Signatures

Newsletter of the Indian Society of Remote Sensing - Ahmedabad Chapter

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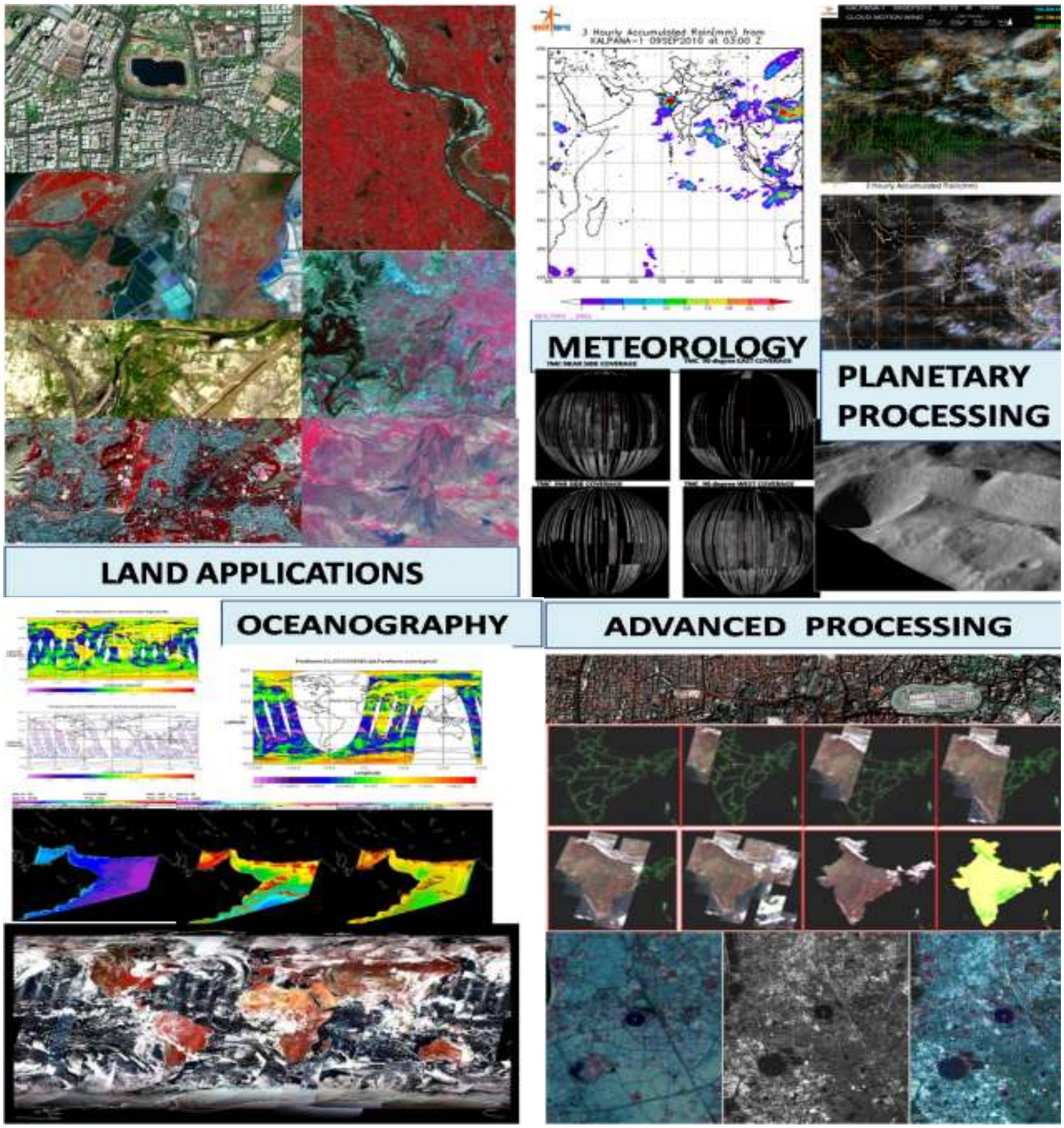
Special Issue on

Remote Sensing Data Products & Retrieval Algorithms



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From the Chairman's Desk

Dear Readers,

ISRS-AC, Newsletter-Signatures has been well appreciated by the ISRS-AC members. The positive feedback coming from the members and some of the valued readers is truly heartening. Since our last issue, the chapter has completed some important events. One year completion of RISAT-1 was celebrated with CEPT. Active participation from academia was the highlight of the event. World environment day was celebrated at Serenity library with great enthusiasm. The participants included underprivileged children from 2 NGOs. National Remote Sensing Day celebrated at Surat was a grand success with Hon'ble Former President of India, Dr A P J Abdul Kalam inaugurating the ISRO Exhibition and addressing the gathering. More than 5000 students from 58 schools participated in the event.

This issue is a special issue on 'Remote Sensing Data Products & Retrieval Algorithms'. The entire team along with the Guest Editor for this issue have done a commendable job in getting invited articles of interest from across the centres of ISRO and compiling them together. I express my sincere thanks to all the authors who have contributed very informative articles for the issue. There is a highly enlightening interview by Dr V Jayaraman, Senior Advisor (Space Applications) & Satish Dhawan Professor at ISRO Headquarters, and Ex-director, NRSC, which will definitely be appreciated by the senior and the junior readers alike.

Another speciality of this issue is the inclusion of two articles in Hindi. The authors showed great enthusiasm and volunteered with these two articles. My special thanks to the authors for this gesture.

Finally, I am extremely grateful to Dr. R Ramakrishnan, the Guest Editor, and Ms Arundhati Misra, the Editor of Signatures, who have been relentlessly working towards making this issue a grand success. I on behalf of the executive committee am extremely pleased to acknowledge the enthusiasm extended by all the members.

My heartiest congratulations to the editorial team.

Best wishes

D Subrahmanyam

Chairman, ISRS-AC

From the Guest Editor's Desk

Dear Members

I have great pleasure in reaching out to you all, the members and well wishers of Indian Society of Remote Sensing – Ahmedabad Chapter through Signatures. I convey my greetings and best wishes to all of you.

This issue of signature focuses on the theme: Remote Sensing Data Products & Retrieval Algorithms. The Signatures Editorial team has compiled a number of interesting articles of topical interests on the theme. Several Scientists/Engineers from SAC, NRSC, ADRIN, ISAC & ISTRAC have contributed to this special issue through their brief and vivid articles on the focal theme. This issue also contains an interview with Dr. V. Jayaraman, Senior Advisor (Space Applications) & Satish Dhawan Professor at ISRO Headquarters, Bangalore. I thank all the authors and Dr. V. Jayaraman for sparing their valuable time from their busy schedule to contribute to Signatures.

Data Products generation System activities start with understanding of payload systems, detector characteristics, attitude, orbit and control systems, and coverage schemes. Study phase is followed by identifying and grouping computational elements patterns to evolve architecture for the data products generation systems. In parallel, host of techniques, models and approaches to be used are explored, necessary R&D efforts are initiated. Many ISRO centres participate and develop sub-systems in the realization of the data products generation system, early identification interfaces are necessary for easy solution integration. Preliminary design is evolved after numerous ground segment deliberations and is subjected to an independent and stringent peer review conducted by a team drawn from multiple centres. Lacunae and gaps, if any, are identified during the preliminary design reviews and communicated to the design teams to rectify, improve and complete the design before it evolves in to detailed design, module & integrated Testing & evaluation and further reviews to release the Data Products to the Indian and international Users through their ground stations. Currently the Retrieval of Parameters are geared up from the Standard Data Products to Value Added Products for Land, Ocean , Meterology and Planetary Applications through ATBD document, reviews and thorough Calibration and Validation

I would like to sincerely thank to the editorial committee of Signature, to provide me this opportunity of being Guest Editor of this issue. I thank Shri Indranil Misra and Ms.Manisha Ghoghara for their support in bringing out this issue.

