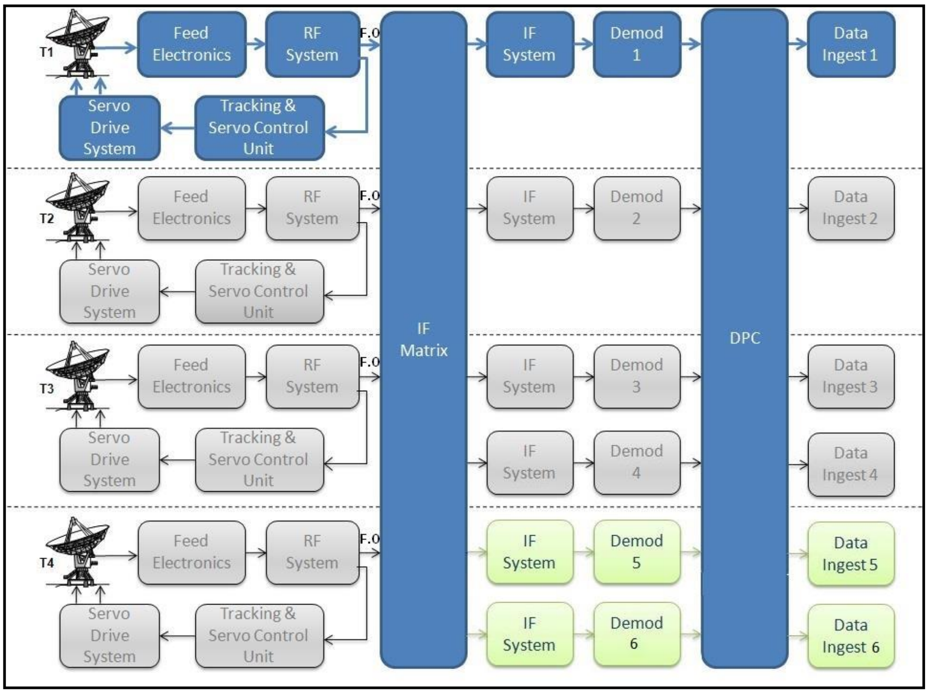


Figure-19 IMGEOS Configurationof Data Reception Station

The data ingest systems are co-located with respective Demodulators. There will be five dual channel data demodulators with dedicated Data Ingest systems in order to cater to simultaneous dual carrier data reception requirements of the four Antenna systems, one of them being a common redundant system.

Dual shaped main reflector	7.5 m dia, parabolic dish
Sub-reflector	0.8 m dia, Hyperbolic dish
Frequency Range	
X-Band	8.000 to 8.500 GHz
S-Band	2.2 to 2.3 GHz
Feed	X/S band composite, Cassegrain
Single Channel Monopulse Polarization	
X-Band	Simultaneous RHCP & LHCP
S-Band	RHCP
Cross pol. Isolation	20 dB
Antenna gain X-Band	54 dBi
S-Band	40 dBi
G/T	
X-Band	31.5 dB/ºK @ 5º EL
S-Band	14 dB/ºK @ 5º EL
Half power beam width	
X-Band	0.27°
S-Band	1.1°
Type of mount	Elevation over Azimuth
Maximum Velocity	AZ- 20º/sec. , EL- 10º/sec.
Maximum acceleration	AZ- 10º/sec² , EL- 2º/sec²
Data rates	320 Mbps (I+Q) in each chain
Tracking	S/ X (R) /X (L) Auto Track
Program Track as back-up	
Threshold Eb/No	12.8 dB for 1X10^{-6}BER

Table-10 Data Reception Specifications

3.3.1.3 Brief description of Data Reception Systems

The data reception station comprises of the following major systems.

- Antenna & Mechanical Systems
- Dual Polarized Feed & RF systems
- IF & Base-Band systems
- Antenna Control Servo Systems
- Station Automation Systems

The station consists of a dual shaped antenna system with a 7.5 m diameter parabolic reflector. The dual shaped antenna along with feed in Cassegrain configuration provides G/T of 31.5 dB/º K. The composite S/X feed is dual circularly polarized in both S & X bands with a capability to receive LHC and RHC polarized signals simultaneously.

The antenna and feed system is mounted over an EL over AZ drive pedestal. The feed and front-end system realizes single channel monopulse tracking. The X-Band data is received through RHCP and LHCP simultaneously using frequency re-use technique.

The X Band data and tracking error signals from RHCP & LHCP chains in identical configuration are amplified in LNA and down converted to a first Intermediate frequency in the range of 2.2 to 2.9 GHz IF. The S-band Telemetry Data and Tracking signals are down converted to 70 MHz IF.

The down converted X and S band tracking IF signals are fed to a three channel Integrated Tracking system (ITS), located at antenna pedestal. The ITS demodulates the tracking IF signal and extracts AZ and EL DC error information from the tracking video. The DC errors are fed to Digital Servo System to control the antenna movement for satellite tracking in Auto Track mode.

The Digital Servo System comprises of Antenna Control Computer, Drive Power Amplifiers Drive motors and Optical shaft Encoders to operate the Antenna in different modes of operation viz, Rate mode, PTS mode, command angle mode and Auto mode. The system has provision for remote control and configuration through Ethernet interface.

The Drive system consists of Power Amplifiers, Brush less DC motors, Gear boxes (Dual drive mode) and Slew-rings in each El. and Az. axis. Each axis is driven by two motors in counter torque mode to avoid backlash. Absolute optical shaft encoders are used for measuring the angular position of the antenna. All safety interlocks are provided in the drive system.

The IF outputs from first data down converter (2 carriers) and S band data IF are driven to the control room through a multi-core optical fiber cable. The S band Data

IF is driven to SPS receiver in control room for further processing of SPS Data. The two data IF signals received in control room are fed through programmable IF Matrix to the second down converter and then to High data rate digital demodulator. The data and clock signals from demodulators are driven through LVDS interface to Data Ingest System for further processing and product generation. The total data acquisition system for all the Antenna Systems are automated through Station Control Computer.

The functional block diagram of data reception station is given in Figure-20 below.

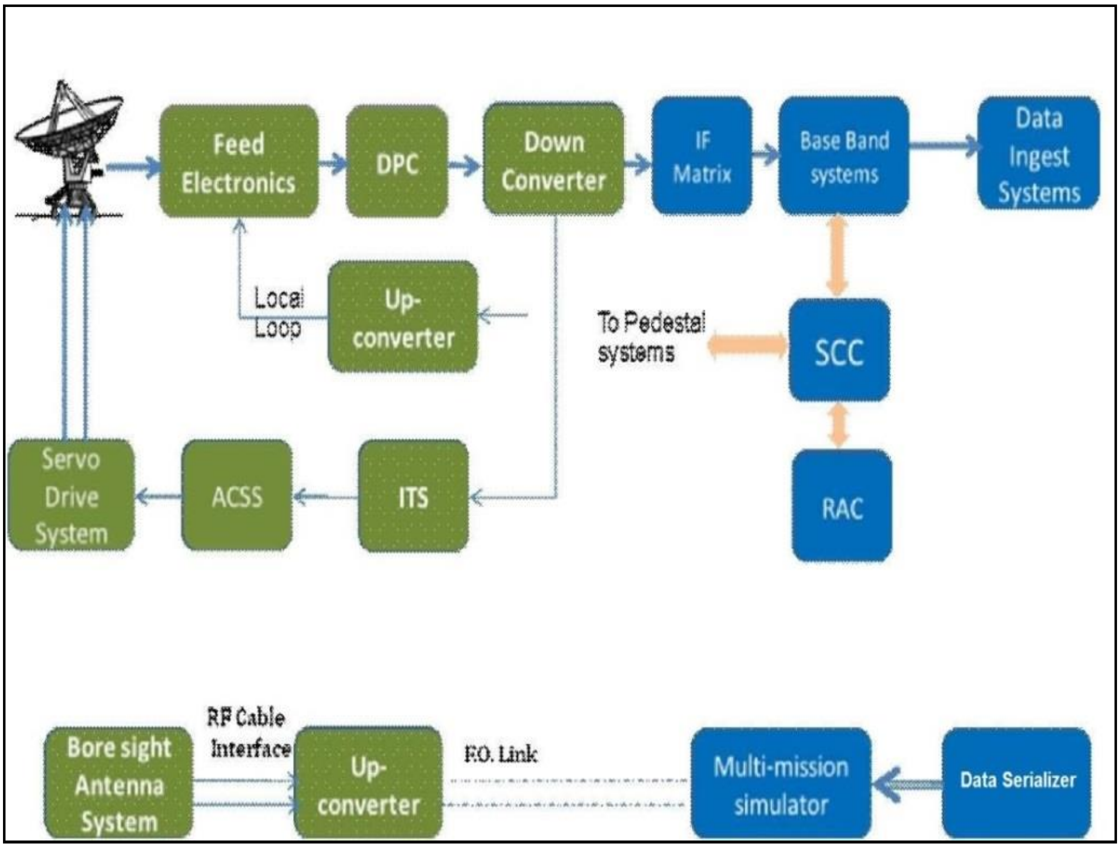


Figure-20 Configuration of Data Reception Systems

3.4 Level-0 Systems

The following sections describe the various sub-systems of the Level-0 Systems for EOS-04.

3.4.1 Sub-Systems of Level-0 Systems

Level-0 Systems are realized in IMGEOS Configuration. Each of the four Antenna System and Data Receive Chains has a dedicated Data Ingest System (Shown in Figure-21) for Real-time data ingest onto RAID and subsequent transfer to SAN for ADP Processing. Based on clash scenario two antenna & data receive chains will be assigned for EOS-04 as main & redundant chains. The Data ingest Systems perform the critical real-time task of raw data ingest. The ADP system generates FRED, Ancillary Data Information file (ADIF), Orbit, Attitude & Time file (OAT) and Metadata files in near real-time. The Level 0 systems at IMGEOS consist of the following sub-systems for real-time Data Ingestion and pre-processing of the archived data.

- Station Work Flow Manager for Event Scheduling and Monitoring
- Data Ingest System
- Ancillary Data Processing System
- SPS PB Data Archival System
- Timing Systems
- Front End Hardware
- Data Serialize

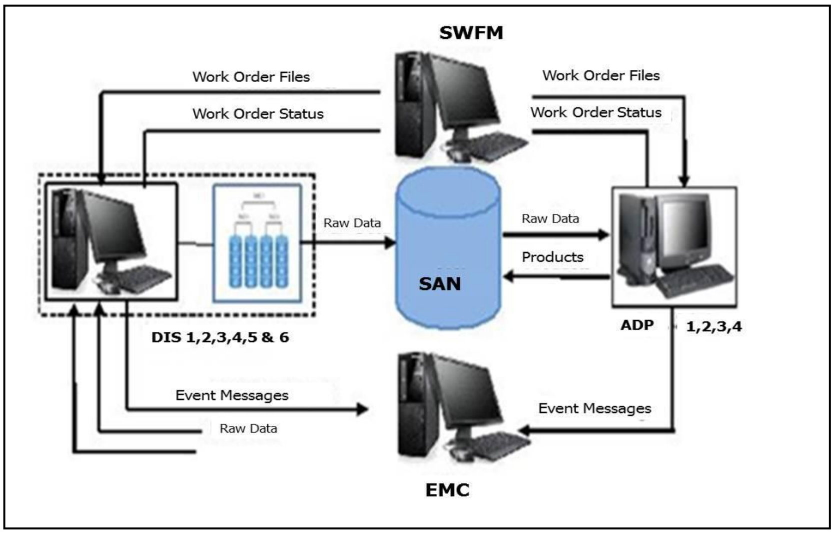


Figure-21 Block Diagram of Level-0 Systems Configuration

3.4.2 Station Work Flow Manager (SWFM)

The SWFM provides centralized event monitor and control functions for station operations with appropriate interfaces with UOPS for pass schedules, state vectors, and urgent/emergency requests. On receipt of pass schedules for a day, SWFM generates work orders for station control computer system for assignment of antenna systems & receive chains. It also generates WO for the respective Data Ingest Systems. On receipt of successful data ingest message post pass from DI, work orders are issued by SWFM for the ADP Processing nodes. Event Monitor & Controller (EMC) displays process status and provides control for process initiation, restart & abort.

3.4.3 Data Ingest System (DIS)

The Data Ingest systems (Figure-22) consist of High end LINUX based Xeon servers with RAID capacity of 1TB for real-time data ingest. Data Ingest System gets work orders from SWFM, schedules the supported passes, acquires real-time data, provides a real-time display of important parameters like Sync Status, FS Errors, GRT & Line Count Jumps, etc. The PCIe Front End Hardware (FEH) cards / PCI Express based Satellite data Processing & Acquisition Reconfigurable Card (SPARC) are connected to the Demodulators with LVDS/ ECL interface. IRIG-G Serial Time is fed to the Time Code Translator which translates the serial time and provides parallel BCD Time to FEH for time stamping the Raw Data

Time Code Translator provides RS-232 I/F for system time synchronization. FEH / SPARC does frame synchronization and word synchronization on the incoming payload data and the data is transferred to RAID along with Meta display in real-time by Data Capture Software. In near real-time, the aux data is extracted by extracting the relevant words from raw data and auxiliary data files are created. After the pass, the archived data will be transferred over FC interface along with quality report to SAN. Appropriate Event Message indicating the status of data acquisition is sent to SWFM for further initiation of ADP Processes.

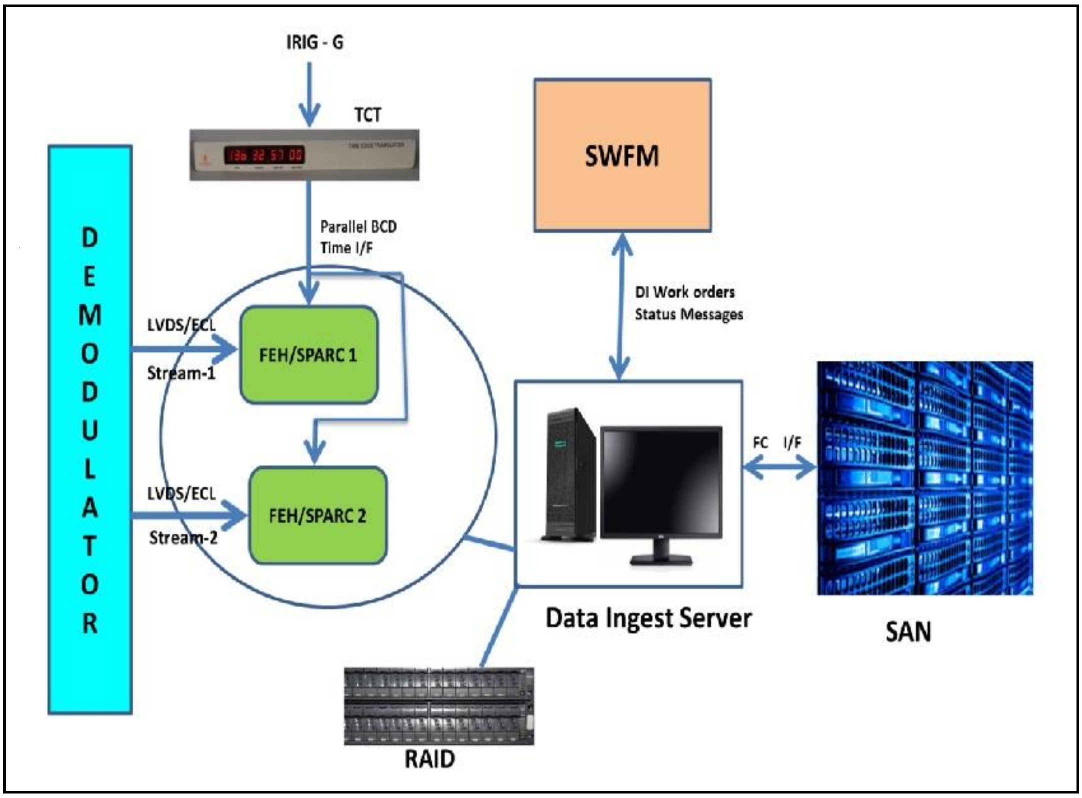


Figure-22 Data Ingest System Configuration

3.4.4 Auxiliary Data Processing Systems (ADP)

The ADP systems perform the function of pre-processing on the RAW data acquired at IMGEOS, Jodhpur & AGEOS and produce the following Level-0 products in near real-time for all the Modes of Operation.

- Orbit Attitude Time (OAT) Files
- Ancillary Data Information Files (ADIF)
- Meta Data Files
- FRED Files

On successful acknowledgment from DI systems regarding the transfer of RAW data to SAN at IMGEOS and on arrival of all the required files over network from Jodhpur & AGEOS, SWFM triggers the ADP processing Chains. The qualified RAW data goes through different processing chains which generate the above mentioned Level-0 products. The processing status is passed to SWFM & EMC for control & monitoring. The ADP Systems are multi mission capable and are configured to share the load appropriately among the systems. All the outputs from the processing nodes are written into SAN for permanent archival.

Functions of ADP System

- Automatic triggering of chains for processing based on work order file
- Provide processing status to Work Flow Manager
- Reading work order & generating inputs for further processing
- Determining good start and end times, identification of pass type and other pass related information
- Identifying the session and strips in the data
- Extracting the LBT, AOCS and gyro fine rate data from LBT data
- Generating the pass data quality report
- Automatic state vector update
- Ephemeris generation
- Orbit determination using the various orbit sources
- Attitude determination
- Scene framing and Footprint Computation using orbit and attitude information
- Ancillary data information file (ADIF) generation and validation
- Metadata generation & transfer

3.4.5 SPS – PB Data Archival Systems

The Satellite Positioning System (SPS) (Figure-23 and 24) Data Archival System consists of SPS Data logger/PCI-e based SPS acquisition Card and a SPS Data Ingest system. The data received through S-Band telemetry chain is down converted, demodulated and the serial data and clock is fed to the SPS data archival system. The incoming serial data from data logger is logged on to computer system using TCP/IP through Ethernet interface/Adlink PCI-e interface card.

The received data is frame synchronized and word aligned by the software in real time before writing on to the hard disk in TCP/IP based system**.** Also the received data is frame synchronized and word aligned in CPLD in real time before writing on to the hard disk by PCI-e interface card. It also displays the SPS parameters on real-time GUI.