Dr. R. Ramakrishnan

Group Director DPSG/SIPA

Space Applications Centre, Ahmedabad

AN INTERVIEW WITH DR. V JAYARAMAN

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ISRS-AC: Remote sensing data was mostly taken on an R&D basis during the days of IRS-1A. Today, we have evolved into operational programs encompassing agriculture, forestry, weather, oceanography, etc. Kindly share your ideas on the steps leading to this and the future trend. What are your views on sharing of information amongst various countries, and joint development for global climate and weather monitoring through GEO & LEO platforms?

Dr. V Jayaraman (VJ): It is true that we have matured over time in taking up many specific operational applications using geospatial technologies as part of the National Natural Resources Management System (NNRMS). These success stories in agriculture, oceanography, forestry, rural development, water resources, just to name a few, are very well appreciated globally and I do not want to go through each one of them to the ISRS community as you are already aware of them. It was done due to tireless efforts of many thematic experts from SAC, NRSC and RRSCs as well as various States, academia as well as industry. NNRMS and its high power Standing Committees provided needed impetus and continued support as well as constructive criticism for these efforts over the past 30 years. But, having achieved these successes, we need to ask ourselves a larger question as to whether we have met comprehensively all the requirements and exhausted all options in any particular application theme. For example, take Agriculture as example. As nicely brought out by RR Navalgund et al. in Current Science (Dec 2007), we have conceptualized and institutionalised FASAL, which itself is the outcome of realization that remote sensing data itself is not a stand-alone system for making multiple and reliable forecasts. Still we need to take up research in the development of better crop models, crop insurance, physiological process-based models for crop condition assessment, carbon auditing, farm variability and precision farming, nutrient cycling in agro-ecosystems, and impact on climate change on agriculture and fish stock assessment. Same is the story in many other areas as well wherein we need to take up concerted R&D efforts. So I do believe that conducting R&D is a continuing task, even as we operationalise certain parts of the applications. I think these R&D and operationalisation tracks may continue to run in parallel even as we mature in geospatial technology applications!! Also, we should realize that we are moving towards quantitative remote sensing with planned future missions with newer sensors and these R&D efforts involving parameter retrieval, model development and assimilation of parameters into models need further push to ensure their ultimate transition to operational applications and institutionalization at the user end.

This question of sharing of information amongst space-faring nations has been addressed by international fora like Committee on Earth Observation Satellites (CEOS), and the Coordination Group for Meteorological Satellites (CGMS) wherein ISRO is an active partner. There has been broad consensus on broad collaborations between space agencies in sharing the space-based observations for weather and climate monitoring by the optimal use of LEO and GEO platforms. Already there are instances of collaborations of such possible missions carrying radio occultation, scatterometers and hyper-spectral IR in LEO & GEO. There are issues of interoperability and consistency of data; and validation of products & of course, extensive documentation. You are possibly aware of our own contribution to such inter-agency efforts through the successful global dissemination of wind vector data products from the Oceansat 2 Scatterometer data in near-real time (within 3 hours of data acquisition) and uploading the products in the WMO Server.

ISRS-AC: What are the future directions in remote sensing data applications? Any application bears its success from the utility of the products. In order to do so user friendly application products and analysis tools and software are called for. How far have we reached in this direction? What more do we need to plan for, and what extra steps do we have to take, in order to get seamless application products for users? What is your assessment of the Data Processing and format standards in ISRO?

VJ: Obviously the challenges of remote sensing data processing community in the coming years will be to handle increasing volumes of data amounting to Peta Flops and beyond; and deliver the information products to the users in near real time. There are talks of Big Data analytics and I think remote sensing fits that bill really well. Further, in the data-information-knowledge-wisdom chain, the users are not just satisfied with the basic data products. Nowadays users are accustomed to Web delivery of products & services ("APPs") and are adept with location aware smart devices and broadband social networking. It needs to be factored in our data processing chain in the future. The user expectation is that one should be able to build sufficient intelligence onboard to derive the required APPs and deliver them to the users directly and that too quickly. While ever increasing hardware computing power seems to possess no major problem, it is the software ability to optimally utilize the full capability of such hardware architecture that continues to remain as the major challenge. I am reminded of the famous Wirth's Law which states, "Software is getting slower than the hardware getting faster". These challenges include physical sensor modeling, automatic, robust, parameterized algorithms development, calibration/validation, and extracting needed thematic information with accuracy and precision. This sort of high level onboard data processing with the requirement to automatically generate theme specific classifiers in a way calls for synergy between the data processing and image processing efforts onboard itself, with the ultimate products delivered in GIS compatible manner to the user. It is going to be much more challenging as we step into quantitative remote sensing of the future with the absolute calibration, and above all, validation of the parameters (such as atmospheric parameters). We will thus move towards providing high accuracy, high precision geophysical parameters demanded by the users in 4D and 5 D applications. It calls for more synergistic working of data processing and image processing experts along with the thematic experts in a more focused manner. Well, I am aware of some such efforts carried out in SAC even as we started working on quantitative remote sensing payloads in MeghaTropiques, SARAL and INSAT 3D. I always recollect with nostalgia the closer interactions SAC scientists developed with IMD and NCMRWF for INSAT 3D products development. Well, we are waiting to see the INSAT 3D products and services!

Regarding data format standards, as you may be aware that ISRO has been making orchestrated efforts since the days of IRS 1A. It was recognized in the early phase of IRS programme itself that while all the data models cannot be accommodated in a single data format, considering the vast remote sensing data then available with NRSA and also the wider global acceptability and user familiarity and interoperability considerations, the LGSOWG (Landsat Ground Station Operators Working Group) or the Super Structure Format was adopted. For microwave SAR data, ISRO adopted the CEOS (Committee on Earth Observation Satellites) format which has become the global standard with satellites like RADARSAT, ERS, and JERS-1 adopting it. CEOS Format itself heavily relies on the LGSOWG and the LTWG (Landsat Technical Working Group) formats. With more and more satellites entering the market and also the entry of commercial image analysis software packages with emphasis on GIS emerging, the adoption of compatible, user friendly formats became a necessity. Thus, as the IRS programme advanced, ISRO went on to provide data products in more types of formats like the GeoTIF, Fast Format and the HDF while continuing with LGSOWG format. HDF format was the preferred format of WMO for meteorological data though it has also gained acceptance from remote sensing community. While these developments are in tune with the time, I do believe that we should make sincere efforts to also follow the "Quality for Earth Observation Guidelines" provided by CEOS. These guidelines put the onus on the data providing agency to define "Quality Indicators" to enable the users to decide on the fitness of purpose of the data products for the end-use and expect the agency to ensure stability of the these Indicators and record deviations, if any, throughout the products' life cycle. Also, it suggests that the data providing agency to come up with a plan for "Traceability" criteria to ensure products' quality assurance with reference to standards. I believe if we adopt these as well in our data formats appropriately, ISRO will set a benchmark for its products.

ISRS-AC: What were the challenges in capacity building inside and outside ISRO? What is your view on the level of involvement of Universities with ISRO? How has private industry evolved to take up the challenges of RS applications? How do you foresee the products and service segments from space data?

VJ: First of all, we should understand that capacity building is not just education and training. It goes much beyond that. It should ultimately result in improving the ability of the concerned user/agency/institution to perform the tasks endogenously. It only means that capacity building encompasses human resources development, and organizational & institutional strengthening in an integrated manner. Obviously, in such a scenario, the concerned institution should also have in-built research capabilities and advisory services apart from education and training. And this is a major challenge for many institutions. ISRO was able to overcome this challenge by concerted efforts over the years. Today, in geo-informatics, ISRO through IIRS, Dehra Dun and other ISRO Centres is able to extend this end-to-end capacity building experience not only for institutions in India but also outside. A lot depends on the recipient agencies to take up the organizational and institutional arrangements in a sustained manner. There lies the major challenge! Regarding academia and industry interface, though we have a vibrant Government-Industry-academy triad concept, I should acknowledge that there is still scope for further improvement. Particularly, I would expect the academia to play much larger role than what they are playing today in our upcoming research areas. It is a fact that much of the research in remote sensing is done in ISRO than in academic institutions today! That needs to change!

Well, industry is generally playing an active role in geoinformatics related activities pertaining to, say, marketing of data, image processing/GIS software development and distribution. There are also a few instruments developers based on our technology transfer to the industry. I would like to see them take up many more application services like what their counterparts elsewhere have done. In USA, the public release of weather data from satellites opened up a new economic sector which includes the operational weather information services, commercial agricultural advisories, and even in the insurance sector. Similarly, we are aware of the GPS empowered innovations taken up by the private industries in other countries including in navigation sectors and even in precision farming. In fact, I understand that even in forward trading of commodities the inputs from remote sensing is used there. Well, we should realize that it has to be supported by conducive policy formulation at the Government level to encourage the Indian industries to get into these services which could even open up global possibilities for them.

ISRS-AC: Do we practice 4th generation technologies in modeling, simulation and computation in every technological component within ISRO? If we have to talk about next generation technologies, what are the key elements?

VJ: I can only provide some random thoughts on the subject from the limited understanding I possess. Modeling, simulation and computation are closely coupled and together they ultimately represent the essential core technologies for any chosen area of exploration. Obviously, if model represents the characteristics of the object and the simulation its behavior, capturing them in the early part of the design & development process enables better cost effective computation and the resultant end results in a cost effective manner, rather than capturing them at a later stage. That means you need to comprehend the overall systemic issues involved in the first place. I think it is generally addressed well in ISRO system, whether you call it 4th generation or by any other name. Like any other aerospace system, ISRO's flight and ground segments strive to adopt innovative means to increase the robustness and reliability by adopting these advanced concepts, though in terms of technology, there could be a slight lag between the commercial system and the aerospace system, due mainly to the expectation of proven heritage of the systems and availability of space qualified components. In both the flight and ground systems, performance is controlled by the complex dependence between the hardware, the algorithms and the problem structure. For example, the availability of high reliability, radiation hardened multi-core computers in the flight systems, and the high-end computing system on ground to support the "Big Data' analytics and the multi-scale physical simulations of advanced space systems working in unique space environments become critical for any meaningful exercise. Added to that, the complexity of integrating heterogeneous models, architectural challenges of simulation, and the involved computational processing, say, for building autonomy onboard with its own reconfigurable exploration systems becomes multi-fold. It needs a combined study by concerned experts. NASA has come up with one such study to work out a Roadmap for the future. May be, as information processing experts in remote sensing, we also need to make a roadmap for ourselves addressing these elements in a coherent manner, at least for some remote science missions pertaining to studying our Earth system or beyond.

ISRS-AC: NRSC is already connected to the arctic station of Svalbard. How is the Bharati station in Antarctica going to serve our future

RS missions? What is the expected turnaround time and timeliness of data from such a network of stations?

VJ: Svalbard has been in the data products chain for the past 8-9 years with physical transfer of products which used to take weeks to reach the basic products to NRSC for further processing. About 4 years back, it was electronically connected to NRSC by a broadband network to cater to the needs of Oceansat 2 global data collection with the idea to reach the Wind Vector data to the modeling community within 2-3 hours. This has been a phenomenal success with the Oceansat 2 Scatterometer data becoming part of global user community as pointed out earlier. The Antarctica station Bharti at Larsemann Hill is an essential extension to this goal of receiving all the 14 passes of IRS data at the centralized location in IMGEOS. It is our own Station unlike Svalbard where the services are hired on pass by pass basis. While initially communication lines will be through INTELSAT through a commercial arrangement, it will be replaced by our own INSAT system in the coming days.

ISRS-AC: How are we working towards an efficient data networking system given the timeliness required for applications like weather nowcasting/forecasting etc?

VJ: You are aware that ISRO as the agency of providing satellite platforms does not have direct responsibility for providing weather nowcasting/forecasting. I think that the user agencies such as IMD, NCMRWF through their modernization programme have built reasonably good infrastructure at their end to handle this. We from ISRO are ensuring that the user agencies directly receive the data at their end, besides helping them to retrieve the geophysical parameters through appropriate algorithms and data processing software modules. We have done the same in the area of Oceanography by providing ground data reception facility at the INCOIS, Hyderabad to improve the efficiency and timeliness required in their end applications like Potential Fishing Zone advisory services.

ISRS-AC: What level of importance is assigned to the remote sensing data processing or geospatial technology developments in ISRO? How would you rate the Impact of BHUVAN in Indian Geospatial Industry?

VJ: ISRO attaches utmost importance to remote sensing data processing or geospatial technology developments as it is the commitment to the NNRMS community. It is that mandate that has made ISRO to invest in satellites and launch vehicles; and ensuring continuity of Earth Observation Satellite missions in identified thematic areas not to mention about the corresponding investments in ground segment. The setting up of the Integrated Multi-Mission Ground Segment for Earth Observation Satellites (IMGEOS) for ensuring a streamlined demand-supply chain with effective delivery mechanisms through real time Web-based services and populating free-ware tools for accessing to data products and services through BHUVAN, BHOOSAMPADA, MOSDAC, IBIN, and WRIS exemplify this process. I will make only one statement about the impact of BHUVAN in the Indian Geospatial industry. You may be aware that BHUVAN bagged the Leadership Award for the Most Popular Geospatial Data Portal in India under the Geospatial World Awards 2013 during the India Geospatial Forum organized at Hyderabad in January 2013. It stands as the proof of what impact BHUVAN has made in India! Don't you agree?

ISRS-AC: Are all the critical areas of technology development mapped for strategy and planning in the area of RS?

VJ: I have pointed out earlier that no single country or agency can cover all areas on their own. Having said that, ISRO has established a very credible indigenous remote sensing programme, and has taken pro-active steps towards developing cutting edge technologies in a cost-effective manner with the realization that the current level of technologies have to be upgraded to a higher magnitude and novel concepts have to be adopted while achieving a better and reliable space system. I am aware of some of the technologies/techniques projected as part of the next 12th FYP in EO and Atmospheric Sciences. Just to cite a few from them –

Agile bus systems with high positioning accuracy, and attitude & platform stability: imaging spectrometer covering larger spectral bandwidth: Green House Gases and Trace gases sensors ; Multi-frequency microwave Ground Penetrating Radar; Millimetre Wave Sounders; LIDARs; Ka band antenna and data processing; Indigenous Processor for space applications, customized for Indian satellites; 2 to 2.5 metre Optics with SiC ; Multi-Band spectral filter development; Newer Detector Development; Printed phased array & Reconfigurable Planar Antennas; High Speed - High Power RF Switches; Reconfigurable – reprogrammable Micro-Controller based systems; Stress free mounting/ holding for very large optical/antenna component s CFRP and composite based telescope/ antenna structures; Grids/ Cloud computing; Online geospatial data processing and development of specialized packages; Development of immersive data visualization techniques; Faster / efficient software for Data Product generation; Platform independent emulators and hardware simulation.

I am sure, you will agree that they are ambitious by themselves and are obviously needed if ISRO has to maintain its competitive relevance in the global Earth Observation scenario. It is a continuous effort. You may be aware, ISRO has a Vision statement for 2025 with identified actions and pursuing them.

ISRS-AC: What is the importance of international collaborations for the IRS programme?