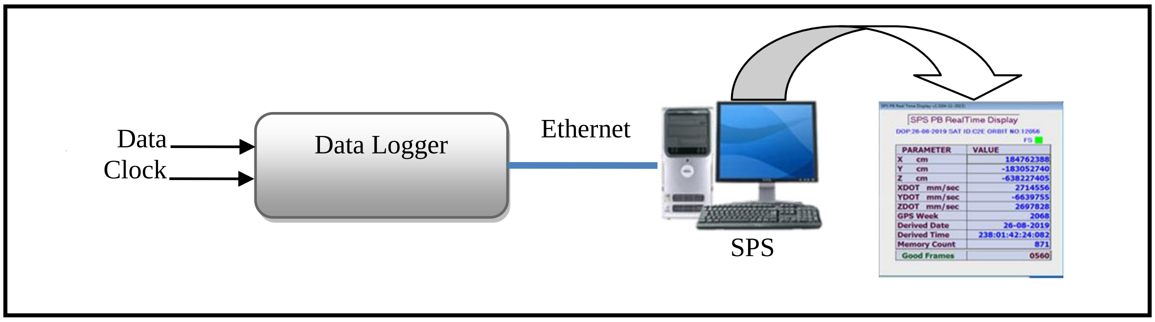


Figure-23 SPS Data Archival System based on TCP/IP

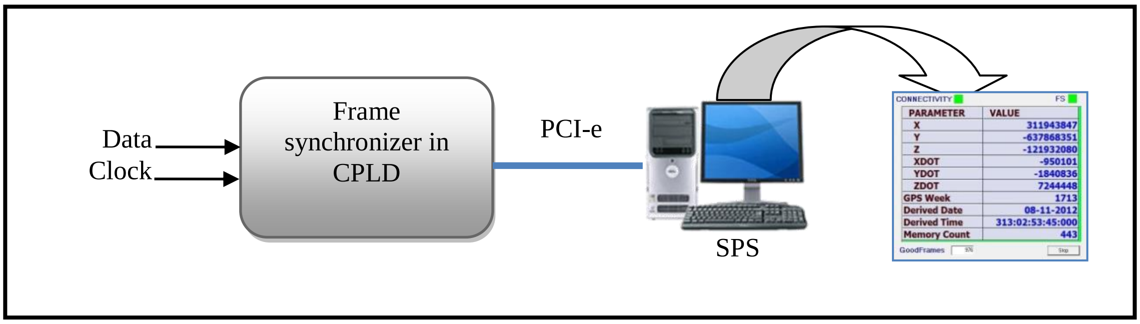


Figure-24 SPS Data Archival System based on Adlink PCI-e

3.4.6 Timing Systems

Station Timing Systems consist of XLI Time and Frequency Unit (NTP Server), Serial Time Distribution Unit and Time Code Translator Units. The XLI Time & Frequency System has 12-channel GPS receiver, GPS synchronized Time Code generator, High Precision Rubidium oscillator for clocking the TCG. The NTP server port on the Unit is used for accurate system time synchronization. Serial IRIG-G time code from XLI unit is fed to the Serial Time Distribution Unit, which buffers and provides the Serial Time to the Time Code Translators on Data Ingest Systems. (Figure-25)

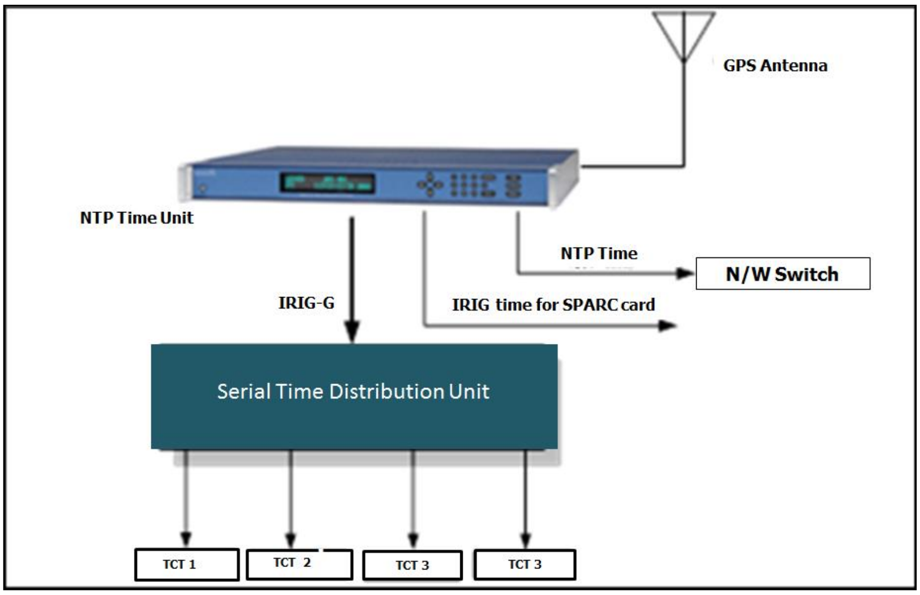


Figure-25 Timing System Block Diagram

IRIG-G Time Code Translator

IRIG-G TCT has been developed in-house for meeting the GRT time stamping requirements of EOS-04 (Figure-26). The TCT accepts IRIG-G Serial Time Code and translates it into Parallel BCD format up to 10 Microseconds to Front End Hardware (through 68 Pin SCSI connector) for time stamping the RAW data being ingested. The serial interface provides the ASCII time for system time synchronization and scheduling of events. The set-time and read-time utilities are provided for off-line configuration of the system and validation of the interface respectively. Displays DAYS: HOURS: MINUTES and SECONDS on the front panel.

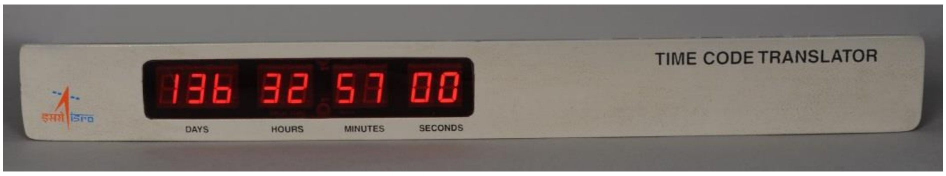


Figure-26 Time Code Translator

3.4.7 Real – time Front End Ingest Hardware

Front End Hardware (FEH)

The Front End Hardware card performs front end processing of satellite data on serial bit stream. The Frame Synchronizer logic will accept serial data from Demod &

Bit synchronizer in real-time and performs frame synchronization on the incoming data. It generates corresponding word clock, extracts data, tags the time code data read from Time Code Translator (TCT) to each line and buffers the parallel data in FIFO. Then it transfers the data to the system for further processing through PCI interface.

FEH is a multi-mission hardware and it can acquire data from all IRS satellites of data rates of 320 Mbps per stream (I channel @160 Mbps, Q channel @160 Mbps). Two FEH cards are required to handle two streams of EOS-04 satellite data each at 320 Mbps. The existing FEH is shown in (Figure-27).

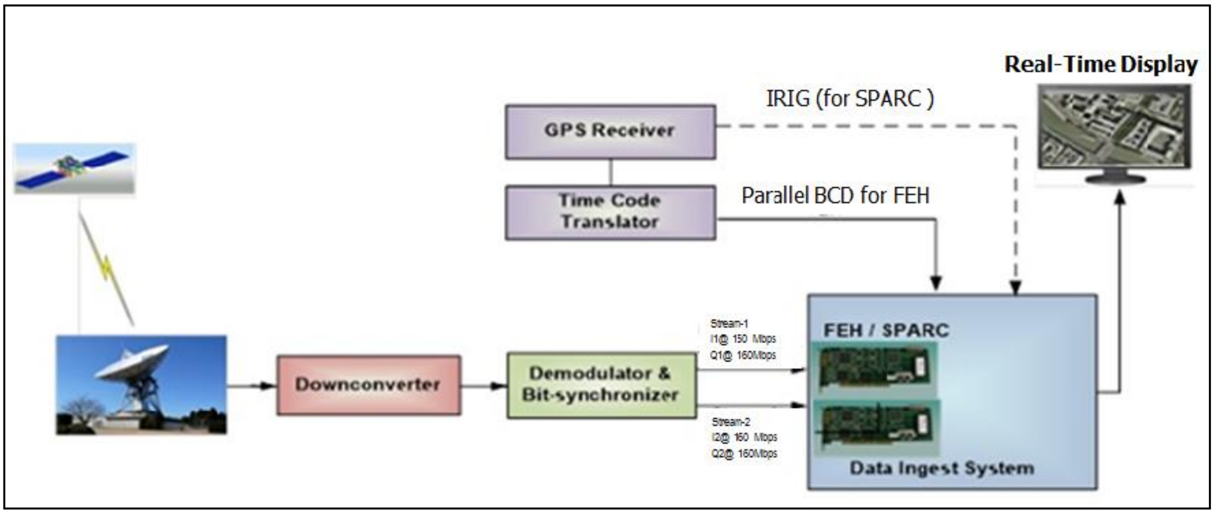


Figure-27 FEH in Ground Receive chain

Features of FEH

- Handles two channels at 160 Mbps each
- ECL/LVDS input interface
- Frame Synchronization with number of agreement selection up to 127
- Programmable error allowance in FS code from 0 to 15
- Bit slips provision +/- 2 bits
- Serial to Parallel Conversion
- Parallel BCD time tagging from IRIG G Time Code translator
- 512K x 8 bytes FIFO Memory
- Programmable number of frames per buffer

- Compliance with PCI bus for host independent interface
- Burst mode DMA transfer
- LED indication on FEH card for frame sync status (lock/loss) and data transfers

Satellite Data Processing & Acquisition Reconfigurable Card (SPARC)

SPARC is a new ingest-cum-processing hardware designed in-house. It is a PCI Express card designed with Xilinx Virtex-6 FPGA.

The main features of SPARC are:

- System-on-Chip (SoC) Architecture centered around embedded soft micro-processor
- Supports data rate up to 750 Mbps per channel
- Automatic Data-Clock Alignment (DCA)
- Frame Synchronization
- Remote Upgradability
- Time Code Translation (TCT)
- Reed Solomon Decoder
- BER Reader

These features are designed as VLSI digital circuits controlled by embedded software. Figure-28 below shows the snapshot of SPARC hardware.

Figure-28 SPARC card

3.4.8 Data Serializer

Data Serializer is a data simulator which generates two streams of data in BDH formats for all remote sensing satellites. The Serializer hardware is in-house developed PCI based add on card and it interfaces to the computer system through PCI 64 bit, 66 MHz bus. It is a full length and full height Add on card which sits in PCI-X slot in the Serializer system. The input to Serializer card is simulated data in BDH format. It reads this data from the disk and gives two streams data on 4 channels as outputs (I1, Q1, I2 and Q2) at different frequencies for different satellites depending on the satellite selected from system. The output of the Serializer will be the input to modulator for testing the entire RF and Data ingest chain or directly connected to FEH bypassing the modulator-demodulator.

For EOS-04, is available in two streams. Stream1 on I1 and Q1 & Stream2 on I2 & Q2 each at 160 Mbps

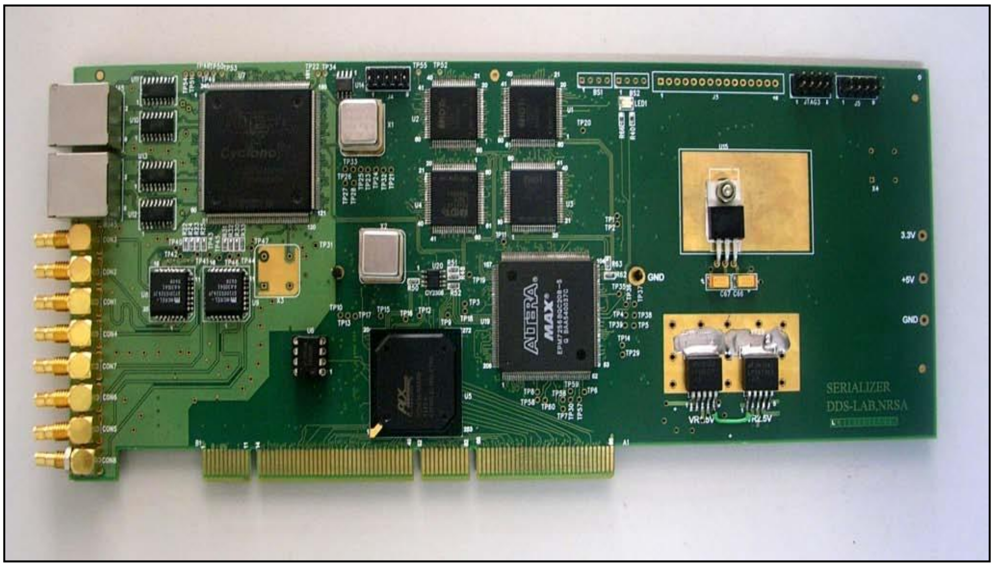


Figure-29 PCI Serializer card

Serializer Hardware

The Serializer reads the data from system hard disk and writes into the FIFO. This data is serialized and sent as two streams on the RJ45 connectors in LVDS logic levels and ECL signals on SMB connectors. Serializer device is interfaced to the system through PCI 64 bit, 66 MHz bus.

The Serializer uses a 160 MHz crystal clock source as reference clock and generates read clocks at the required frequency to read the 32 bit parallel data from the FIFOs. After converting this parallel data into serial, it is sent out in a serial fashion with the corresponding serial clock.

The PCI control logic resides in the Altera EPM 7256 CPLD and it receives the configuration data from the system. After receiving data-on command from application it clears all FIFOs and enables the PCI Interrupt input from device to system. Whenever the data in FIFO goes below to the certain level then controller sends an interrupt to the system. In response to the interrupt, the system transfers a block of data to the device. The necessary write clocks to the FIFO are generated from the control logic.

Device Driver

Serializer device driver supports Linux platform with kernel version 2.6 and above. It provides standard interface to the application program for configuring and accessing the device resource. Data transfer to the device is done through interrupt I/O using on board DMA controller. Also device driver maintains the circular buffer to cater to system performance variations.

Application Software

Serializer application software is developed in C and C++ language. There are three modules SSD, SSS and front-end GUI in the application software module. These modules communicate with each other through shared memory and semaphores. There are two modes of operation of Serializer i.e. Scheduler mode and Manual mode. In Scheduler mode device is commanded from the Scheduler.

Chapter-IV

4. EOS-04 DATA PRODUCTS

4.1 Introduction

EOS-04 data products are available for following Imaging modes:

- Fine Resolution STRIPMAP **(FRS-1)** mode
- Fine Resolution Full-Polarization STRIPMAP **(FRS-2)** mode
- Medium Resolution SCANSAR **(MRS)** mode
- Coarse Resolution SCANSAR **(CRS)** mode
- High Resolution SPOTLIGHT **(HRS)** mode

Different levels of data products have been defined for the mission. The product can either be **scene based or mosaic based**. The scene wise products can be generated for nominal product levels as well as value added products. All basic **Level-0, Level-1 and Level-2** products will be available as similar to RISAT-1 with some minor changes.

In EOS-04, Full – Polarimetry imaging capability has been introduced for all imaging modes except for HRS mode. Value added products such as **Polarimetric and MOSAIC** have been introduced in EOS-04.

4.2 Data product types/Levels

Level-0: RAW Product

Available only to specific users

Level-1: Geo-Tagged Product

1. Level-1A : Single Look Complex (SLC); Slant Range products
2. Level-1B : Ground Range products

Level-1 data products are available in both CEOS and GeoTIFF format.

Level-2: Terrain Geo-Referenced Product. Level-2 product in EOS-04 is same as the Level-2A Enhanced Terrain Geo-Referenced Product of RISAT-1 as True–Height from Digital Elevation Model (DEM) is used in Geo-Referencing. DEM options available will be CARTODEM (Indian region), Copernicus-30m DEM, SRTM, NASADEM, Arctic (North Pole) and REMA (South Pole) DEM.

Level-2 products are only available in GeoTIFF from.

The Level and type of EOS-04 Data Products are listed in Table-11 below.

Img. Mode	RAW (CEOS)	L1-SLC (CEOS &GeoTIFF)	L1-Ground Range (CEOS &GeoTIFF)	L2-Geo-referenced (GeoTIFF)
FRS-1	✓	✓	✓	✓
FRS-2	✓	✓	✓	✓
MRS	✓	✓	✓	✓
CRS	✓	✓	✓	✓
HRS	✓	✓	NA	✓

✓ : *Available* NA*: Not Available*

Table-11 Levels and Type of EOS-04 Data Products

All levels of products are available in Single/Dual , Circular/Full Polarizations for FRS1, FRS-2, MRS and CRS modes and in Single/Dual and Circular polarization for HRS mode.

Transmit Polarization(Tx)	Receive Polarization(Rx)	Mnemonic
Vertical	Vertical	VV
Vertical	Horizontal	VH
Horizontal	Vertical	HV
Horizontal	Horizontal	HH
Right Circular	Vertical	RV
Right Circular	Horizontal	RH

Table-12 Polarization Combinations for EOS-04 Products

Table-13 below briefly describes the different levels of EOS-04 data products.

SCENE WISE PRODUCTS	*Nominal Levels of Products*	
	Level 0	**RAW Signal Product**
		BAQ Decoded I/Q Samples and CEOS formatting
	Level-1	**Geo-Tagged Product**
		Slant (Level-1A) / Ground (Level-1B) Range Product along with Grid File
	Level-2	**Geo-Referenced Product**
		UTM/UPS using Carto/SRTM/GTOPO
		DEM along with Grid File

<table>
<tr><td rowspan="8"></td><td colspan="3">Value Added Products</td></tr>
<tr><td rowspan="3">Level-1C</td><td colspan="2">Geo-Tagged Polarimetric Product along with Grid File</td></tr>
<tr><td colspan="2">DP/CP: 3 Layers (2 real Diagonal: 1 complex Off Diagonal Elements of COV Matrix)</td></tr>
<tr><td colspan="2">FP: 6 Layers (3 Real Diagonal : 3 Complex Off Diagonal Elements of COV Matrix)</td></tr>
<tr><td rowspan="4">Level-3A</td><td colspan="2">Geo-Referenced Polarimetric Product</td></tr>
<tr><td colspan="2">in UTM/UPS projection along with Grid File</td></tr>
<tr><td>m-delta/m-chi decomposed</td><td>Yamaguchi/Freeman decomposed</td></tr>
<tr><td>(for circular polarization mode)</td><td>(For Full polarization mode)</td></tr>
<tr><td>MOSAICS</td><td>India Mosaic
(for systematic coverage)</td><td>Large Area Mosaic</td><td>Full Strip Mosaic</td></tr>
</table>

Table-13 Different levels and types of data products of EOS-04

4.3 SAR data processing

Synthetic Aperture Radar (SAR) is an active microwave imaging system. An imaging radar transmits pulses of microwave radiation to a target and receives the back scattered radiation from the target in the form of complex samples. The time delay of the return signal gives information about the position of the target. Target history is spread in across track as well as along track direction. Information about target is retrieved through signal processing techniques. The across track direction (fast time) is known as range direction and the along track direction (slow time) is known as azimuth direction. The range R of a target is given by,

$$R = ct/2 \tag{4.1}$$

where 't' is time delay. Ideally, the range resolution is given by,

$$\rho_r = c\tau/2 \tag{4.2}$$

In order to improve the range resolution, a linear FM chirp with a large bandwidth is transmitted which effectively reduces the pulse width required and hence improves the range resolution.

$$\rho_r = \frac{c\tau_{eff}}{2} = \frac{c}{2B} \qquad 4.3$$

Where 'τ' is pulse duration, B is chirp bandwidth and τ_{eff} is effective pulse width. Ground resolution is given by,

$$\rho_g = c\tau_{eff}/2\sin\theta \qquad 4.4$$

Where 'θ' is the incidence angle. From above equations it is clear that ρ_r is independent of range but ρ_g improves with increasing range and varies across the swath.

In real aperture radar, the azimuth resolution is determined by the 3-dB beamwidth of radar and is given by,

$$\rho_{az} = \theta_{3dB}.R = \lambda R/2 \qquad 4.5$$

Where, λ is wavelength of radar, R is range and D is length of antenna.

In SAR, the forward motion of the platform is used to construct a much longer effective antenna. To form the long linear array, the pulse returns from each echo must be combined coherently. suppose a synthetic aperture of length *L* is constructed from a real aperture of length *D*. The beamwidth of synthesized antenna would be,

$$\beta_s = \lambda/2L \qquad 4.6$$

which is half the beam width of a physical antenna of the same length.

The maximum synthetic aperture length L is limited by the time the target remains in the visibility of antenna, which is equal to the antenna foot print on the ground in azimuth direction at range R. This is also equal to the azimuth resolution of the real aperture.

$$L \leq \lambda R/D \quad (4.7)$$

Azimuth resolution in SAR is given by,

$$\rho_a = \beta_s . R = \lambda R/2L \quad (4.8)$$

Substituting for *L*,

$$\rho_a \geq \left(\frac{\lambda R}{2}\right) . \left(\frac{D}{\lambda R}\right) \quad (4.9)$$

Suppose an isotropic antenna is transmitting power P_t. Then the power incident on an imaginary sphere of radius R is,

$$P_i = P_t / 4\pi R^2 \quad (4.10)$$

Where $4\pi R^2$ is surface area of sphere. The power density P_i , incident on a target from a directive antenna with gain G, is given by

$$P_i = P_t . G / 4\pi R^2 \quad (4.11)$$

Radiated power incident on a target is scattered by it in all directions. A measure of the proportion of the incident power scattered back or reflected in the direction of the radar is known as target radar cross section (RCS) or σ. The power density P_e of the echo received at the radar from a target of RCS, σ would be,

$$P_e = \left(\frac{P_t . G}{4\pi R^2}\right) \left(\frac{\sigma}{4\pi R^2}\right) \quad (4.12)$$

The RCS, σ has units of area and is a characteristic of the target on the ground. If the radar antenna receives power over an effective area of A_e (meter^2), then the total signal S, received by the radar from a target of cross section σ at range R is given by,

$$S = \frac{P_t G \sigma A_e}{4\pi^2 . R^4} \qquad 4.13$$

From antenna theory. The relationship between the transmitting gain and receiving effective area of an antenna is,

$$G = \left(\frac{4\pi A_e}{\lambda^2}\right) \qquad 4.14$$

Therefore, S can be written as,

$$S = \frac{P_t G^2 \lambda^2 \sigma}{4\pi^3 . R^4} \qquad 4.15$$

Signals received by radar are usually contaminated by noise (statistical fluctuations), arising from random modulations of the radar pulse while propagating through the atmosphere, or due to fluctuations in the receiving circuits. For measuring radar cross section properly, it is required to optimize signal to noise ratio,

$$\frac{S}{N} = \frac{P_t G^2 \lambda^2 \sigma}{4\pi^3 . R^4 N_0} \qquad 4.16$$

Where N_0 is average noise power.