VJ: I think the answer is straight forward. Earth is a coupled system of systems. No single country can have all the satellites with varied payloads meant for different applications due either to affordability or capability. Further, these satellites cover the whole globe which could optimally be planned by the space-faring nations to derive mutual benefits in a cost effective manner. This rational over-riding principle drove international arrangements like Committee on Earth Observation Satellites (CEOS); Coordination Group on Meteorological Satellites (CGMS); and intergovernmental Group on Earth Observation (GEO) to work out better coordination of strategies for earth observation. ISRO is an active partner in all these forums, and today Indian Remote Sensing Satellites (IRS) is considered as an essential element of the CEOS Virtual Constellation of Satellites. These forums bring in expertise from different parts of the World that enable information exchange on technologies, standards, and calibration/validation exercises to name only a few. You also will appreciate that besides these cooperative ventures, the type of low earth orbit we have for IRS missions also call for International collaboration (may be on commercial terms) for TT&C support and setting data reception stations.

ISRS-AC: What is the expectation of the data from planetary missions? Is there any data policy so far as the International science community is concerned?

VJ: Well, to my knowledge, there is nothing like a data policy that is being insisted or binding when it comes to Planetary Missions. You are aware that the UN Outer Space Treaty 1967, which represents the de facto framework for International Space Law, declares that the celestial resources such as the Moon or a Planet are the Common Heritage of Mankind, and are not subject to national appropriation by claim of sovereignty by means of use or occupation or by any other means. At the same time, the State that launches a space object retains jurisdiction and control of that object, and that probably includes the data acquired and its dissemination as well. That may include specific policies drawn accordingly; like what we did for Chandrayaan 1 data sharing, which had a lock-in period during which only the Principal Investigators (PI) and their teams had access to the data. After that period, the data is given to others on a non-discriminatory basis.

Incidentally, at international level, the recently formed International Space Exploration Coordination Group (ISECG) in which ISRO is also a Member, enables exchange of information regarding interests, plans and activities in space exploration. The ISECG has developed a Global Exploration Roadmap in September 2011, and is expected to issue next edition sometime in 2013. Essentially, the roadmap illustrates the planned and conceptual near-term missions which will advance human and robotic exploration starting in the Earth-Moon system. We need to wait and see how ISECG develops in the coming years in regard to policy formulation, and hope that it does not bring in unnecessary binding clauses!!

ISRS-AC: Can you kindly elaborate on the IMGEOS facility for the benefit of our readers?

VJ: The essential feature of the Integrated Multi-mission Ground Segment for Earth Observation Satellites (IMGEOS) is towards process re-engineering of all the related activities to have an improved near-real time data delivery mechanism in tune with the ever increasing expectations of the user community. It is a network-centric approach with a multi-tier storage system with built-in automated processes to clear the data products within a few hours after data reception. With multitude of thematic satellite missions on the anvil, IMGEOS aims to have a unified system addressing the needs of newer payloads in terms of varying data rates and formats. Obviously, such a unified system should provide improved turn-around-time for delivery of data products benefiting the vast user community. With the operationalisation of IMGEOS, NRSC was able to bring down the inter-pass gap to less than 2 minutes in the data acquisition facility by automating station operations using remote configuration through TCP/IP. This has been achieved through network based distributed software across multiple machines for multi satellite data reception. The upgraded antenna stems with state-of-the-art servo control systems with DSP based Antenna Control Unit and digitally configurable antenna drive systems along with an IF matrix used to route the data from any antenna system to any data receive chain has enabled fail-proof data reception. The data is stored in Storage Area Network (SAN) in real time for subsequent data product generation. Data processing facility has further optimized the operations by parallelizing the data ingest and ancillary data processing activities through independent computer systems with SAN storage for data sharing between these systems. Multi-threaded programming concepts and other real time features of Linux have been optimally used in the complex ancillary data processing software modules like RS decoding and data compression, thus, effectively enhancing performance as well as improving turn-around-time. The data processing facility is configured with scalable processing nodes with high performance and multi core, multi-CPU servers, as a loosely coupled cluster to optimize the utilization of resources based on the production load. A 4Gbps network provides high speed connectivity between the data acquisition and data processing servers. As said earlier, these servers are connected with high performance and hierarchical 3-tier SAN storage for faster access and data sharing. Data Exchange Gateways enable the transfer of data products to Web/TCP servers. Enough precaution has been taken to ensure to protect the systems with multi layer network security arrangements. Yet another highlight of IMGEOS is the provision of 200KW solar power generating at least 7.5% of IMGEOS power requirement. It will be shortly enhanced to 300 KW meeting more than 10% of the total power requirement from solar power. The whole IMGEOS facility is evolved as per green building norms striving to meet LEED Platinum rating. Well, obviously IMGEOS will need continuous upgradation of technologies and techniques in the coming days, and I am sure, it will shape as a facility of international standard in the years to come.

ISRS-AC: We have generated archives 1 km to 1m spatial resolution data. What is the data policy related to sub-meter and cartographic quality data? What are the data policies being followed for the Indian vis a vis the International users?

VJ: You should be aware of the prevailing Remote Sensing Data Policy (RSDP) adopted by the government of India in 2011, which prescribes appropriate guidelines to be adopted for dissemination of satellite remote sensing in India. It says that all data of resolutions up to 1metre shall be distributed on a non-discriminatory bass and on “as requested basis”. With a view to protect the national security interests, data better than 1m shall be screened and cleared by appropriate agency prior to distribution and a procedure has been prescribed thereon. RSDP 2011 is in the ISRO website for anyone to see (www.isro.org/news/pdf/RSDP-2011.pdf).

Currently, satellite images better than 1 m resolution data is already available for browsing, visualization and down-loading through internet/web based service in public domain by the global players like Google Earth and Wikimapia. Taking into account of technological advances and global trend, the RSDP is expected to be reviewed from time-to-time by Government, as per the provision contained in the policy. Government is also in the process of enacting a Bill to regulate the dissemination of images (satellite & aerial), Geo Spatial Information and terrestrial photography through web-hosting and in physical form and subject to a transparent licensing conditionality and in consonance with prevailing National Policies.

ISRS-AC: What are the future activities planned in Earth Observation, Astronomy, Planetary science and their applications under ISRO's vision till the year 2020?

VJ: It would be a long answer if I start explaining all the elements planned till 2020. Rather, I would like you to just refer the “12th Five Year Plan of Department of Space’ for the details. In short, I can tell that the EO programme envisages continuity of the established operational services with improved capabilities in the thematic series of satellites in Land and Water; Cartography; and Ocean & Atmosphere. Missions are planned to provide inputs for user agencies to enable them enhance the weather and ocean state forecasting, natural resources assets build-up, natural disaster risk reduction including early warning of disasters; and also for climate change adaptation through monitoring the Essential Climate Variables (ECVs) with precision and accuracy. Similarly, on the Space Science& Planetary Missions, the efforts will be to understand the mysteries of our Universe by investigating the process governing solar radiation, evolution of planetary system, formation of galaxies, and evolution of stellar systems and the Universe. These missions will also enable develop cutting edge technologies.

ISRS-AC: India is going to witness the first IRNSS-1 series of navigation satellites. How will

it provide linkage between Remote Sensing (RS) and communication?

VJ: Yes, ISRO is entering the navigation area in a big way after the Satellite Communication, Broadcasting, Remote Sensing, and Meteorological applications. IRNSS will provide a boost to all ICT applications, be it in surveying and mapping & GIS applications; agriculture including precision farming; geodesy; mobile communication; disaster management; space weather monitoring for situation awareness; emergency and location based services to cite only a few. In short, exciting days are ahead!

ISRS-AC: Sir, thank you very much for sparing your valuable time and giving us this interview. Kindly say a few words for our readers which will give them some insight into the role of Indian Remote Sensing programme in the future.

VJ: Indian Remote Sensing programme, starting from the experimental days of Bhaskara-I & II days, has seen a quantum jump in terms of technological capabilities both in the space and ground systems. This period also saw ISRO emerging as a major space power in satellite remote sensing, thanks mainly to development of high quality electro-optics systems and very high volume data handling capability, essentially due to increasing computing power and broadband networking capability. Correspondingly, there have been enhanced capabilities in image processing, GIS and GPS, once again enabled by convergence of pervasive digital technologies. Meanwhile, remote sensing itself has moved from an era of awe to a common man forte with Google Earth and the like services exploding the myth and reaching larger populace with ease. The world has also seen the concerns for global warming and climate change adaptation, calling for more concerted international cooperation in the Earth Observation initiatives to monitor the Essential Climate Variables (ECVs). Along with climate change adaptation, disaster risk reduction (DRR) and natural resources accounting are drawing increasingly attention, wherein the geospatial technologies have a significant role to play. ISRO has also emerged as one of the leading players in the world, contributing its mite to the virtual constellation of EO Satellites in the CEOS and GEOSS domains. Our Oceansat-2, Megha-Tropiques and SARAL have already become part of these global constellation efforts bringing ISRO into the forefront of international cooperation. These missions and the upcoming INSAT 3D mission and the like have also shifted the focus from the hitherto mapping applications to quantitative remote sensing with associated parameter retrievals and their assimilation in models. There have been corresponding developments on the ground segment with emphasis moving towards generating knowledge products and services, and delivering them in real time for many researchers working on modeling, be it on weather or in climate applications. There are many challenges still! We have been talking about multi-frequency, multi-polarisation microwave remote sensing and the emerging advances in hyper spectral imaging for many years along with the possibilities of artificial intelligence and neural networks.

Well, it needs more focused attention as they have more or less remained as experimental, particularly when one talks about the applications emanating from them, not only in India but elsewhere in the world. Further, globally convergence of technologies in miniaturised devices and instruments, and shrinking of satellite sizes are leading to developments such as sensor web, formation flying, and event triggered missions. In addition, the advent of disruptive technologies like smart phones and social networking along with cloud computing and crowd sourcing has made a world of difference to the community participation in applications, and also resulted in enhanced expectations. With these possibilities, and with the upcoming Internet of Things, Wearable Devices, and Bring Your Own Device (BYOD), handling the resultant Big Data with appropriate data analytics is expected to be the challenge for the coming days.

Obviously, we need to enter these areas in a big way and also develop appropriate human resources to derive maximum benefits of these emerging scenarios. I always say, "Data is no more a fascination, but application is always". In short, the future will be much more exciting for the remote sensing community, and professional societies like ISRS will have a major say in this.

Dr V Jayaraman

Dr V Jayaraman graduated in Electronics & Communication Engineering from College of Engineering, Guindy, Madras. He did his MS (by Research) from IIT, Madras; and Doctorate in Physics from Bangalore University. He also holds a Diploma in Management from All India management Association (AIMA), New Delhi.

Starting his professional career in ISRO in October 1971 as an electronics System Designer for X-ray Astronomy Payload for India's first satellite, Aryabhata, Dr Jayaraman moved on to remote sensing area in 1977 as Systems Engineer in the experimental satellite missions, Bhaskara-I & II, and later in early 80's, as Principle Systems Engineer for Mission, Payloads and Ground Segment in the operational Indian Remote-sensing Satellite (IRS) Programme.

He has served as **Director, Earth Observations System (EOS) Programme** at ISRO HQ (1997-2008), as the **Member Secretary of the Planning Committee of National Natural Resources Management Systems (PC-NNRMS)**, as **Director of NNRMS- RRSSC**, as **Director, ISRO Geosphere- Biosphere Programme (ISRO GBP**), and as the **Director, National Remote Sensing Centre (NRSC), ISRO, Hyderabad.**

As Director NRSC, he concentrated on developing a warehouse of accessible, affordable, & actionable knowledge products and services from aerial and satellite remote sensing and efficiently delivering them through near-real time web-based services; and in populating free-ware tools for user access. He launched the major ISRO initiative, BHUVAN, to provide a 2D and 3D visualization of the EO products & services. He was also instrumental in setting up a state-of-the-art Integrated Multi-mission Ground segment for Earth Observation Satellites (IMGEOS) at NRSC. He also initiated in NRSC setting up of Antarctica Earth Station for IRS data reception.

Dr. Jayaraman also had a short stint in UN Economic and social Commission for Asia & the Pacific (UN ESCAP), Bangkok, and later, served many times as Senior Consultant in UN ESCAP. He is well known in global Earth Observation community through his active contributions in Committee on Earth Observations Satellites (CEOS) and Global Earth Observation System of Systems (GEOSS).

Currently, he is the Senior Advisor (Space Applications) & Satish Dhawan Professor at ISRO Headquarters, Bangalore. He has more than 275 publications to his credit with around 70 of them appearing in peer reviewed journals.

RECEPTION, PROCESSING AND DISSEMINATION

MISSION OPERATION SYSTEMS AT ISTRAC

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Introduction: ISRO Telemetry Tracking & Command Network (ISTRAC) with its headquarters located at Bangalore, India is responsible for providing Space Operation services that include

- Telemetry, Tracking and Command (TTC) activities through the ISTRAC TTC ground stations located at various places during all phases of
  - Launch Vehicle
  - Earth Observation Spacecraft (EOS) or Inter-Planetary Mission (IPM) spacecraft
  - Crew Module (CM) for manned mission,
- Health monitoring and control of the EOS or IPM spacecraft during pre-launch, LEOP, Initial Phase, Normal Phase and Terminal Phase of the mission
- Health Monitoring and control of Crew Module during ascent, in-orbit phase and descent phase of the mission.
- Payload data (science data) reception, processing, archival and dissemination to users.

ISTRAC ground segment consists of a comprehensive network of ground stations distributed all over the globe to provide Telemetry, Tracking and Command (TTC) support to Satellite and Launch vehicle missions. For supporting Inter Planetary Missions, Indian Deep Space Network (IDSN) and Indian Space Science Data Center (ISSDC) provide TTC and Payload data reception support during earth orbiting phase, cruise phase and planetary orbiting phase. Ship Borne Terminal (SBT) that can be located either on land or on ship augments the TTC support for launchers or crew module during various phases of the mission. Air Borne Terminal (ABT) located on a Helicopter provides telemetry support during descent phase and touchdown. **Figure-1** gives the overall organization of ISTRAC ground segment.

Multi-mission operations support at ISTRAC includes:

1. TTC network operations
2. Spacecraft operations
3. Scheduling Operations
4. Flight Dynamics Operations
5. Computer network support
6. Communication network support
7. Facilities support

TTC network operations : ISTRAC has a comprehensive network of S-band TTC stations and X-Band Stations to provide Telemetry, Telecommand, Tracking and Payload data reception support for low earth orbiting satellites, Science missions and Inter-planetary missions. ISTRAC provides multi-mission support with a network of TTC stations established at Bangalore, Lucknow, SHAR (Shriharikota), Thiruvananthapuram, Port Blair, Brunei, Biak (Indonesia) and Mauritius. Also a transportable terminal (TT) with 4.6m antenna that can be located either on ship or on land is available for deployment for meeting mission requirements. Apart from these stations, ISTRAC takes support from external agencies like KSAT stations (Svalbard, Tromso, Troll) and Kiruna Station for TTC support and payload data download.

The functions to be performed by TTC network are:

- Telemetry data reception, recording, conditioning and transmission to Mission computers in
  S/X Band for launch vehicle as well as satellite.
- Transmission of commands to the satellite in S/X-band
- Tracking the satellite and transmission of tracking data to SCC
- Reception and transmission of diverse health monitoring data like Dwell data, Housekeeping Playback data, Star Sensor Playback data, Telecommand Playback, SPS Playback, etc.
- Reception of Payload data from various science missions and transmission to ISSDC.