SAR data product generation involves many steps viz.

- SAR image formation
- Radiometric correction
- Geometric correction
- Calibration etc.

SAR image formation steps viz.

- BAQ decoding
- IQ imbalance correction
- Doppler parameter estimation
- Range compression
- RCM correction
- Azimuth compression

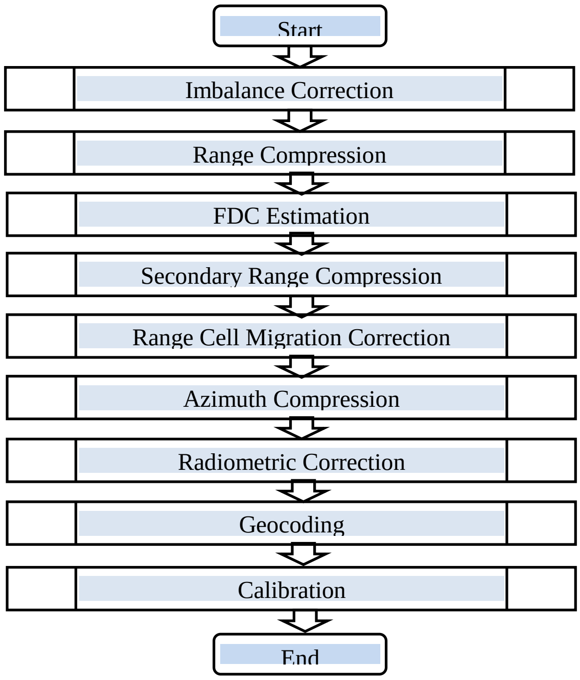


Figure-30 SAR Image formation steps

Range compression, RCM correction and azimuth compression are core image formation steps in SAR.

Other steps are pre-processing steps which generates information required for SAR image formation.

4.4 Data Formats

EOS-04 products are provided in two types of formats.

- CEOS
- Geotiff

4.4.1 EOS-04 Data Products Contents

EOS-04 data products for the user are identified with a unique work-order identity Eg. WO_ID. For a particular data product following are the contents of WO_ID directory:

- **BAND_META.txt**

  It is a ASCII File having a listing of several product parameters.

- **Grid Files**

  Image space is divided in a grid at the interval of N*N (e.g. 32*32) in scan and pixel direction, wherein first grid point corresponds to (0,0) in image space. The grid is listed in a text file along with the product in row major format. Attributes of the each grid point are latitude, longitude, slant range and incidence angle. Any of the above given attributes for any scan pixel position (s,p) can be calculated by interpolating the attributes from the neighboring grid points.

Note: -9999.000000 is FLAG value in Level-2 product in case the pixel does not belong to imaged scene.

Product wise naming convention of Grid Files is as follows:

Level-0 RAW product: *There will be no grid files for RAW product*.

Level-1A SLC product:

WO_ID_TxPolRxPol_L1_SlantRange_grid.txt

Ex: 208385331_HH_L1_SlantRange_grid.txt

Level-1B Ground Range product:

WO_ID_TxPolRxPol_L1_GroundRange_grid.txt

Ex: 208385331_HH_L1_GroundRange_grid.txt

Level-2 product:

WO_ID_TxPolRxPol_level_2_grid.txt

Ex: 208385331_HH_level_2_grid.txt

- **Scene Files**

  Scene Files are contained in the directory : **scene_TxPolRxPol**

  For **CEOS product**.

  This directory contains four files namely

  - vdf_dat.001
  - lea_01.001
  - dat_01.001
  - nul_vdf.001

  For **GeoTIFF product**:

  This directory contains one file namely

  - imagery_TxpolRxpol.tif

- **XML File**

  A **product.xml** file with several product attributes is available for the **Level-1 and Level-2 GeoTIFF** product.

- **Jpeg Files**

  Thumbnail images (*not for RAW product*) of the scene imaged for the product are available in .jpg format with the following naming convention.

  WO_ID_TxPol_RxPol.jpg

  Ex: 208385331_HH.jpg

4.4.2 EOS-04 Level-2 Product contents

Level-2 data product is the **Enhanced Terrain Geo-Referenced Product,** provided to user in map projected (UTM, Geographic, UPS) domain. Two auxiliary files for Layover mask and Local Incidence angle is also provided along with the Level-2 product with the following naming conventions.

1. **WO_ID_mask.tif** Ex: 208385331_mask.tif
2. **WO_ID_lia.tif** Ex: 208385331_lia.tif

Local Incidence Angle Map :

The angle of Incidence is defined as the angle between the radar line of sight and the local vertical at the point where radar beam intersects the earth's surface. Using slant range vector and the local surface normal vector, Local Incidence angle is generated. Topography has an impact in changing the nominal incidence angle (available in Grid File) i_0 (without topography) to i_t (with topography). Local incidence angle for each pixel of the geo-referenced SAR scene is provided with the Level-2 product as a **GeoTIFF (data type: Float)** file in degrees.

Value	Significance	Region
0.0 to 90.0	Valid Incidence Angle Range	(A)
0.0 to 90.0	Layover Region (Masked region from Layover mask file)	(B)
-2	Region Outside Geo-Referenced Image	(C)

Table-14 Definition of Local Incidence Angle Map

LayoverMask :

Areas of SAR layover are determined via the slant range distance, which in general increases for a scan line from near to far range. Layover occurs as soon as the slant range reaches a turning point and decreases when tracking a scan-line from near to far range. Layover information for each pixel of the geo-referenced SAR scene is provided with the Level-2 product as a **GeoTiff (data type: unsigned short integer)** file.

Value	Significance	Correspondence with Local Incidence Angle Map
128	Undistorted usable Region in Image	Region (A)
16	Distorted Layover Region in Image (to be used for further analysis)	Region (B)
0	Region Outside Geo-Referenced Image	Region (C)

Table-15 Definition of Layover Mask

The correspondence between Local Incidence angle map and the layover mask can be established from column three of Table-14 and 15.

Note: Any analysis to be done on the EOS-04 Level-2 product should be done by applying/overlaying Layover Mask over SAR image data.

4.5 Radiometric Calibration of EOS-04 Data Products

Radiometric calibration of the data is required to transform processed SAR data or images into measurements of Radar back scatter of targets. Depending upon the plane of measurement, radar backscatter coefficients can be classified as Sigma0 (σ_0), Gamma0 (γ_0) and Beta0 (β_0). EOS-04 images for different polarizations are available as Beta-Naught (Beta0) images (RISAT-1 were Sigma0 images). Following are the Calibration Equations for generating Sigma-Naught (σ_0), Gamma-Naught (γ_0) and Beta-Naught (β_0) for EOS-04 Data Products.

(These formulae change from time to time. For latest information please refer to the data products document in NRSC web site www.nrsc.gov.in)

4.5.1 Equations used for computations are :

$$Beta0_p = \frac{DN_p^2}{K_{cal\_Beta0\_linear}} \quad (1)$$

$$Sigma0_p = \frac{DN_p^2 \; X \sin i_p}{K_{cal\_Beta0\_linear}} \quad (2)$$

$$Gamma0_p = \frac{DN_p^2 \; X \tan i_p}{K_{cal\_Beta0\_linear}} \quad (3)$$

where,

$Beta0_p$ is the radar backscatter coefficient Beta0 for pixel p: eqn. (1)

$Sigma0_p$ is the radar backscatter coefficient Sigma0 for pixel p: eqn. (2)

$Gamma0_p$ is the radar backscatter coefficient Gamma0 for pixel p: eqn. (3)

DN_p is the digital number or the image pixel gray-level count for the pixel p

$$K_{cal\_Beta0\_linear} = 10^{\left(\frac{Kcal\_Beta0\_dB}{10}\right)} \quad (4)$$

Kcal_Beta0_dB is the product calibration constant in dB for computing Beta0 and hence Sigma0, Gamma0.

Kcal_Beta0_linear is the Beta0 calibration constant derived from Kcal_Beta0_dB,

ip is the incidence angle for the pixel position p and can be obtained from *grid.txt file available with product.

4.5.2 Computation of Sigma0, Gamma0 and Beta0

Parameters required for computation of Sigma0, Gamma0 and Beta0 using the equation (1), (2), (3), (4) can be extracted/computed as follows:

- **Digital Number (DN_p)**

For the CEOS products Image pixel Digital Numbers can be extracted from field 53 pdr_data of the Processed Data Record.

For the GeoTIFF products, Image pixel Digital Numbers can be extracted from file imagery_TxPolRxPol.tif.

For SLC products:

$$DN_p = Sqrt(DNI_p^2 + DNQ_p^2)$$

DNI_p:: DN Value of I component

DNQ_p:: DN Value of Q component

- **Calibration Constant (KdB)**

For the CEOS products, Kcal_Beta0_dB can be extracted from field's calib_const_Beta0 of the Radiometric Data Record.

For the GeoTIFF products Kcal_Beta0_dB is available in the tag calibration Constant_Beta0 in the product.xml file.

Kcal_Beta0_dB is also available in tag Calibration_Constant_Beta0_TxRx in the BAND_META.txt file.

- **Incidence Angle**

For computing the incidence angle for any pixel position p incidence angle values in grid files along with product can be used. Computation can be made as per the write up under Grid Files in section 4.4.1. Scene Center incidence angle i_{center} can also be obtained directly from the Incidence Angle field of BAND_META.txt file. For the CEOS products, field 40 incident_ang of the Data Set summary Record also gives scene center incidence angle. For Level-2 products, Local Incidence Angle is also available in file **WO_ID_lia.tif.**

- **Note on Noise Bias Usage:**

During radiometric correction process, an estimate of the expected contribution from additive thermal instrument noise has been subtracted from each image pixel. Due to the statistical nature of SAR imaging and the randomness of the noise, calibrated digital value for some pixels may become negative. To avoid negative numbers in the processed image, an image noise bias "N" has been added on EOS-04 images (available as IMAGE_NOISE_BIAS for all polarizations in BAND_META.txt). To reconstitute the digital numbers, IMAGE_NOISE_BIAS should be subtracted from

DN2 for every pixel in equation (1)-(3). The application of noise bias, though results in improvement of backscattering coefficient accuracy, it also results in negative pixel values. The efficacy of this improvement is prominently seen in low SNR regions. It is up to the user or end application to decide how best to handle pixels having negative calibrated values, for example whether to clip them at zero or to leave them as it is.

4.5.3 RCS (σ) Calculations for Point Targets

For computing Sigma parameter i.e. σ and not the Sigma Naught parameter σ0, area of target has to be taken into account. Hence, the equation for σ is:

Integration Method:

$$Sigma_p = \frac{(\sum_W DN_W^2)\ X\ \ Scattering\_Area_{integration}}{K_{cal\_Beta0\_linear}} \qquad (5)$$

where,

- "w" is considered a window around Point Target over which return power is integrated e.g. (5x5, 9X9, 11X11 …)
- Scattering_Areaintegration = (OutputLineSpacing X OutputPixelSpacing) (tags available in BAND_META.txt)

Peak Method:

$$Sigma_p = \frac{DN^2{}_{interpolated\_peak}\ X\ Scattering\_Area_{peak}}{K_{cal\_Beta0\_Linear}} \qquad (6)$$

(DN^2) interpolated peak: Interpolated Peak of Point Target Impulse Response

$Scattering\_Area_{peak}$ = (Output_Azimuth_Resolution X Output_Range_Resolution) (to be derived from Point Target Impulse Response). Azimuth Resolution and Slant Range Resolution can be obtained from Input Resolution Along and Input Resolution Across tags respectively of BAND_META.txt file.

4.6 EOS-04 Value Added Data Products

EOS-04 payload provides features of :

- Hybrid Polarimetric acquisitions (similar to RISAT-1)
- Fully Polarimetric acquisitions

Also, a systematic coverage of the Indian region every 17 days will be available in Medium Resolution ScanSAR (MRS) modes to cater to various application requirements.

In addition to the basic Geo-Tagged Level-1 and Geo-Coded Level-2 data products the following value added products have been introduced for EOS-04 which are described in following sections.

- Polarimetric value added products
- MOSAIC value added products

4.6.1 Plolarimetric Value Added Data Products

EOS-04 polarimetric data products will be scene-wise products available as following:

- **Slant-Range Geometry** (Level-1C) for Dual-Polarization (DP), Circular Polarization (CP) and Full-Polarization (FP) acquisitions.
- **Geo-Coded polarimetric decomposed data products** (Level-3A) for CP and FP data. Table-16 below gives the detailed contents of these data products.

Level of Product	Product Description (Scene Wise Data Products)
Level-1C	➢ Geo-Tagged Polarimetric Data Product ➢ Slant Range Geometry ➢ Auxiliary product contents like Grid File, Meta File, Xml file, Thumbnail jpg will be available as similar for Level-1 SLC data product **Image File Contents** ➢ **CP/DP :**3 Layers (2 real Diagonal : 1 complex Off Diagonal Elements of COVariance Matrix) ✚ Product Volume: 2 times the volume of standard DP/CP SLC product ➢ **FP:** 6 Layers (3 Real Diagonal : 3 Complex Off Diagonal Elements of COVariance Matrix) ✚ Product Volume: 2.25 times the volume of standard FP SLC product **FORMAT: GeoTIFF**

Level-3A	➢ Terrain Geo-Referenced Polarimetric decomposed data product in UTM/UPS projection ➢ Geometry similar to EOS-04 Level-2 data product ➢ Auxiliary product contents like Grid File, Local Incidence angle, Layover Mask, Meta File, Xml file, Thumbnail jpg will be available as similar for Level-2 data product **Image File Contents** ➢ **CP:** • Single Bounce , Double Bounce and Volume Scattering Images for m-delta or m-chi circular polarimetry decomposition *Product Volume: 3 times the volume of standard CP Level-2 product* ➢ **FP:** • Single Bounce , Double Bounce and Volume Scattering Images for **Freeman Full polarimetry decomposition** • Single Bounce , Double Bounce ,Volume and Helical Scattering Images for **Yamaguchi Full polarimetry decomposition** *Product Volume: Freeman Decomposition: 1.5 times the volume of standard FP Level-2 product* *Product Volume: Yamaguchi Decomposition: 2 times the volume of standard FP Level-2 product* **FORMAT: GeoTIFF**

Table-16 EOS-04 Polarimetric Value added data product

4.6.1.1 Level – 1C Polarimetric Data Products :

EOS-04 Level-1C products are the Covariance products, with matrix elements as given in equation (1) e.g. for an RH-RV acquisition case and in equation (2) for Full-Polarization acquisition.

Circular Polarization :

For the Circular (Right/Left) or Linear (Horizontal/Vertical) transmit and Linear (Horizontal/Vertical) receive, the covariance matrix is as follows (RH-RV case):

$$C=\begin{pmatrix} S_{rh}S_{rh}^* & S_{rh}S_{rv}^* \\ S_{rv}S_{rh}^* & S_{rv}S_{rv}^* \end{pmatrix} \qquad (1)$$

Equation (1) can be assumed for other cases like for LH-LV replacing RH with LH and RV with LV. Similarly, RH with HH and RV with HV for an HH-HV case.

In product there will be Three (3) layers comprising of the Two Real diagonal terms and One off diagonal complex term i.e. C12 of eq. (1). C21 can be derived from C12 by a conjugate operation. So, we can generate all elements of the Covariance Matrix C.

Full Polarization:

For Fully polarimetric acquisition, Covariance matrix (assuming symmetricity of HV and VH polarizations) elements are as defined in equation (2).

$$C=\begin{pmatrix} S_{hh}S_{hh}^{*} & S_{hh}S_{vh}^{*} & S_{hh}S_{vv}^{*} \\ S_{vh}S_{hh}^{*} & S_{vh}S_{vh}^{*} & S_{vh}S_{vv}^{*} \\ S_{vv}S_{hh}^{*} & S_{vv}S_{vh}^{*} & S_{vv}S_{vv}^{*} \end{pmatrix} \quad (2)$$

In product there will be Six (6) layers comprising of the Three Real diagonal terms and Three off diagonal complex terms i,e C12 , C13 , C23 of eq. (2). C21 can be derived from C12, C31 from C13 and C32 from C23 by a conjugate operation. Hence, we can generate all elements of the Covariance Matrix C.

In Level-1C product, there will be no multi-looking applied on elements of Covariance matrix.

4.6.1.2 Level-3A Polarimetric Data Products:

Contents and Format of Level-3A Polarimetric decomposed Geo-Coded data products is provided in Table-16 above.

4.6.2 Mosaic Value Added Data Product

The following types of mosaic data products would be available for EOS-04 users:

4.6.2.1 Large Area Mosaic from EOS-04 MRS Systematic Coverage

For effective utilization of EOS-04 SAR data for Regional and National level decision making, value added MOSAIC products will be generated from Systematic coverage MRS mode acquisitions.

Following will be the features of these products:

- EOS-04 Mosaic products will be Analysis Ready Data (ARD) – Gamma0 products
- In case of multiple date data for a pixel, latest acquisition data will be retained
- Product will be in Gamma0, so incidence angle normalization will be applied
- In case of missing data, fill value (-100 dB) will be there in Mosaic product

- Mosaic product of a region (Country-India, State, district etc.) for different seasons/date extent will be registered with one another and hence can be readily used for Time-Series analysis
- Local Incidence Angle Map, Layover mask will be provide for each pixel in GeoTIFF format
- Date Map stating date of acquisition of each pixel will be available in GeoTIFF format

Detailed description of these MOSAIC products are provided as follows:

Large Area Mosaic product for the user required Area of Interest (AOI) and date extent will be generated from MRS mode systematic coverage acquisitions. As shown in Figure-31 Country (India), state and district Mosaics can be generated as products.

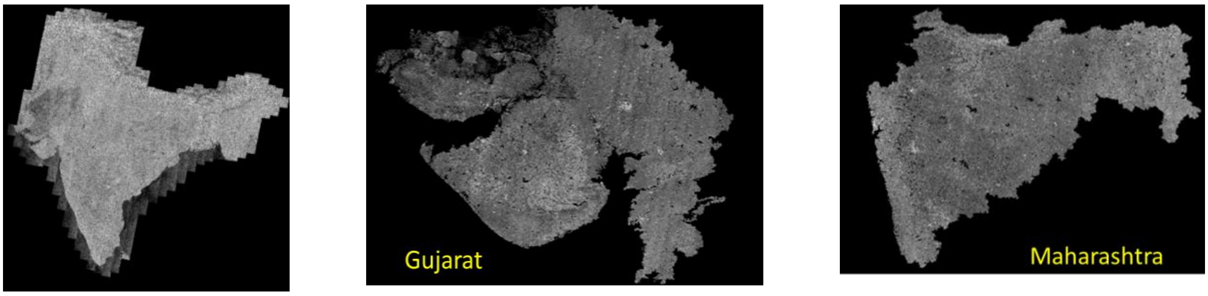


Figure-31 Large Area MOSAICS for EOS -4 MRS Systematic Coverage Acquisitions

1	Mosaicked output will be available as Gamma0 Image for each polarization (HH/HV) in Geographic Projection (For full India : 80 GB for full image/polarization : Unsigned Short Int)
2	Every Pixel will be filled by the latest data available
3	Mosaicked output will be made available in user opted spacing (18/36/54/72/90/180/360/540/900) meters
4	Mosaicked output to be made available in 1 X 1 deg. Or 5 X 5 deg. Tiles
5	Output Format : GeoTIFF/BigTIFF , Unsigned short Int
6	Decimated Jpeg File will be available with the product

Table-17 EOS-04 MRS Systematic Coverage Large Area MOSAIC

4.6.2.2 Area Of Interest (AOI) Mosaics from EOS-04

EOS-04 Large Area MOSAIC products listed in the previous section are for MRS systematic coverage cycles. They will ensure fidelity of Incidence Angles, acquisition time span for targets of interest over Indian region.

User may be interested in a MOSAIC of his Area of Interest (AOI) acquired by EOS-04 in a particular Imaging mode over a certain time span. Hence, a MOSAIC product depending upon the acquisitions availability will be generated with features as provided in Table-18.

1	AOI Mosaicked output will be available as Gamma0 Image for each product polarization in Geographic or UPS Projection
2	Mosaicked output can be made available in user opted spacing (1x/2x/2x/4x/5x/10x/20x/30x/50x) or standard Level-2 product spacing for the imaging mode
3	Mosaicked output to be made available in 1 deg. X 1 deg. Tiles or Full Image
4	Output Format : GeoTIFF/BigTIFF , Unsigned short Int
5	Decimated Jpeg File will be available with product

Table-18 EOS-04 User Requested (Non-Systematic Coverage) AOI MOSAIC product

4.7 EOS-04 Quality of Data Products

Objectives :

- To monitor platform stability and data products geometric accuracies.
- To monitor the radiometric response of the Sensor by Internal and External Calibration passes and using standard qualified radiometric sites.
- To verify and certify the operationalized products generated in the IMGEOS Chain.