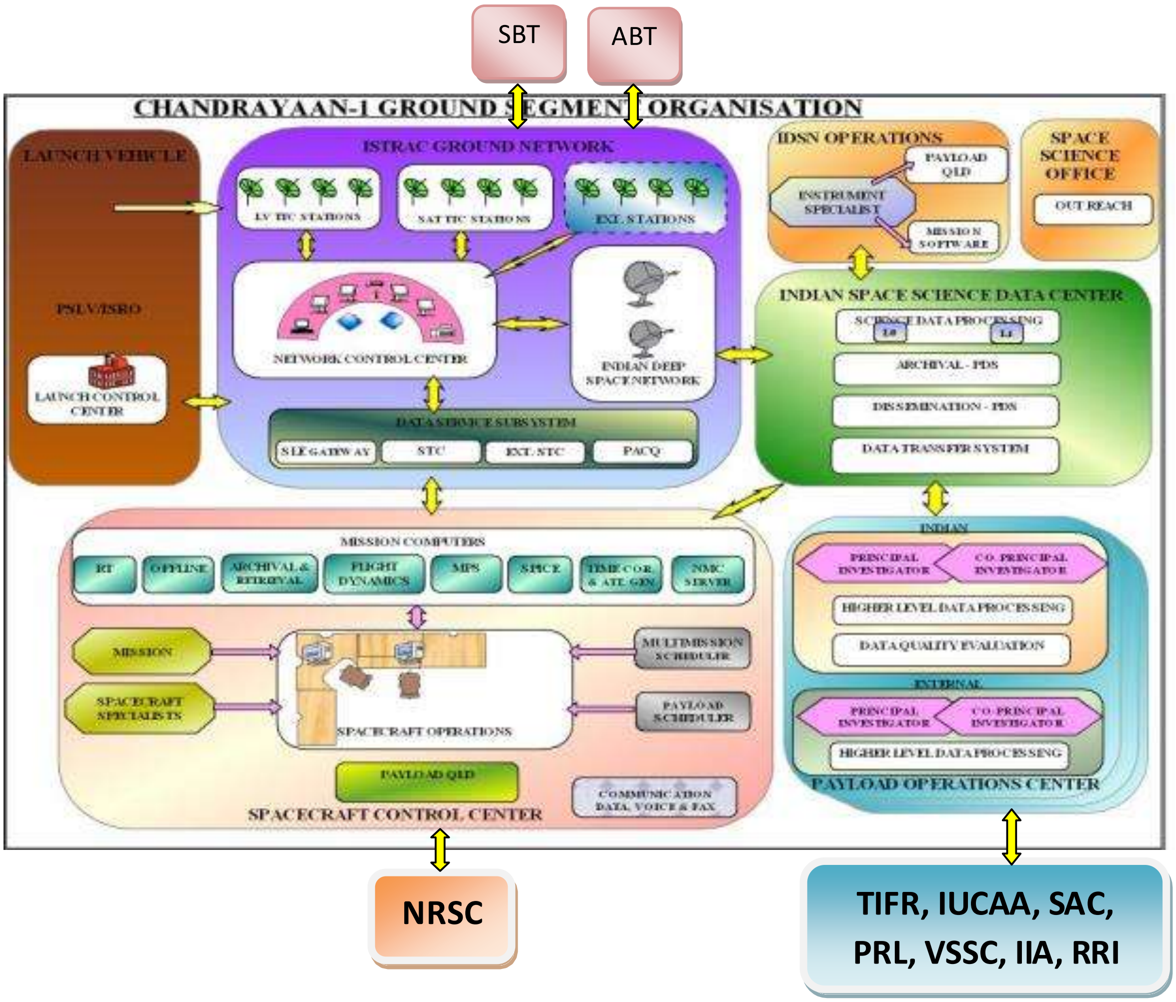

Figure 1: ISTRAC Ground Segment

To efficiently use the TTC station network for operations in multi-mission scenario, following features are implemented

- Remote monitoring and Control of all ground station equipment from ISTRAC Network Control Center (INCC), Bangalore
- Schedule based automated operation of the ground station.
- Remote operation of ISTRAC Network stations from a centralized INCC.

The following table shows the network stations that are used for supporting launch vehicle and satellite along with their capabilities.

Table 1: List of ISCTRAC network stations

Station	Antenna Size	No of Antennas	Capability	Support
ISTRAC Network				
Bangalore	10m/11m	4	BL1 & BL4: S/X Band; BL2 & BL3: S Band	LV/Satellite
Lucknow	11m/10m	2	LK1 & LK2 : S Band	Satellite
Mauritius	10m/11m	2	MU1 : S-Band; MU2 : S/X Band	LV/Satellite/MCF
Biak	10m/11m	2	Biak1: S-Band; Biak-2: S/C Band	LV/Satellite/MCF
Port Blair	11m	1	PBR: S-Band	LV/Satellite
Brunei	10m	1	BRU: S-Band	LV/Satellite
Sriharikota	10m/11m	2	SH1 & SH2: S-Band	LV/Satellite
Trivandrum	11m	1	TVM: S-Band	LV/Satellite
TT	4.6 m	1	S-Band	LV/Satellite
D18,	18m	1	D18: S-Band	Satellite
D32,	32m	1	D32: S/X-Band	Satellite
KSAT Network				
Svalbard	13m/7.3m	4	SVB: S/X Band	Satellite
Tromso	10m/5.4m	2	TRO: S/X Band	Satellite
Kiruna	13m/11m/7m	4	S/X Band	Satellite
Trolsat*	7.3 m	1	TRL : S-Band	Satellite

Figure 2, 3, 4 & 5 depict the picture of various ground stations and Figure 6 shows the location of stations on the world map. Figure 7 shows Network control architecture.

Figure 2: D32 IDSN 32m Antenna at Byalalu, Bangalore

Figure 3: Transportable Terminal deployed at Rodrigues ISLAND for RISAT-1 Launch

Figure 4: D18 18m Antenna at Byalalu, Bangalore

Figure 5: (Bangalore-3) 11m Antenna supporting IRS Missions

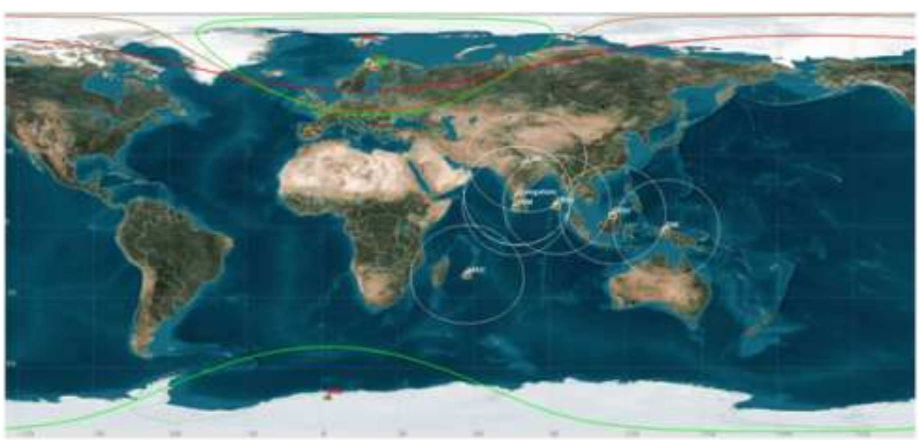

Figure 6: ISTRAC Network supporting IRS Missions

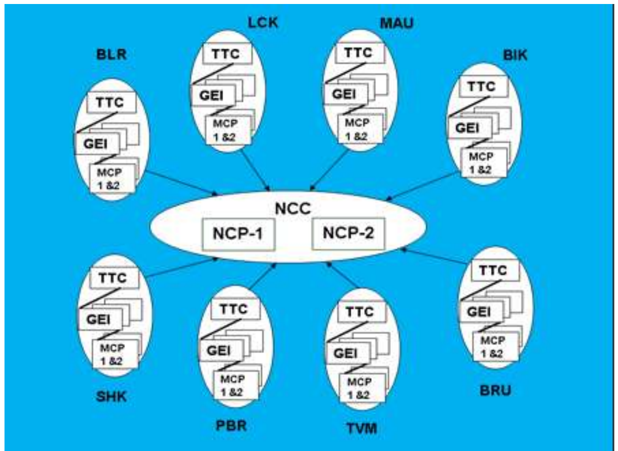

Figure 7: Network Control Architecture.

The architecture is layered wherein each layer will perform defined tasks. The General Equipment Interface (GEI) is at the lower most layer, which will interface with the ground station equipment. The configuration of GEI is distributed and there will be more than one GEI dedicated for a group of equipment based on their physical locations and performance requirement. These GEIs will interface with equipment through GPIB, RS-232C, RS-485, parallel drive and LAN interfaces. The main responsibility of GEIs is to continuously monitor all the station equipment and to send control commands to the equipment as and when required. The GEI software is completely database driven which will help in maintaining a uniform configuration in a heterogeneous environment of equipment.

The next layer is the Monitoring and Control Processor (MCP), which will be typically two per station (Main and Redundant). MCPs interact with GEI to get the M & C data from GEI and provide useful information to the user. MCPs decide the configuration of the ground station for a particular pass support and configure the equipment accordingly. It will serve as local station operating console. MCP will also run automated software, which will configure the station equipment automatically based on the schedule. All the real time operations of the station will be carried out based on time-line as well as on pre-defined conditions.

Network Control Centre (NCC) will be the new element in the modernized ISTRAC network. All TTC ground stations will be remotely monitored and controlled from NCC for regular operation. All ground stations will be configured based on the general schedule for the required support configuration automatically. Normal operations will be executed automatically. Critical operations will be carried out with the intervention of network controller. Interlocks will be provided for critical operation. A long term network operation data base will be available at the NCC for performance evaluation of all ground stations as well as subsystems in any ground station.

Spacecraft Mission operations : ISTRAC provides support for various phases of the mission during the life time of the LEO satellites. Presently, twelve satellites namely RISAT-1 & 2, Resourcesat-1 & 2, Cartosat-1, Cartosat-2/2A/2B, Oceansat-2, Megha-tropiques, SARAL and HAMSAT are being controlled from ISTRAC. The various mission operation phases are Pre-Launch Phase, Launch and Early orbit phase, Initial Phase, Normal Phase and Terminal phase. Figure 8 shows the overall organization of Mission Operations.

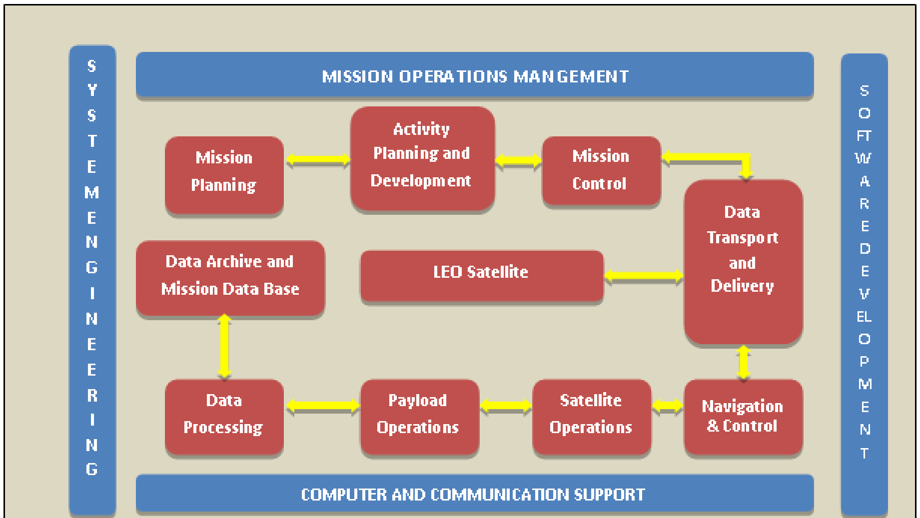

Figure-8: Overall Mission Operations Organization

Pre-Launch Phase activities

- Ensuring all hardware and software elements of ground segment are in place as per the mission requirement
- Test and evaluation of all ground elements involved
- Training of operations team to familiarize spacecraft subsystem functioning and command sequence procedures for various operations
- Prelaunch simulations to check the interface and compatibility of all the ground H/W and S/W elements involved, to exercise the initial sequence of operations, to check the time adequacy for different operations.

Launch and Early Orbit Phase activities

- Spacecraft initialization commands after power on
- Lift Off
- Monitoring spacecraft injection and solar panel deployment
- Monitoring spacecraft HK data and commanding
  3-axis attitude acquisition

Initial Phase activities

- 3-axis earth/sun Pointing attitude stabilization with reaction wheels and magnetic torquers
- Subsystem performance validation
- Payload commissioning
- Orbit acquisition and phasing
- Star sensor, Gyro and Payload Calibration exercises

Normal Phase activities

- Routine spacecraft health monitoring and commanding operations in 24x7
- Payload programming to meet the user request on daily basis
- Special operations like Orbit maneuver operations, gyro drift corrections, slope and offset corrections for onboard clock etc.
- Contingency handling operations like loss of attitude, solar panel non tracking, processor hang up etc.

Terminal Phase

Generally for LEO missions, the terminal phase plays vital role in terms of health monitoring, payload programming and maintaining the bus for following reasons

- Systems Degradation
- Loss of redundancy
- Power generation and degradation
- Fuel availability & Local time control (Inclination correction)
- Visibility support from TTC network

Interplanetary Spacecraft operations: Interplanetary mission operations are more or less conceived similar to EOS mission operations except for the fact that the Deep Space Network stations are involved for carrying out TTC operations and payload data reception when the spacecraft distances are larger. Mission operations can be broadly classified into four phases: LEOP phase, Earth Burn Phase, Cruise Phase and Orbit Insertion phase (planet capture). Figure 9 shows mars orbit profile. For example considering the Mars Orbiter interplanetary mission ground segment involves

- Planning of two Ship Borne Terminal (SBT) in pacific ocean to provide launcher support
- Suitable global network to support all perigee burns as well as acquisition operations. Currently along with ISTRAC stations external stations like Alcantra, Cuiba, Heartbeatshoek, JPL DSN stations and IDSN are planned.
- Suitable communication links to transmit data from network to control center and vice versa. To transport data from SBT, geostationary satellites are used.
- Software to handle CCSDS data exchange from control center to ISTRAC as well as external network
- Space Link Extension (SLE) software for interface with external agency
- ISSDC interface for processing the payload data at various levels and maintaining the archival (see Fig 10 & Fig 11)
- Separate network to integrate all the Payload Scientists with ISSDC for science data analysis and payload planning.