4.7.1 Data Products Specifications:

The Intended data products quality specifications are shown in the table-19 below.

Parameter	Intended specification
Geolocation accuracy (RMSE)	50 m
Radiometric Resolution (Single Look)	3.1 dB
PSLR	-17 dB
ISLR	-10 dB
Relative radiometric accuracy	1 dB
Absolute radiometric accuracy	±1 dB

Table-19 Data Products specifications

4.7.2 Monitoring Mission performance and radiometric response

The Strategy for monitoring the Mission performance and the radiometric response are shown in the Figure-32.

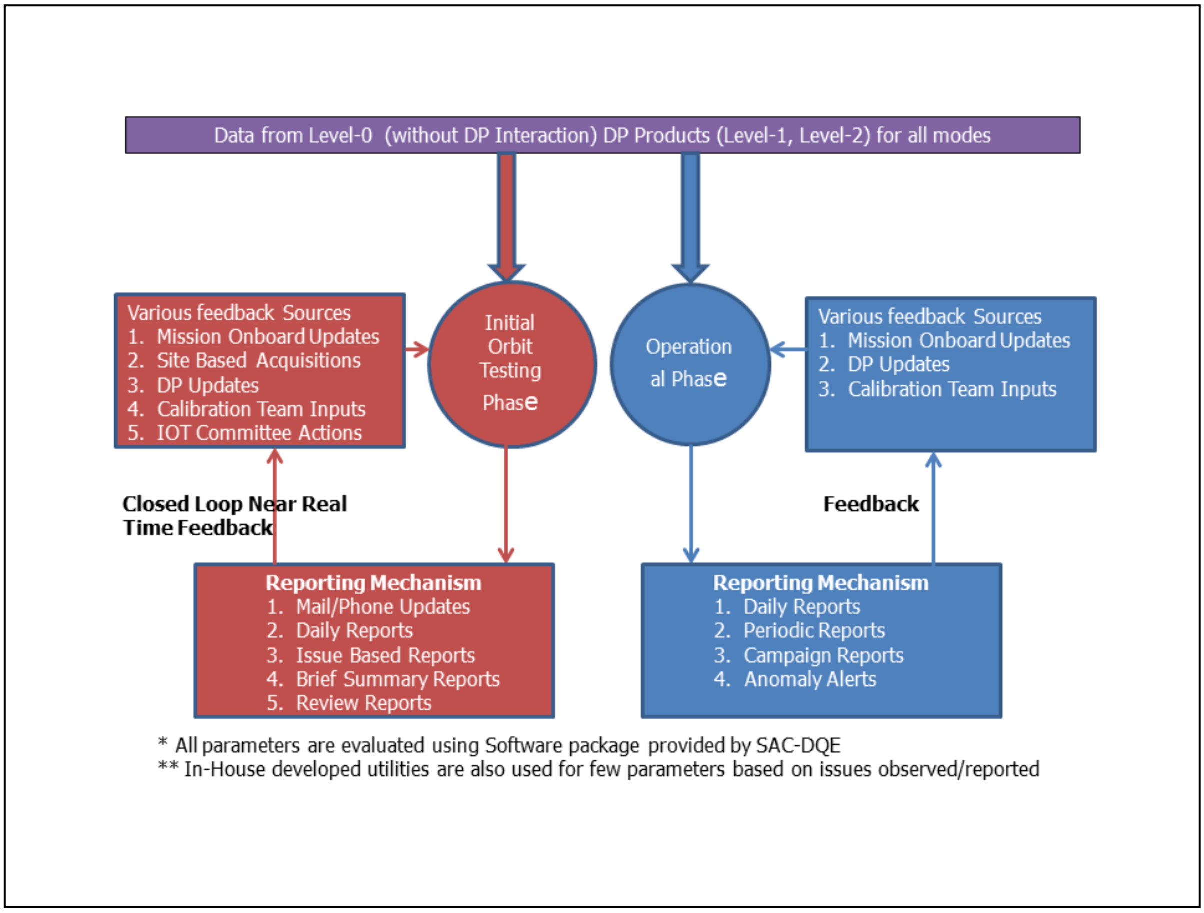


Figure-32 Strategy & Functional Flow chart

4.7.3 Methods/Procedures for monitoring data quality:

4.7.3.1 Data quality evaluation :

Data and data product qualification mainly comprises of Evaluation of data with regard to the RAW data quality, radiometric quality, targeting accuracy, geometric accuracy and trending during the orbital period. The other important aspect of data qualification is the calibration, spatial resolution, and polarization characterization

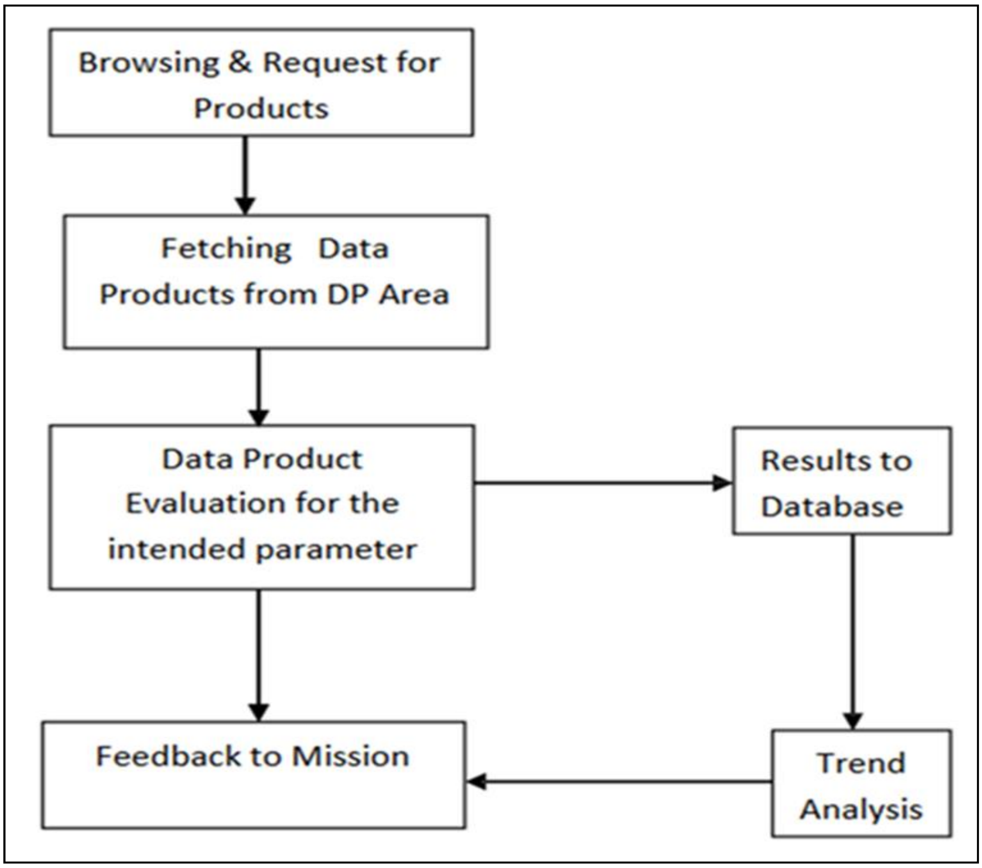


Figure-33 Monitoring of data and data product quality parameters:

Details of planned quality parameter evaluation :

- Location accuracy : Mode wise
- RAW data analysis: As data acquired
- Temperature monitoring: LBT data
- Target accuracy for HRS mode
- Calibration parameters:

- Internal Cal pass
- Point target based analysis
- Opportunity based for MRS/FRS/HRS
- Extended target: 'Amazon Forest' etc.

- Systematic coverage (Cycle based)
    - Side lap/Ground track maintenance
    - Pol mis-registration(DP, CP & FP)

4.7.3.2 Data products certification process:

All EOS-04 data products will be thoroughly verified and will be subjected for stringent quality checks before disseminating to users. Data products that conform to quality standards and specifications will be dispatched to users. Different types of data products defined for EOS-04 satellite are verified on sampling basis and are subjected for data qualification and certification at product quality control for geometric as well as radiometric fidelity. PQC assesses the quality of data products by following internal check procedures like format validation and through visual/manual methods.

The quality criteria for accepting or rejecting EOS-04 data products are based on radiometric anomalies as mentioned in the disclaimers and also as per the standard check list which are finalised at the end of the IOT (Initial Operations Testing) phase with the achieved quality specifications.

Visual Quality Assessment:

All EOS-04 data products are subjected for data qualification through visual quality assessment. Products that meet QC standards will be dispatch to the users. Non conformal products will be critically evaluated through failure analysis and undergo regeneration and re certification. The process is shown in Figure-34 below.

Details of planned quality verification and certification aspects:

- Format and meta file validation
- Geometric fidelity
- Radiometric fidelity

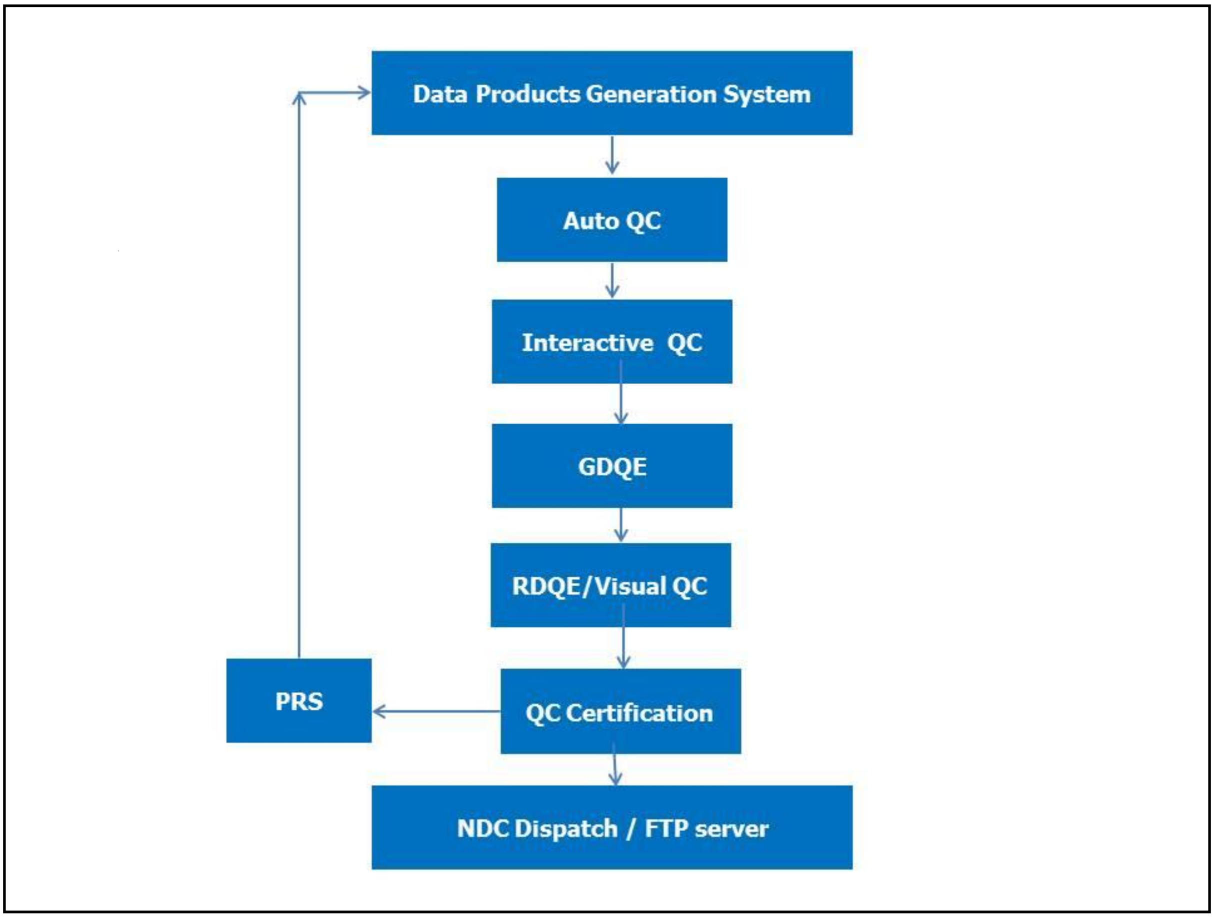


Figure-34 Data products verification and certification

Chapter-V

5. Data Access and Distribution

5.1 General Information

5.1.1 System Overview

Keeping in mind the global trends and need to promote greater utilization of remote sensing data which emanate from the space assets created from government funded programs, it is suggested to release some of the selected data products free for the online users.

Bhoonidhi - ISRO Open Data Access web application facilitates the dissemination of free satellite data products to online users on web.

It is equipped with various user friendly search options to ease target area identification and subsequent download. CART interface is also available for user to select the products and store for later download.

Bhoobidhi URL: https://bhoonidhi.nrsc.gov.in

5.1.2 Point of Contact

- For Queries related to Bhoonidhi:

  Bhoonidhi Team: bhoonidhi@nrsc.gov.in

- For Querie related to Data sales

  NDC Team : sales@nrsc.gov.in

This section is to guide to use Bhoonidhi web application for ordering EOS-04 satellite data products. It covers all the options and features available at Bhoonidhi for ordering data.

5.2 User Interfaces

In order to order the products, user has to first identify the product of interest. Various user friendly search options are provided to the user to target the area of interest from the product catalogue. The selected products are to be added to the CART. These saved products in the CART are to be converted to PI and if sufficient funds are available can be directly converted to orders.

5.2.1 User Access Levels

In order to browse through the products catalogue no login is required but product ordering can be done only by registered users after login. Users should have financial account with NRSC. The procedure to get the financial account is also available at Bhoonidhi while generating Performa Invoice (PI).

Following are the major user interfaces provided to the user for ordering priced EOS-04 satellite data products from the product catalog.

5.2.2 Archives

This view shows the data available in the catalogue which is also shown on the map to the user along with the color coded frequencies of collection in our archive. The list of satellites and sensors which are available for online download as well as priced data along with the data availability are displayed to get the quick view of data in the archives.

5.2.3 Explore

This option is for search and ordering the data. User has to select the AOI, resolution, date range, product types, and Priced/Open data wise sensors for searching the data sets. Each search by user is assigned a SearchID which is the reference for adding the priced products. User has to select the data as per the required specification and add to CART. The selected data based on priced/open is added in the Priced/Open CART. Satellites/sensors are displayed for selection to the user based on validity (launch date etc) and date range selected by user. Every product has a unique Product ID for quick reference.

This menu has following 3 sub menus:

5.2.3.1 Search Criteria

This is the main view using which user can browse through the catalogue, identify the area of interest, select the products and add them to Priced CART.

Following are the types of searches available at Bhoonidhi:

Area of Interest (AOI) Identification

User can provide the area of interest either using the map tool kit or manually entering the values. Location, Polygon, Point, Mapsheet, Shapefile and event based options can be used to specify the target area of interest for which products are to be ordered.

Following options are available:

- **Location/Point**

By specifying the location name or by providing few characters in the location name, the application will automatically fetch the matching locations. The user can then select the desired location from the list.

The user can also specify a point and extent of area (in km) around the point.

- ***Polygon***

By specifying the top-left and bottom-right coordinates.

- ***Shapefile***

Selecting the shapefile from existing list of state / district level shapefiles.

By uploading the shape file for the target area of interest.

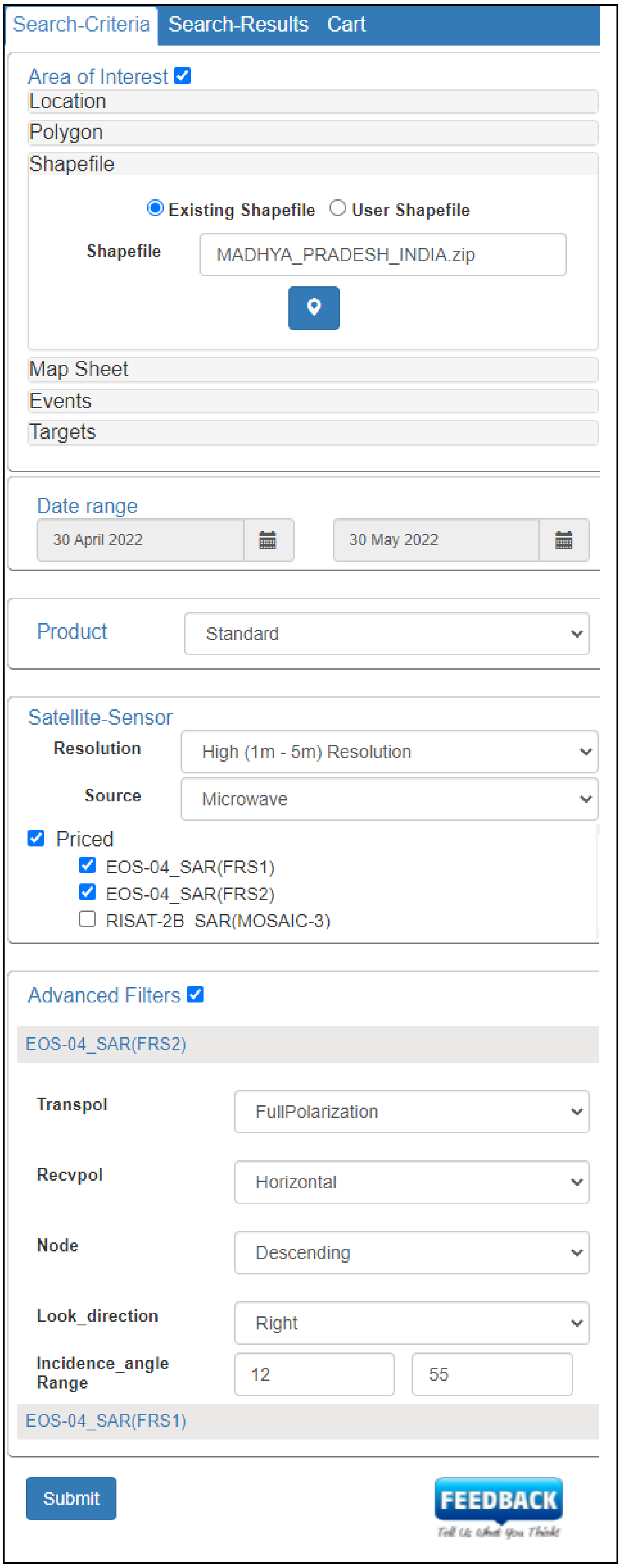


Figure 35 AOI specification

- ***Event Based***

The major events like floods, draught, avalanche, earthquake, etc will be tagged and made available to the user for selection. The software will automatically fetch all the data products belonging to the area in which the selected event had occurred. The user can then order the selected products from these fetched products.

- ***Map toolkit***

The map tools are described in 5.3

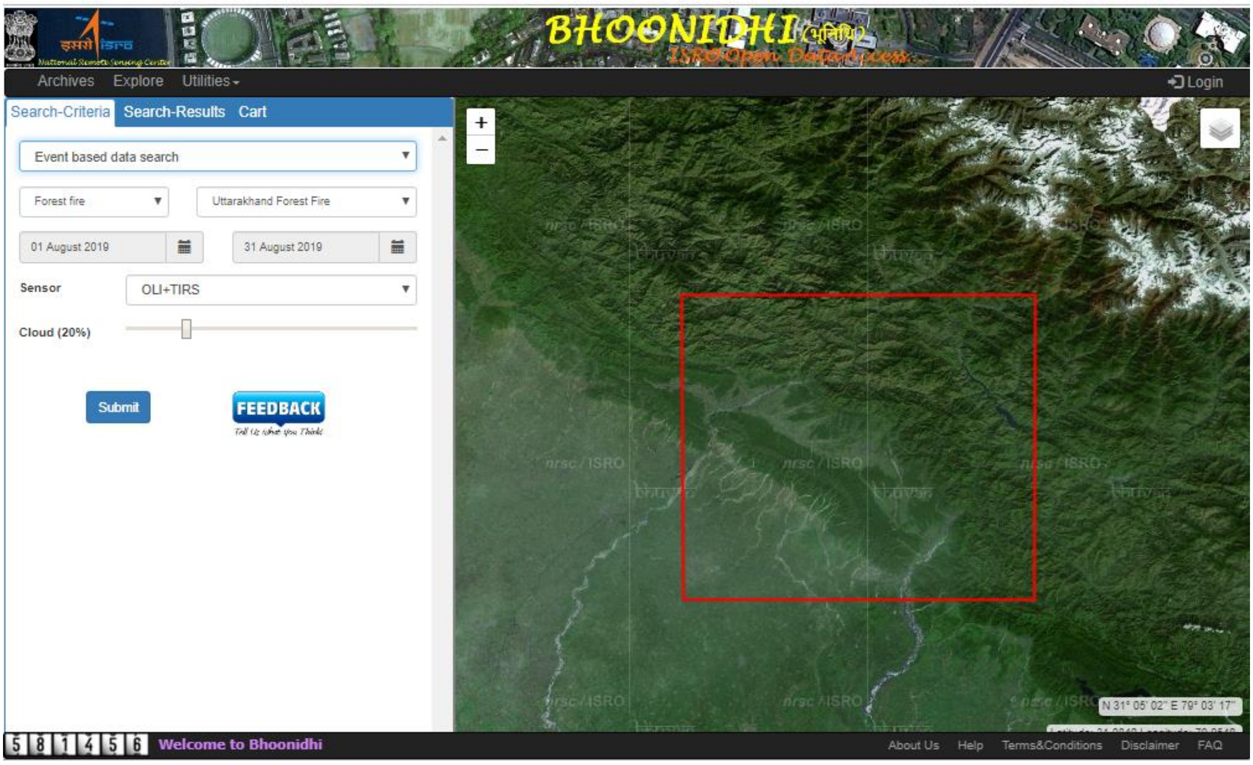


Figure-36 Event based data search

- ***Date Range***

This field is to specify date range for which data is to be searched from the catalogue.

- ***Product Type***

This field is to specify type of products (standard / stereo / thematic) for which data is to be searched from the catalogue.

- ***Satellite Sensor***

This field is to specify the satellite and sensor for which data is to be searched from the catalogue. The satellite sensors are grouped based on the resolution range and source (optical, microwave, etc) and further categorized under Priced / Open data category.

Advanced Filters

These filters are satellite specific and are enabled for selected satellites where such filters are available. These are generalized search filters configured dynamically for various satellite-sensors. For EOS-04 there are advanced filters like transmit polarization, receive polarization, node, look direction and incidence angle.

5.2.3.2 Search Results

This tab displays all the products which are found for the search filters provided by user under "Search-Criteria" tab. Against each product there are following options available:

- View and Download Metadata
- Image extent – This icon on clicking takes to the selected scene
- Publish on Map
- Add / Delete from CART

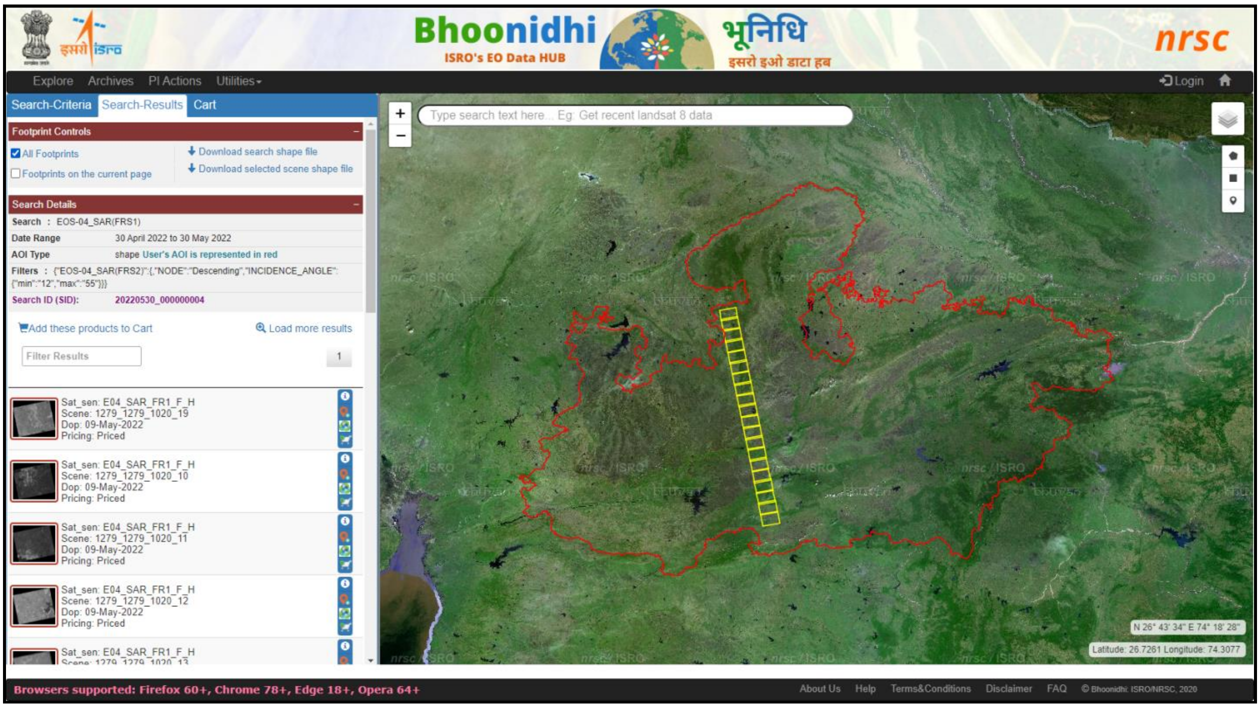


Figure-37 Search Results with footprint controls, search information and pagination

The "Filter Results" option can be used to sub filter the selected products based on any text which is displayed on the right side of the product image. The footprints of products on map are also filtered accordingly.

The "All Footprints" check box in footprint controls can be used to toggle footprints of the resultant products on the map.

The "Footprints on the current page" check box in footprint controls, can be used to toggle footprints of the products on the current page.

The "Load More results" option can be used to load next set of results for the search criteria.

The " Add these products to Cart" option can be used to add all the resultant products to Cart.

An option is provided for showing either

- Footprints in the current page
- All footprints cumulatively in all the pages
- Brings the clicked footprint to the front on click of show footprint button

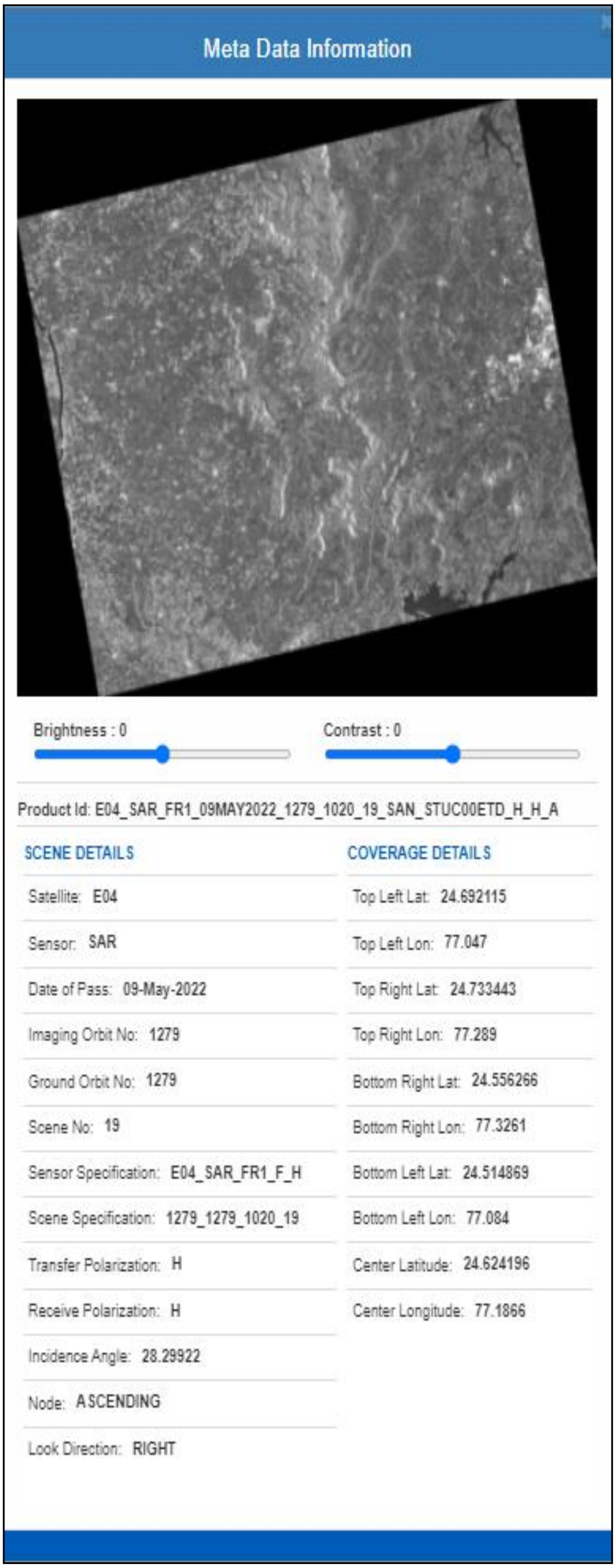


Figure-38 Meta Data Information

The number of items in the CART also can be seen in this view. In addition, the footprint of selected Area of Interest (if any) is displayed in red color on the map.

- ***Search Id***

Each search by user is assigned a SearchID which is the reference for adding the priced products. For each SearchID, user can check the products confirmed in the CART on the map and convert to PI. This also gives the design flexibility where same user can login from multiple systems. Every search is handled independently.

- ***Pagination***

Pagination is enabled for 100 products at one fetch. The resultant products are segmented with 100 products per page. Add more results option is provided to fetch the next set of 100 products. The product fetch is ordered/ sorted based on sensor and imaging date. The footprints of the fetch results are displayed on the map. This gives the design flexibility to provide wider range for AOI and date range for fetching the data from backend.

- ***Metadata download***

This option provides a view to display the selected product's metadata, quick view of product, it's footprint along with the download option. Using this download option user can download the metadata information/file associated with the selected product. This file is also available in the zip/archive of each product downloaded.

5.2.3.3 Cart

At integrated Bhoonidhi there are two different carts; Open and Priced. The look and feel for both the carts is same. This also shows the layout of selected items in white color on map.

If not logged in, ask for login with registered user Id. If not registered, alert to register with registration option available. Using this action "Add All to Cart", all the products fetched till that time can be added to cart at one shot.

Under PRICED CART option user has to select "Single Scene" and then select the SID for which CART is to be confirmed

Once the scenes are added to the priced cart, user has to provide the product details using "Product Specification" button. Next the user has to Generate PI by using "Generate Proforma Invoice" button at the GUI.

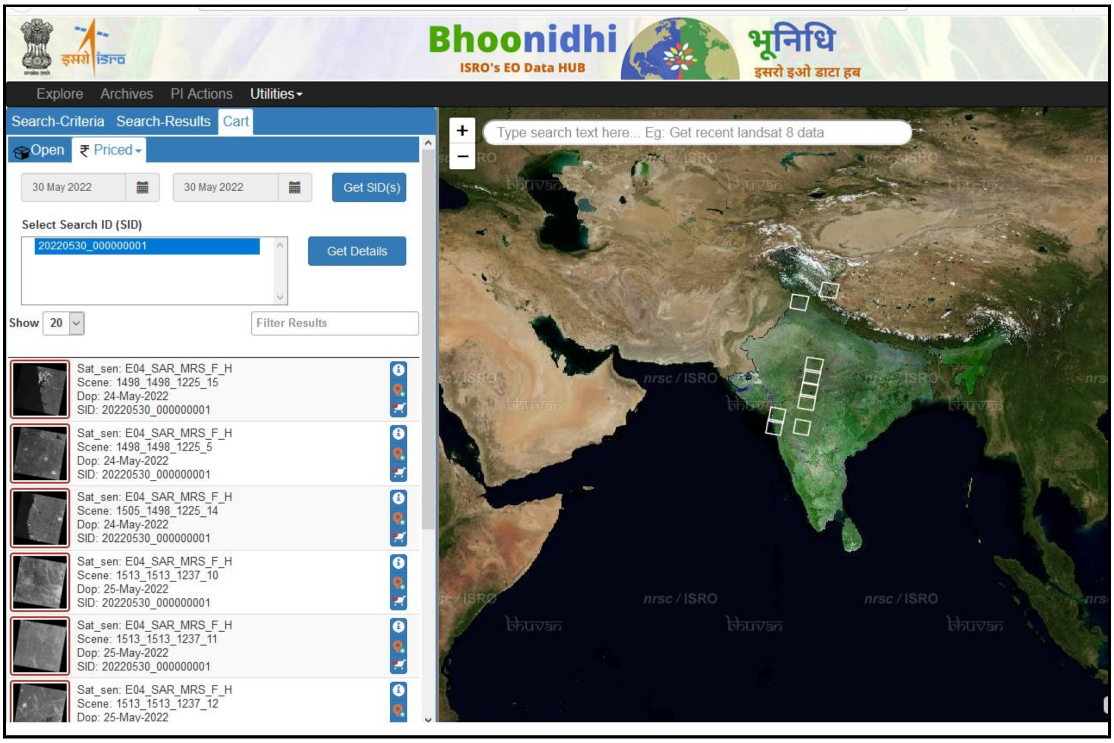


Figure-39 Priced Cart selection

5.2.4 Product Specification

User has to provide the details of the products to be generated on demand. These details are to be provided for all the sensors selected in the current search Id. This can be added by using "Add Products" button. Once the product specification is provided for all the sensors, after providing "PI Reference" and "PI Date", user has to select "Generate Proforma Invoice" button.

5.2.5 Proforma Invoice (PI) Operations

Once the PI is generated it can be converted to the order using "Generate Order option". This option has following services

- View PI
- Delete PI (All, selected)
- GSTIN Selection and Delivery address
- Save as PI PDF

The user can view the PI details, delete all/ selected items from a PI and can also download PI pdf.

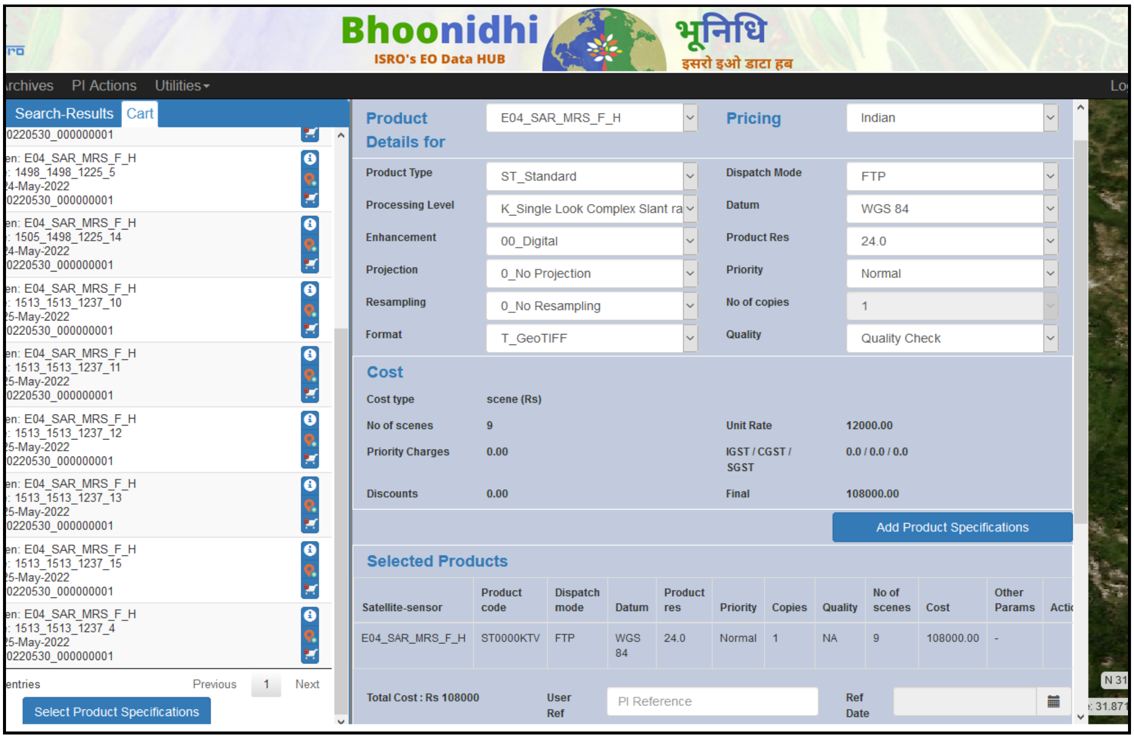


Figure-40 Product Specification

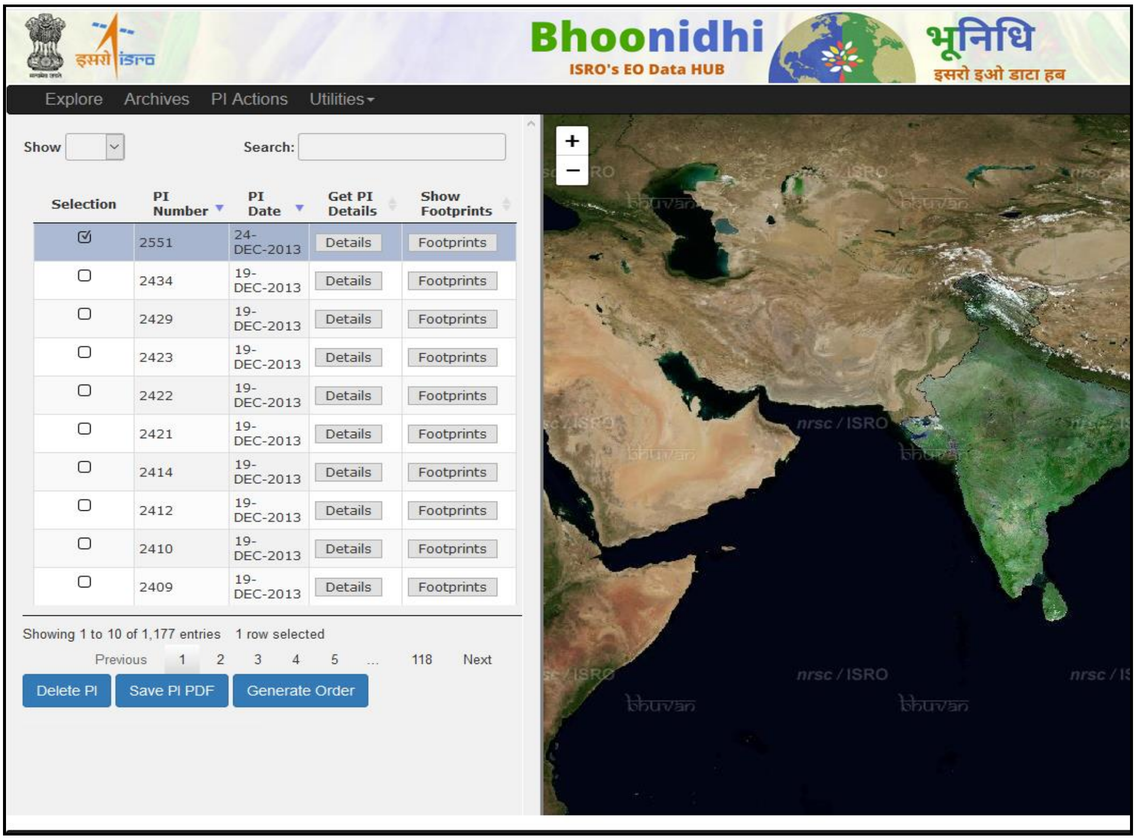


Figure-41 Proforma Invoice (PI) Operations

5.2.6 Order Operations

After the PI is, generated the order is to be generated. This has following services. This option is available under "PI Actions".

- Generate Order
- Order display
- Save as Order PDF

Once the order is generated the order details are displayed to the user along with the item level details. While generating an order user has to also provide the shipping address and also Account number.

5.3 Maptoolskit

Bhoonidhi application provides an interactive mapping interface where the users can draw the area of interest and visualize the extents of the result datasets. The various mapping tools that are available on Bhoonidhi are:

Bhuvan map server: It will be used for both satellite map as well as administrative boundaries.

Map server (GeoServer): It will also be deployed to facilitate publishing of the image chip, drawing image boundaries/ footprint, etc.

Following are the features made available :

- Free draw to facilitate drawing the area of interest
- Product footprint
- Publishing Product (tiff) on Map by Geotagging and On mouseover displays the backend layer of cities
- Zoom to center of the product selected on Map. This will help in focusing back to the scene selected after large zooming was done
- Layer Selection Tool
- Point Marker

5.3.1 Layer Selection Tool

This tool enables the users to toggle between the various base layers. Two base layers are provided by default i.e. Bhuvan Satellite base layer and Bhuvan Admin base layer.

5.3.2 Drawing Tools

Two drawing tools are available through which the users can draw the Area of Interest (AOI).

- Draw Rectangle: Users can select the draw rectangle option and drag the mouse on the appropriate location on the map to draw a rectangular AOI. As soon as rectangle is drawn, data search is triggered to fetch the datasets intersecting the AOI. Users can draw a maximum rectangular AOI of 8 degrees by 8 degrees.
- Draw Marker: Users can select the draw marker option and drop the marker at the appropriate location on the map. As soon as marker is drawn, data search is triggered to fetch the datasets intersecting the marker location.
- Free draw option to make polygon using multiple points marked at the Map.

5.3.3 Latitude-Longitude Display

This tool displays the latitude and longitude of a point on mouse over. The tool displays latitude and longitude in decimal format as well as DMS (Degrees Minutes Seconds) format.

5.3.4 Point Marker

This tool helps dropping a pointer at any given point and capturing the corresponding latitude and longitude of the selected point automatically.

5.3.5 Publishing Product

The image chip is converted into tiff and published at geoserver. This helps in getting the view of overlaying the product over based Bhuvan map.

5.3.6 Zoom Tool

This tool enables the users to zoom-in to and zoom-out from a particular location. Mouse scroll wheel can also be used to zoom-in and zoom-out.

5.4 Utilities

There are various utilities available which are basically for search and user order status motoring. Saved search option can also be used where the context saving is enabled.

5.4.1 SID Monitoring

Every Search Id can be monitored using this utility for AOI and coverage w.r.t. scenes selected. It displays the search criteria like AOI, date range, satellite, sensor, etc.

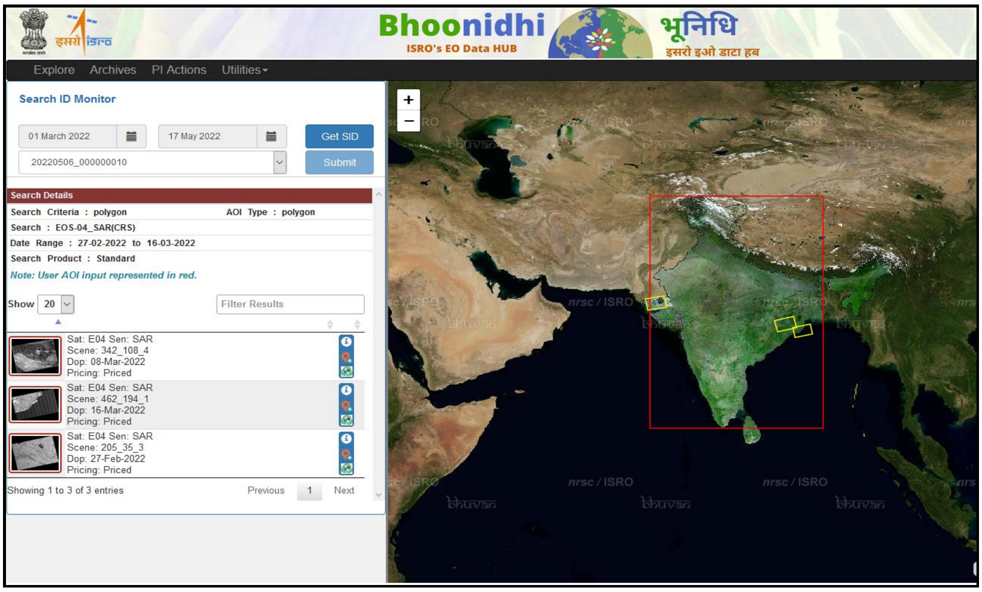


Figure-42 SID Monitoring

5.4.2 User Order Status Monitoring

This utility is to monitor the status of order. Along with the order, items under the selected order also can be monitored. The user has to provide a date range and for that date range all the orders are filtered. User can select any order and monitor the status. The scenes under the order are also shown on the map. Yellow color footprint on the map means "Product Not Yet Dispatched" and green footprints on map means "Product Dispatched".

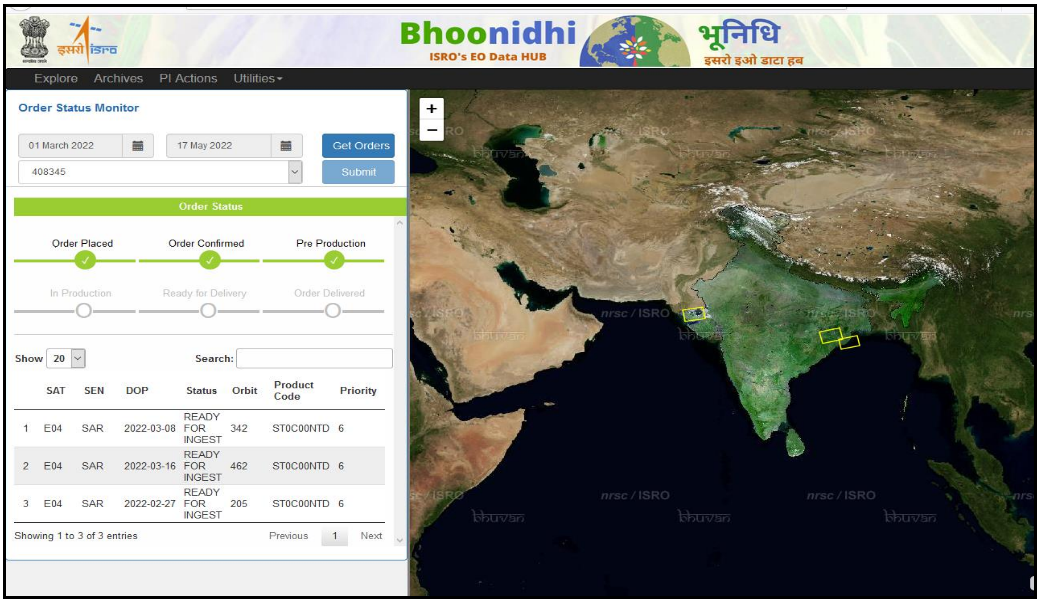


Figure-43 Order Status Monitoring

5.4.3 Saved Searches

This option has all the searched for which products were added to the CART but no action was further taken. This is basically enabled for context saving.

5.5 Registration & Login , Feedback Mechanism

5.5.1 Registration & Login

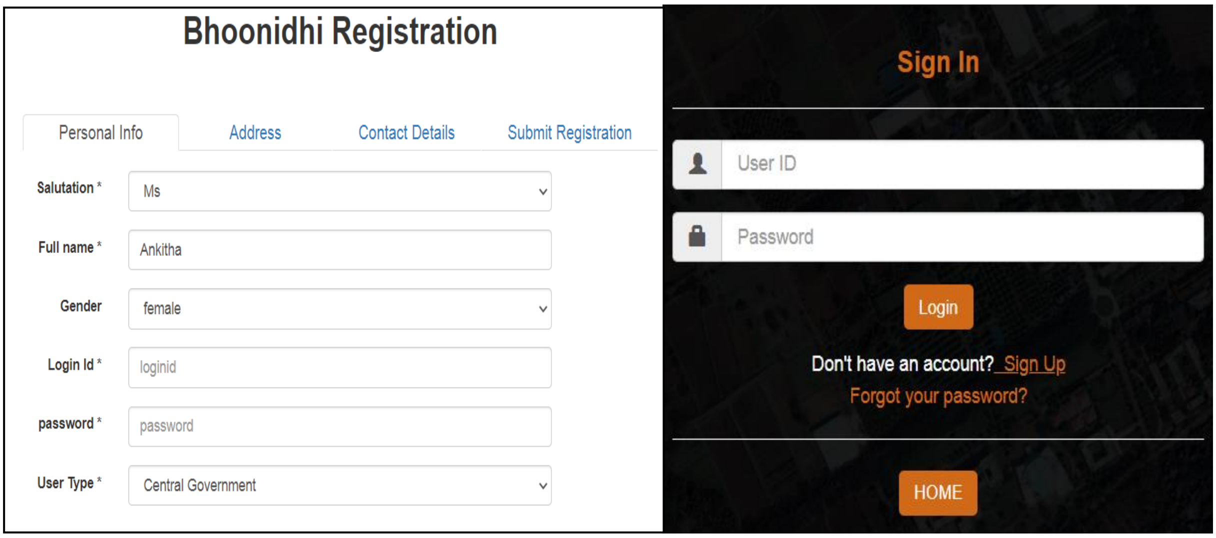


Figure-44 Registration Screen

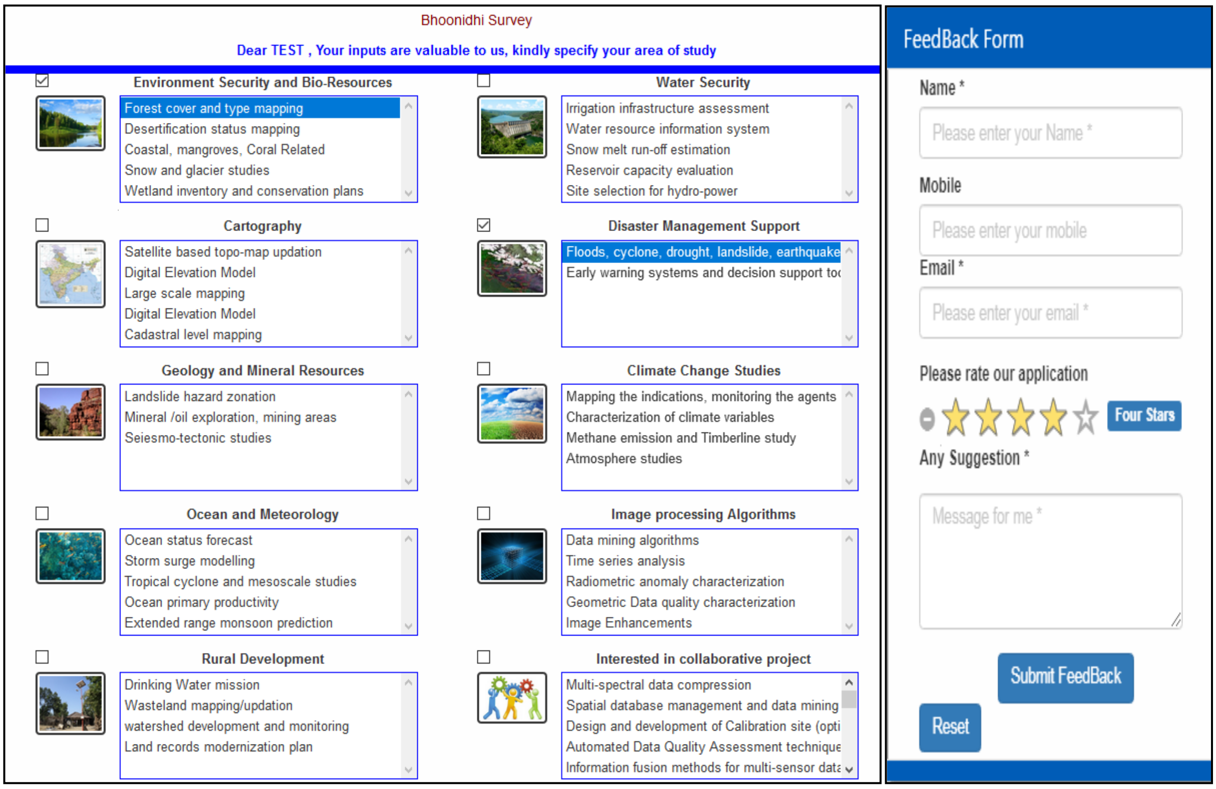


Figure-45 Feedback Form

5.5.2 Feedback Mechanism

For every user session, user has to provide feedback on the product usage. User has to specify the research/analysis/applicability domain in which the products being downloaded will be utilized.

User can also provide feedback on ease of download, target area and products search options, download speed, etc. This feedback from users will be utilized for continuous improvement.

5.6 Payload Programming Services

Payload programming activity involves programming the satellite acquisitions based on the user requirements, International ground station requirements and archival buildup. EOS-04 provides different beam modes and the incidence angle or "beam positions", this flexibility makes the planning and ordering of data slightly more complex. This activity is split across three different systems located at NRSC and ISTRAC.

EOS-04 is a programmable satellite and the data will be collected based on the user specifications like look angle, period, mode etc. NDC is also responsible for generating the final schedule files which is used by ISTRAC to further satellite commanding. ISTRAC uploads the state vectors and other related files through the online facility which are further used for preparing the schedules.

The requests are accepted through a web application. MMPPS is the Planning s/w available at NDC, NRSC to generate the daily schedule files. All the requests entered through web application are validated and are transferred to Master Scheduler of the MMPPS (Multi-mission Payload Planning System) for further planning. It allows to view, select/deselect the requests so as to generate an optimal acquisition plan. It has also the capability to perform emergency request planning on the same day. The pass schedule file thus generated is sent to ISTRAC, Bengaluru where the command sequence is generated and uplinked to the satellite.

5.6.1 Planning of User Requests:

Presently, the Users' requests will be taken up by NDC on their behalf and the proposals will be sent to the users for confirmation and further planning. Users should confirm their planning proposals at least three days in advance of the acquisition date.

Options for placing the programming request

The options for placing request for programming are similar to that of the data browsing and ordering which are mentioned below.

- Polygon
- Mapsheet
- Location
- Point
- Shape file

Apart for the above, the other inputs required form the users are:

Pass direction:

- Ascending mode or descending mode

Imaging mode:

- Coarse resolution mode

- Medium resolution mode
- Fine resolution mode-1
- Fine resolution mode-2
- High resolution spot light mode

Polarisation: The Table-20 below provides the valid polarization for each of the imaging mode.

Mode	Polarization
MRS	HH/ VV/ HV/ VH/ HH+HV/ VV+VH/ Full/ Circular
CRS	HH/ VV/ HV/ VH/ HH+HV/ VV+VH/ Full/Circular
FRS-1	HH/ VV/ HV/ VH/ HH+HV/ VV+VH/ Full/ Circular
FRS-2	HH/ VV/ HV/ VH/ HH+HV/ VV+VH/ Full/ Circular
HRS	HH/ VV/ HV/ VH/ HH+HV/ VV+VH/ Circular

Table-20 Polarization Per mode

Range of beam positions and incidence angles:

Based on the modes acceptable and the incidence angles beam positions will be automatically decided while planning. Either the minimum and maximum Incidence angle or user application specified incidence angle will be taken as input.

The following is the diameter factor that can be planned for each mode.

Mode	Diameter value
FRS-1	1-84
FRS-2	1-84
MRS	1-23
CRS	1-17
HRS	1-3

Table-21 Diameter Factor

Period of Interest:

- Start Date
- End Date

Polarization:

- Either Linear/dual /circular/quad

Priority:

Either urgent, normal or emergency priority option can be chosen.

- Normal: These requests can be placed 15 days in advance.

- Urgent: The requests, which are placed within T-3 days of acquisition, are treated as Urgent. These will be included in the daily acquisition plan.
- Emergency: The user requests are of highest priority followed by the archival build up. However in case of natural calamities and manmade emergencies, all other requests will take a lower priority. These requests are triggered only by NDC with high priority.

5.7 PPS – System

The Payload Programming system at NDC is designed as a multi-mission Payload Programming system. It takes inputs from UOPS and allows for scheduling. The operations involved in generating the daily schedule are:

- Login
- Selection of Systematic and User Requests
- Assigning of playback station for each recording Requests
- Generation of schedule file

The schedule thus created is sent to ISTRAC for commanding to the satellite.

The PPS system along with the selection of user requests serviced are shown in Figures- 46 & 47. The status of the requests serviced and the schedule file thus generated from the PPS are available in UOPS which are shown in Figures-48.

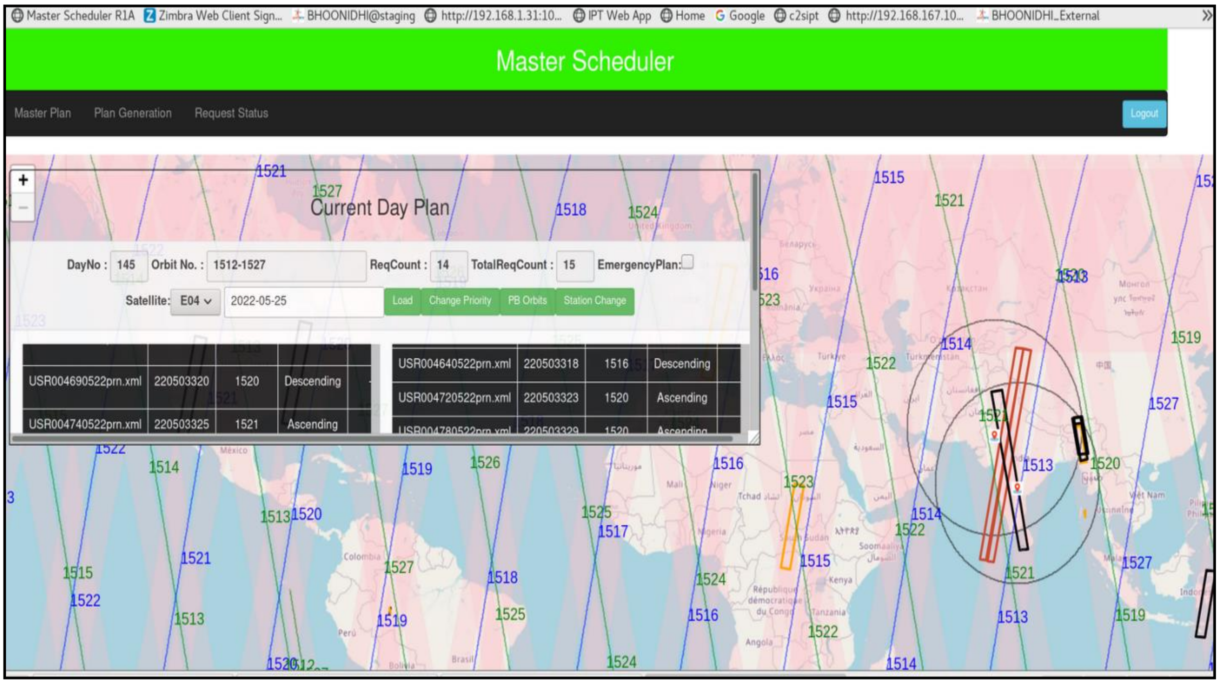
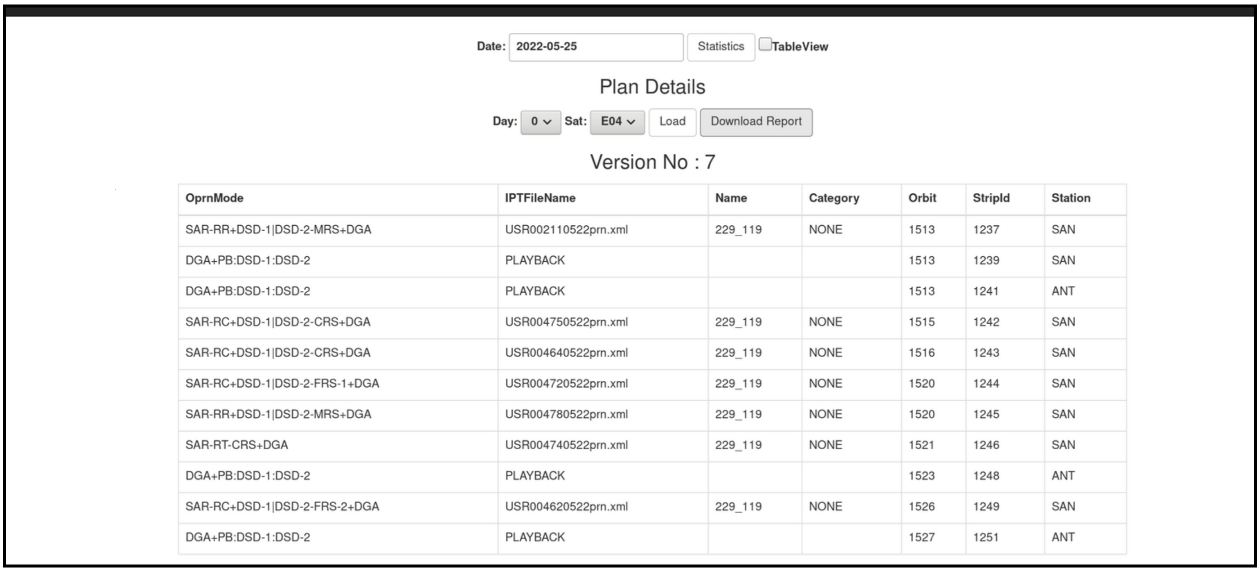
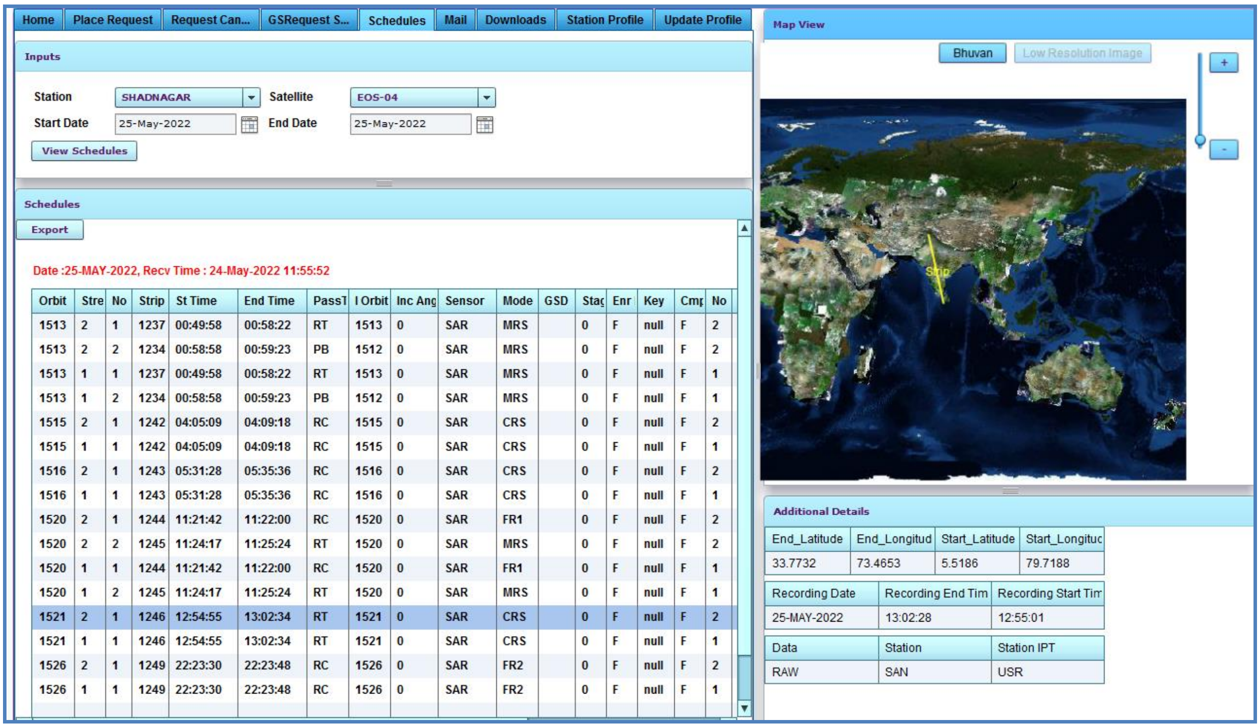


Figure-46 PPS System



OprnMode	IPTFileName	Name	Category	Orbit	StripId	Station
SAR-RR+DSD-1|DSD-2-MRS+DGA	USR002110522prn.xml	229_119	NONE	1513	1237	SAN
DGA+PB:DSD-1:DSD-2	PLAYBACK			1513	1239	SAN
DGA+PB:DSD-1:DSD-2	PLAYBACK			1513	1241	ANT
SAR-RC+DSD-1|DSD-2-CRS+DGA	USR004750522prn.xml	229_119	NONE	1515	1242	SAN
SAR-RC+DSD-1|DSD-2-CRS+DGA	USR004640522prn.xml	229_119	NONE	1516	1243	SAN
SAR-RC+DSD-1|DSD-2-FRS-1+DGA	USR004720522prn.xml	229_119	NONE	1520	1244	SAN
SAR-RR+DSD-1|DSD-2-MRS+DGA	USR004780522prn.xml	229_119	NONE	1520	1245	SAN
SAR-RT-CRS+DGA	USR004740522prn.xml	229_119	NONE	1521	1246	SAN
DGA+PB:DSD-1:DSD-2	PLAYBACK			1523	1248	ANT
SAR-RC+DSD-1|DSD-2-FRS-2+DGA	USR004620522prn.xml	229_119	NONE	1526	1249	SAN
DGA+PB:DSD-1:DSD-2	PLAYBACK			1527	1251	ANT

Figure 47 Details of the User requests serviced in PPS System



Orbit	Stre	No	Strip	St Time	End Time	PassT	I Orbit	Inc Ang	Sensor	Mode	GSD	Stag	Enr	Key	Cmp	No
1513	2	1	1237	00:49:58	00:58:22	RT	1513	0	SAR	MRS		0	F	null	F	2
1513	2	2	1234	00:58:58	00:59:23	PB	1512	0	SAR	MRS		0	F	null	F	2
1513	1	1	1237	00:49:58	00:58:22	RT	1513	0	SAR	MRS		0	F	null	F	1
1513	1	2	1234	00:58:58	00:59:23	PB	1512	0	SAR	MRS		0	F	null	F	1
1515	2	1	1242	04:05:09	04:09:18	RC	1515	0	SAR	CRS		0	F	null	F	2
1515	1	1	1242	04:05:09	04:09:18	RC	1515	0	SAR	CRS		0	F	null	F	1
1516	2	1	1243	05:31:28	05:35:36	RC	1516	0	SAR	CRS		0	F	null	F	2
1516	1	1	1243	05:31:28	05:35:36	RC	1516	0	SAR	CRS		0	F	null	F	1
1520	2	1	1244	11:21:42	11:22:00	RC	1520	0	SAR	FR1		0	F	null	F	2
1520	2	2	1245	11:24:17	11:25:24	RT	1520	0	SAR	MRS		0	F	null	F	2
1520	1	1	1244	11:21:42	11:22:00	RC	1520	0	SAR	FR1		0	F	null	F	1
1520	1	2	1245	11:24:17	11:25:24	RT	1520	0	SAR	MRS		0	F	null	F	1
1521	2	1	1246	12:54:55	13:02:34	RT	1521	0	SAR	CRS		0	F	null	F	2
1521	1	1	1246	12:54:55	13:02:34	RT	1521	0	SAR	CRS		0	F	null	F	1
1526	2	1	1249	22:23:30	22:23:48	RC	1526	0	SAR	FR2		0	F	null	F	2
1526	1	1	1249	22:23:30	22:23:48	RC	1526	0	SAR	FR2		0	F	null	F	1

End_Latitude	End_Longitud	Start_Latitude	Start_Longituc
33.7732	73.4653	5.5186	79.7188

Recording Date	Recording End Tim	Recording Start Tim
25-MAY-2022	13:02:28	12:55:01

Data	Station	Station IPT
RAW	SAN	USR

Figure-48 Schedule file

Chapter-VI

6. EOS-04/RISAT-1 Applications

As described in the previous chapters, EOS-04 SAR is capable of all weather imaging capability in HH, VV, HV, VH and circular polarizations, with incidence angles of 12 – 55 degrees. The swath ranges from 15 km in high resolution mode to 223 km in coarse resolution mode and a repeat cycle of 17 days. The system is capable of acquiring data in both right and left looks in data acquisition modes like CRS, MRS, FRS-1, FRS-2 and HRS during both ascending and descending passes.

The various applications where RISAT-1 SAR was used or can be used are applicable to EOS-04 also and are as follows:

6.1 Agriculture

The use of temporal amplitude of HH polarization data has been demonstrated for rice and cotton crop identification and monitoring, rice biomass and transplantation date retrieval. For groundnut and soyabean crop also, the crop discrimination and estimation of cropped area was found feasible, but the accuracy standards of 90/90 criteria have to be met. The FRS-1 data has shown the potential of mapping and monitoring of rainfed/upland rice grown in the high rainfall regions without the traditional method of transplantation. For these kind of applications, the satellite is operated in systematic collections mode over Indian region, in MRS mode with H Dual polarization (HH+HV) These multi-temporal SAR data for jute crop identification has been operationalised using RISAT-1 MRS data. Cotton crop identification using multi-temporal, multi-polarization and polarimetric SAR data has been demonstrated. Applications like

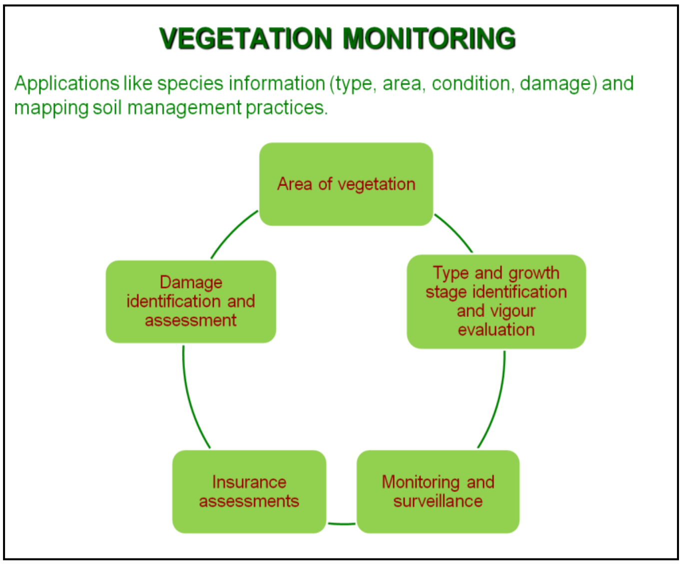


Figure-49 Vegetation Monitoring

vegetation monitoring have also been demonstrated successfully. Figure-50 represents the flow of the same.

Following images show the crop monitoring using RISAT-1 over Tamilnadu area.

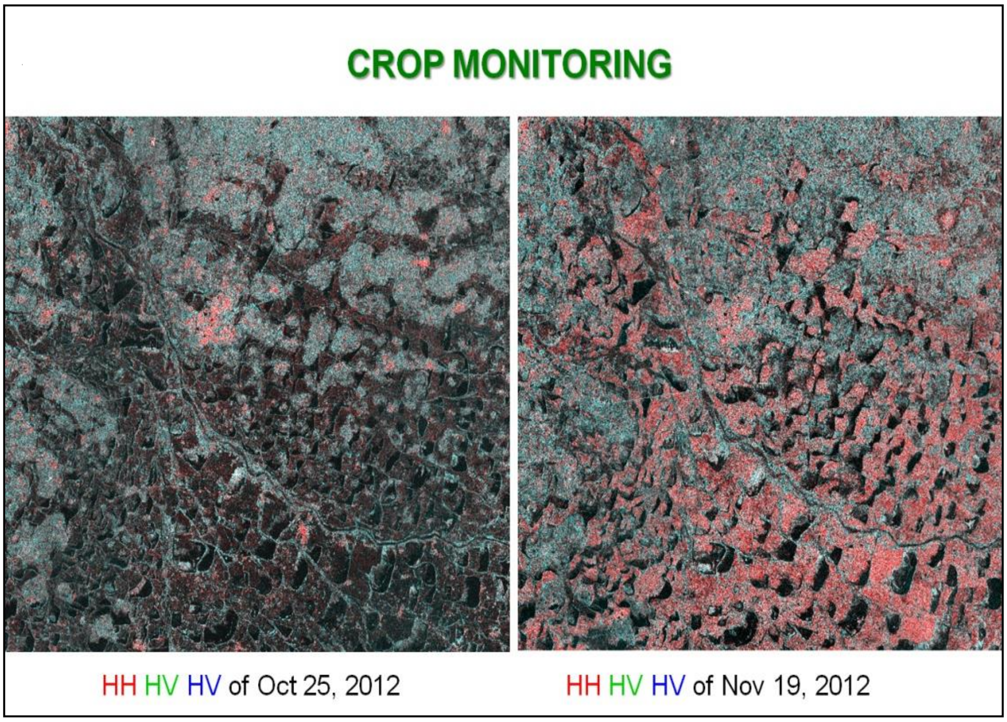


Figure-50 MRS Image Over Sivaganga area of Tamilnadu

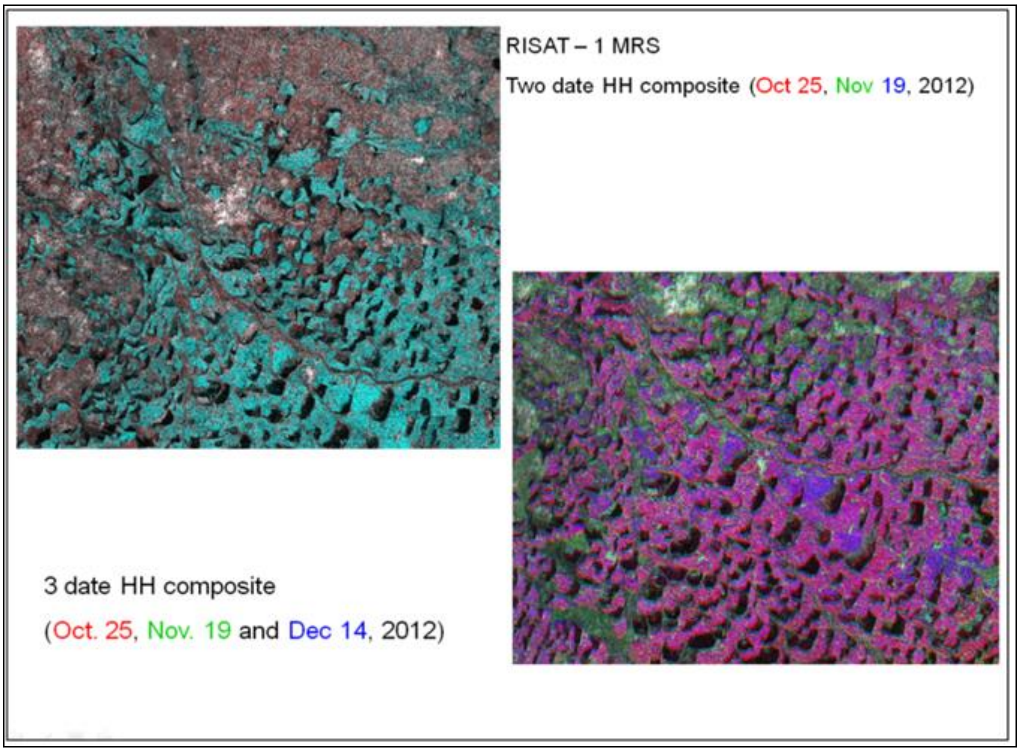


Figure-51 MRS image of Sivaganga area of Tamilnadu showing Samba Rice area around the water bodies

6.2 Flood

Microwave data plays an important role during flood season as the optical data has the problem of cloud. SAR data has proven that it is suitable for generating the real time flood maps using both MRS & CRS data acquired in H DUAL polarization (HH +HV). The SAR is useful for delineating river morphological features for the braided river system. Some examples of images showing flood inundation shown below.

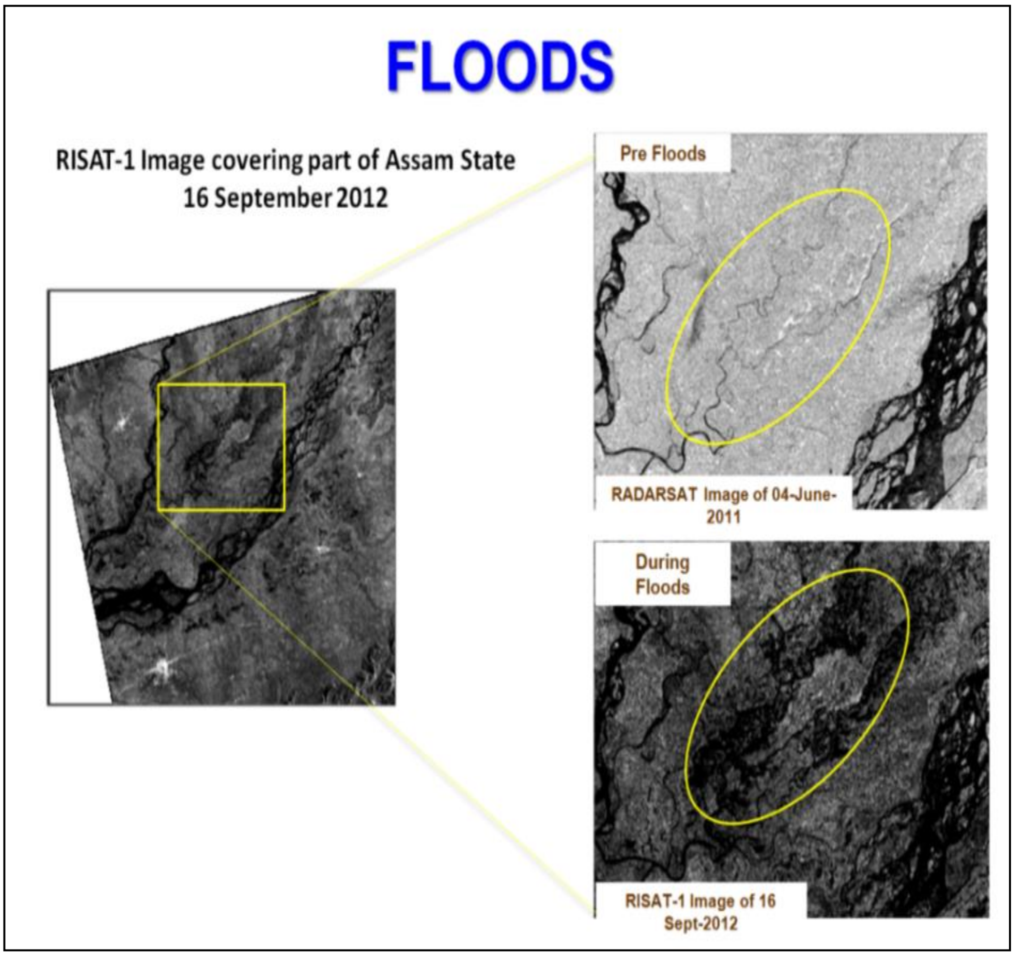


Figure-52 Flood Inundation

6.3 Forestry studies

SAR data has proven to have significant potential for estimating stand density in dry deciduous forests. Broad discrimination of forestry types from FRS has been demonstrated along with Biomass estimation (up to 80 T/Ha). Following image shows the biomass generated using the MRS data.

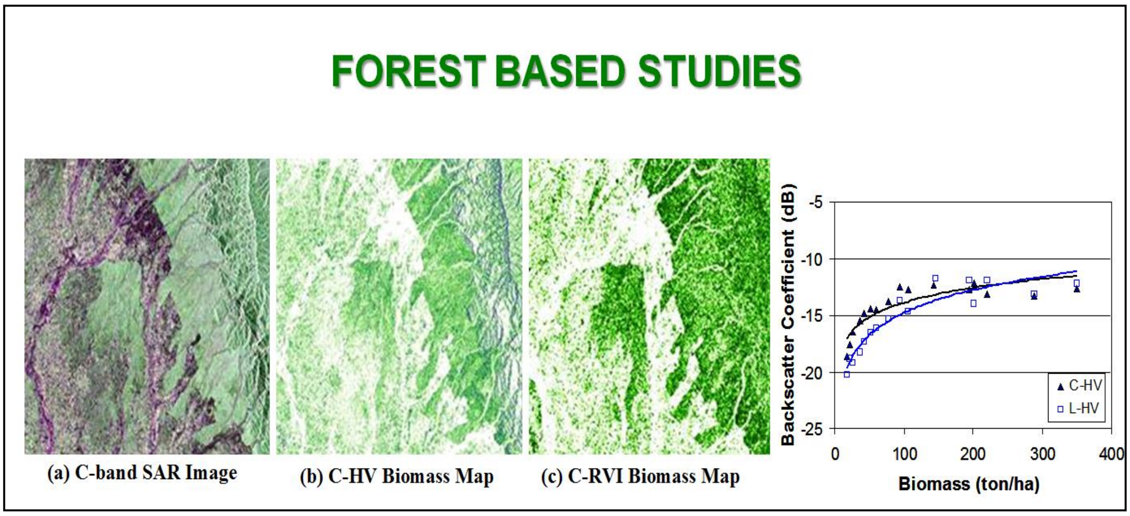


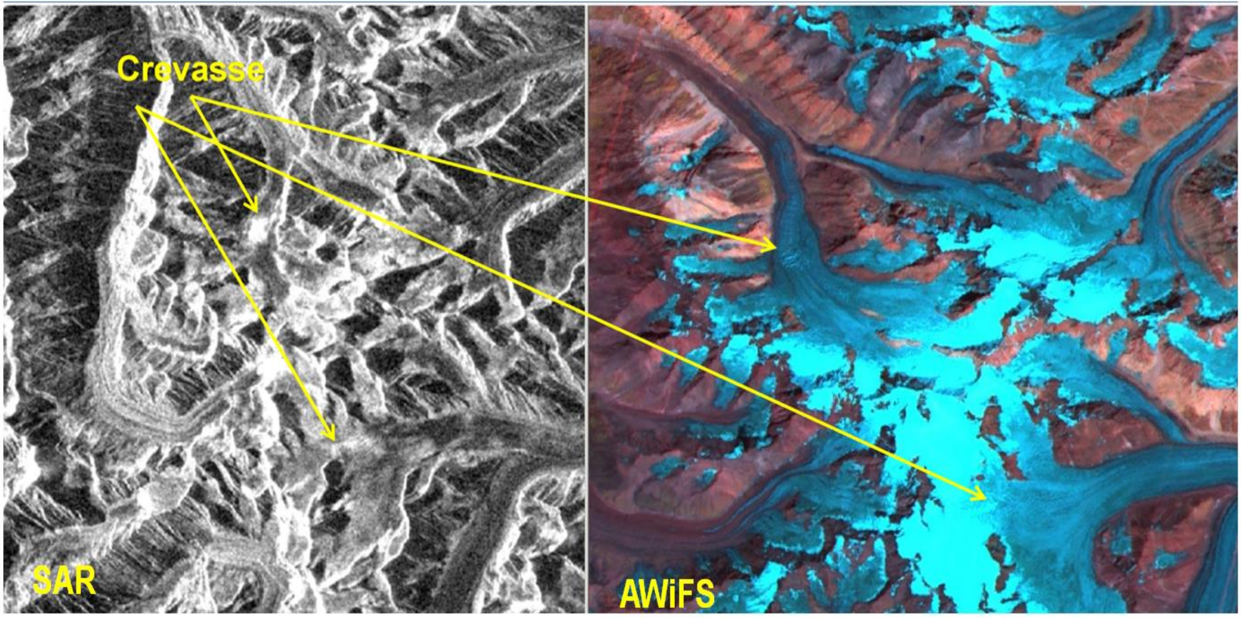
Figure-53 Biomass estimation

6.4 Snow, Glacier and Polar Ice

RISAT-1 SAR data acquired in MRS, FRS (HH/HV) can be used for identification of glacial features wet Snow Cover Area mapping and Monitoring from watershed to river sub-basin scale. RISAT-1 hybrid data (RH/RV) data can be used for glacier feature mapping and can be further explored to use its pseudo HH/VV components for derivation of snow physical properties. SAR is sensitive to snow wetness. It aids in demarcation of wet and dry snow. It is also useful in development of short term forecasting of snow melt runoff, important for reservoir operation, inventory of glacial lakes / water bodies. Figure 54 gives an example of snow identification using C-Band SAR over the Himalayan ranges.

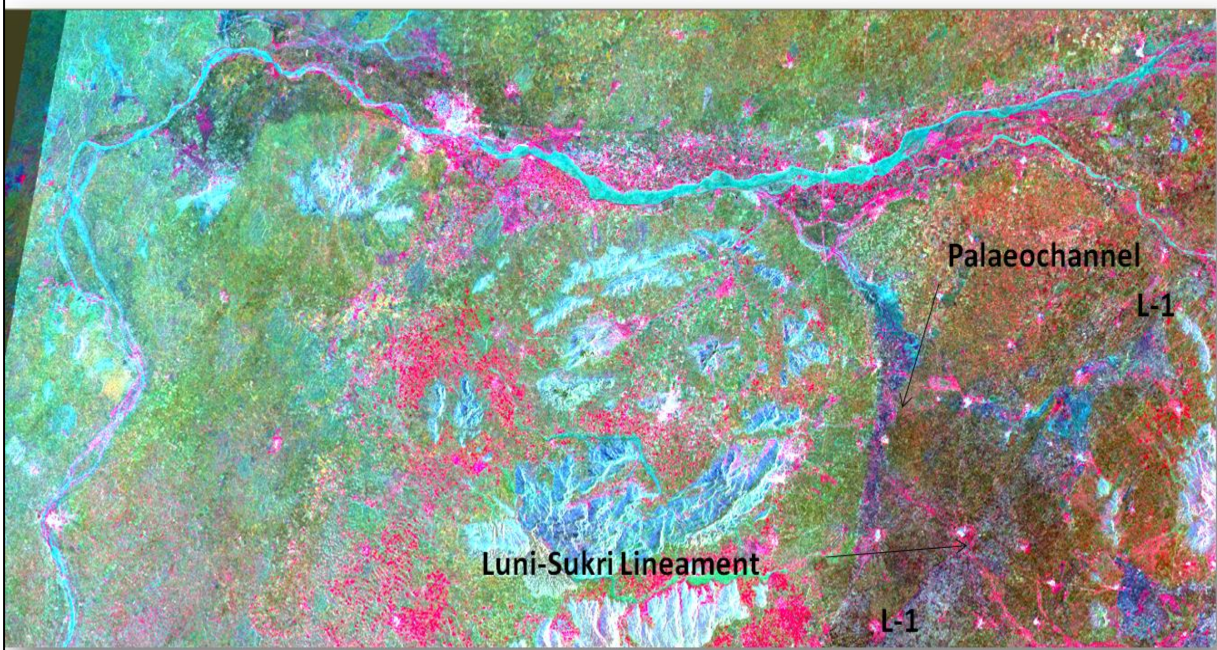
6.5 Geology and Geomorphology

MRS data has been used for Lithology and structural mapping. RISAT-1 MRS (HH/HV) data gave a few additional lineaments in comparison to optical data for weathered and shallow buried pediplain areas. RISAT-1 SAR fine resolution data is useful in retrieval of Hydrological parameters required for groundwater management. SAR is suited for geo-morphological / structural investigations like detecting subsurface fluvial landscape, rocks and minerals etc. Distinct texture of SAR image may indicate erosion surfaces, buried channels etc. It also provides information on subtle changes of earth surface (Land subsidence /Tectonic etc.,). Figure 55 shows the RISAT-1 merged data with LANDSAT ETM bands 6 5 3 for delineation purpose**.**



Crevasses show high backscatter which helps in identifying them in the glaciated region. Crevasses are covered with dry snow during winter which is transparent to C-band SAR, otherwise not possible to detect using optical sensor.

Figure-54 Water Identification using C-BAND SAR over the Himalayan Ranges.



(MERGED RISAT SAR and LANDSAT ETM FCC 6,5,3)

Figure-55 RISAT-1 merged data with LANDSAT ETM bands 6 5 3

6.6 Landuse and Land cover

The MRS data has been useful for updating of existing land use/land cover layers, mapping of home stead's and wet lands with varying degrees of accuracy.

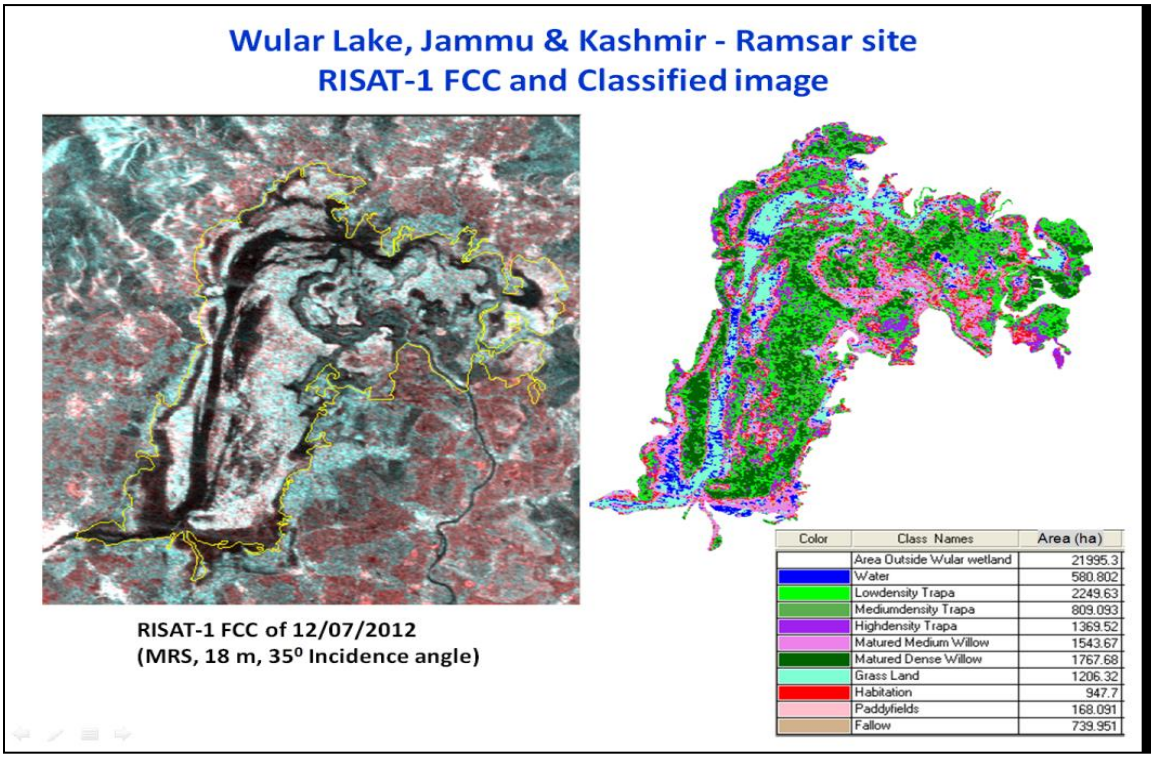


Figure-56 Land use/Land cover layers

6.7 Oceanography

SAR data has proven its capability of detecting ships and oil spill using the linear polarization (VV polarization). Retrieval of coastal bathymetry using SAR data is another Ocean application. Studies have been carried out to detect oil spill using Hybrid polarimetry. Oil spill detection using RISAT-1 on the Norway ocean circular polarization) is shown in the Figure-57 and the signatures in V&H polarisations are shown in Figure -58.

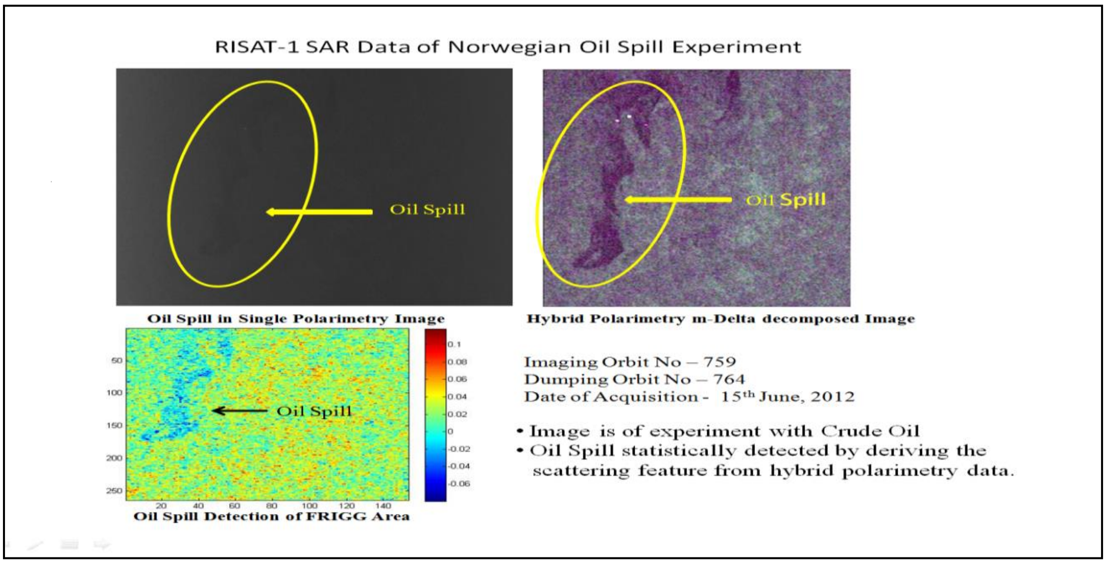


Figure- 57 Oilspill detection using RISAT-1 on the Norway Ocean region

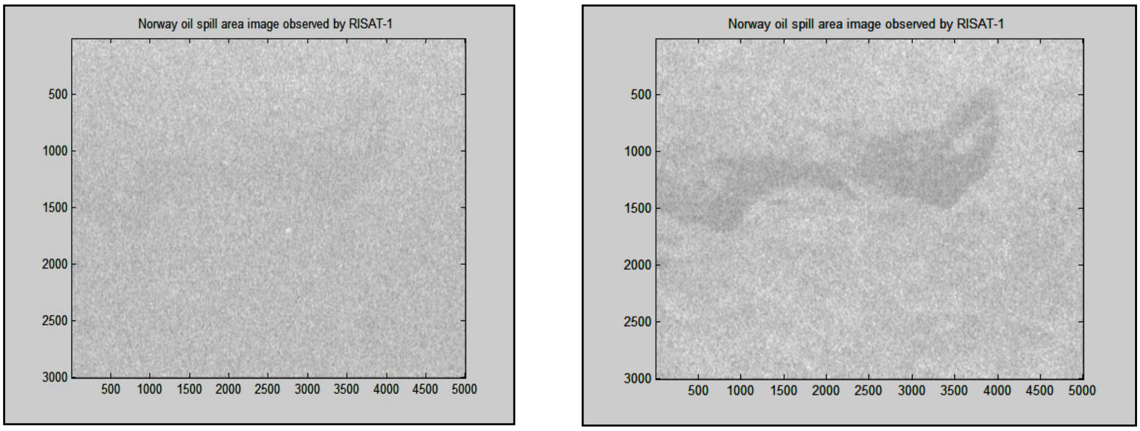


Figure-58 Oil signatures in V polarization and in H polarization

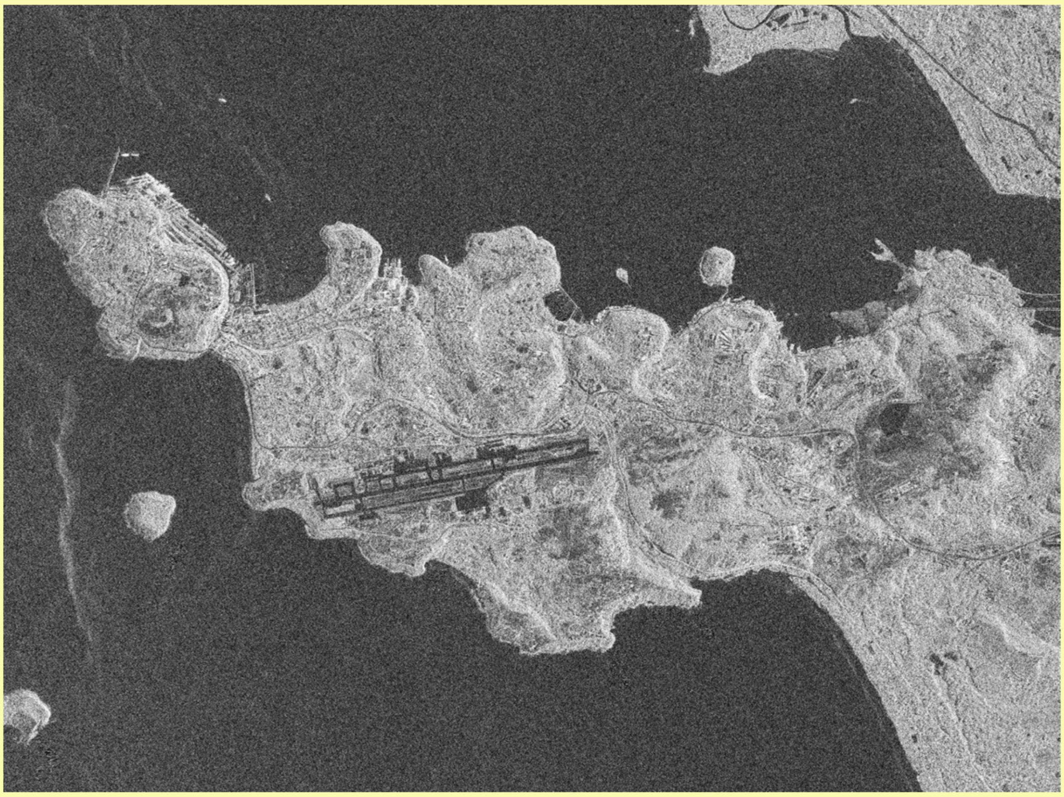
The future versions of the Hand Book will be updated with applications using EOS-04 data.

LIST OF ACRONYMS

ACC	Antenna Control Computer
ACSS	Antenna Control Servo System
AGC	Automatic Gain Control
AOCS	Attitude and Orbit Control System
ASIC	Application Specific Integrated Circuit
ATC	Automatic Temperature Control
AWIFS	Advanced Wide Field Sensor
AZ/EL	Azimuth / Elevation
BAQ	Block Adaptive Quantisation
BCD	Binary Coded Decimal
BDR	Battery Discharge Regulator
BMU	Bus Management Unit
CC	Computer Control
CL	Coupled Logic
CRS	Coarse Resolution Sensor
DACR	Data Acquisition Control Room
DC	Direct Current
DC-DC	Direct Current to Direct Current
DEG	Data Exchange Gateway
DFO	Dual Frequency Oscillator
DI	Data Ingest
DOD	Department of Defense
DPGS	Data Products Generation System
DSP	Digital Signal Processing
DSS	Digital Sun Sensor
DTG	Dynamically Tuned Gyro
ECL	Emitter Coupled Logic
EMC	Event Monitor Control
ES-DTG	Earth Sensor - Dynamically Tuned Gyro
FC	Frame Count
FCL	Field Coupled Logic
FO	Fibre Optics
FRS	Fine Resolution Sensor
FS	Frame Sync
FTP	File Transfer Protocol
GRT	Ground Trace Time
HRS	High Resolution Sensor
I/O	Input / Output
IAC	Inertial Attitude Control
IF	Intermediate Frequency
IMGEOS	Integrated Multi mission Ground Segment Earth Observation Satellites
INSAT	Indian National Satellite System

INTELSAT	International Telecommunications Satellite Organization
IRIG-G	Inter Range Instrumentation Group
IRU	Inertial Reference Unit
ISDN	Integrated Service Digital Network
ISTRAC	ISRO Telemetry, Tracking and Command Networks
ITJ	Improved Triple Junction
ITS	Integrated Tracking System
JPEG	Joint Photographic Experts Group
JPL	Jet Propulsion Lab
LHCP	Left Hand Circular Polarization
LISS	Linear Image Self Scanner
LNA	Low Noise Amplifier
LO	Local Oscillator
LOS	Loss of Satellite
LVDS	Low Voltage Digital Signal
LZW	Lempel–Ziv–Welch
MOHA	Mission Operations and Health Analysis
MRS	Medium Resolution Sensor
NDC	NRSC Data Centre
NTP	Network Tie Protocol
OBC	On Board Computer
OCM	Ocean Color Monitor
ODAP	Open Data Access Portal
OSR	Optical Solar Reflector
OTS	Off the Shelf Archival
P/L	Payload
PAA	Phased Array Antenna
PB	Play Back
PCI	Peripheral Component Interconnect
PCM	Pulse Code Modulator
PRF	Pulse Repetition Frequency
PSLV	Polar Satellite Launch Vehicle
QC	Quality Check
QPSK	Quick Phase Shift Key
RAD	Radiometric
RAID	Redundant array of Inexpensive/Independent Disk
RCS	Reaction Control System
RCS	Radar Cross Section
RF	Radio Frequency
RHCP	Right Hand Circular Polarization
RW	Reaction Wheels
SADA	Solar Array Deployment Antenna
SAN	Storage Area Network
SAR	Synthetic Aperture Radar

SCSI	Small Computer System Interface
SIR-C	Space Borne Imaging Radar
SLC	Single Look Complex
SMA	Sub Miniature version A
SPS	Satellite Positioning System/Sun Presence Signal
SQNR	Signal to Quantization Noise Ratio
SSR	Solid State Recorder
SWFM	Station Work Flow Manager
TCP/IP	Transmission Control Protocol/Internet Protocol
TCT	Time Code Translator
TM	Telemetry
TR	Transmit & Receive
TTC	Telemetry & Tracking Command
UOPS	User Order Processing System
UTM	Universal Transverse Mercator
WO	Work Order
XLI	Ultra Precision Time



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