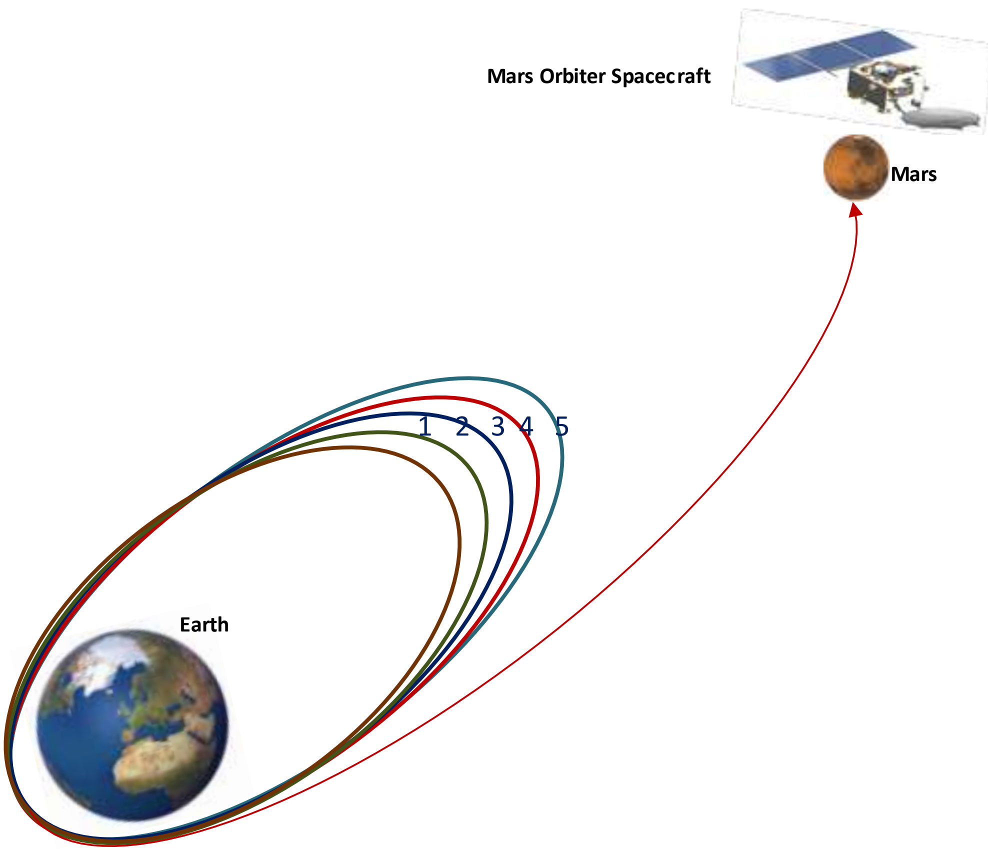

Figure-9: Mars Orbiter Profile

Mission operations for interplanetary mission comprises following operations

- Once the spacecraft is injected, the satellite is configured in to sun orientation with solar panels deployed producing full power to support all loads
- Attitude is stabilized by selecting suitable control mode that uses star sensor and wheels
- Orbit is stabilized by collecting large amount of ranging data and carrying out orbit determination
- Before the start of earth bound perigee burns, gyro calibration is carried out using suitable maneuvers. Drift, Misalignment and Scale factor values are determined using ground software and compensation commands are uplinked.
- Earth bound perigee burns (EBN) (5 to 6 burns) are carried out with suitable large angle attitude maneuver using reaction wheels to achieve the burn attitude and new orbit is achieved. All the maneuvers are carried out in closed loop mode using delta v cut-off logic.
- Final burn will put the orbiter in transfer trajectory. Generally this phase is longer in duration (9 months for MOM) and some of the payloads are calibrated.
- Small deviations in transfer trajectory can cause large variations in the arrival geometry, hence Trajectory Correction Maneuvers (TCM) are planned after final burn orbit determination.
- After reaching the destination orbit insertion maneuvers are carried out for capturing the planet. Subsequently required orbit is achieved by suitable burns at perigee point.

The main challenge of conducting Mars Orbiter Mission operation is the delay of reception of telemetry signals and commands when distances involved are as high as 220 million Km (~7 mins one way) to 400 million Km (22.5 mins one way). Another challenge is communicating with the satellite, large amount of signal degradation due to path loss can cause low margins on the signal received and transmission of commands to the satellite involves High Power Amplifiers (20 Kw) to ensure commands reach the satellite. Both uplink and downlink data rates are reduced to ensure error free communication.

Figure-10: ISSDC Computer Server Room

Figure-11: Front View of ISSDC Building

Human space mission operations: Human Space mission is different with respect to satellite mission in terms of Environment Control and Life Support System (ECLSS), Crew health parameters, additional voice and video uplink/downlink. Also the network coverage has to be planned to ensure minimum gaps between visibilities. Human space mission operations can be broadly classified in terms of three phases as: Ascent phase, In-orbit phase and Deboost & Descent phase. Since human life is involved, the mission operations planning, ground systems, crew module and launcher has to be designed such a way that at no point of time any single failure will jeopardize the mission and more than two failures will ensure safe return of human being. Failure at all stages of ascent, in-orbit and deboost/descent has to be addressed and crew escape system has to be provisioned for safe return by proper planning of recovery ships at appropriate points. Figure-12 shows the network supporting HSP along with the orbit trace. Figure-13 and Figure-14 shows Crew Escape system Profile and Deboost and Re-entry Profile. Figure-15 shows orbital vehicle

For support of mission operations during ascent phase are as follows

- Real time display of all orbital module parameters such as:
  - Crew health parameters
  - ECLSS parameters
  - Orbital parameters
  - Crew module health
- Commanding through the uplink.
- Ranging
- Preliminary Orbit Determination
- Real-Time Display of Launch Events, In-orbit telemetry parameters, descent events.
- Real time voice communication with crew
- Live video display
- Positioning of Ship Borne Terminals (SBT) and Air Borne Terminals (ABT) for TTC.
- Interaction with Crew recovery ships for crew recovery (In case of Launch Pad or in-orbit Abort)

During in-orbit phase apart from above operations, following operations are to be carried out

- Interaction with Crew recovery ships for crew recovery (For readiness of descent phase)
- Calibration of sensors by special maneuvers
- Carrying out science experiments by crew
- Preparation by crew for deboost and descent phase

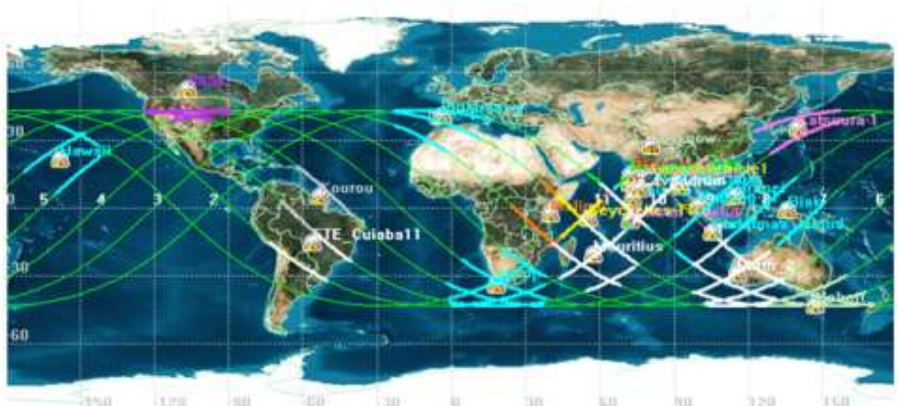

Figure 12 Network supporting Human Space Mission along with orbit trace.

During De-boost and Descent phase following operations have to be addressed for safe return of crew

- Service Module contingency and any thruster failure contingency plans
- Large angle maneuver and Monitoring of retro firing
- Preparation by crew for descent phase
- Parachute deployment contingency plans
- Monitoring of descent trajectory
- Monitoring of touchdown point with ELT / Radar Tracking / Mobile communication
- Recovery of crew, passivation of crew module and recovery from sea

To support human in space operations large amount ground network and ship borne terminals has to be configured to get better coverage that results in increase of complexity and cost. In order to reduce the number of ground stations two satellites in Geo-Stationary orbit acting as Data Relay Satellite is planned (Indian Data Relay Satellite System) that receives data from crew module and transmits to control center. This system ensures high availability and provides capability to continuously monitor crew module.

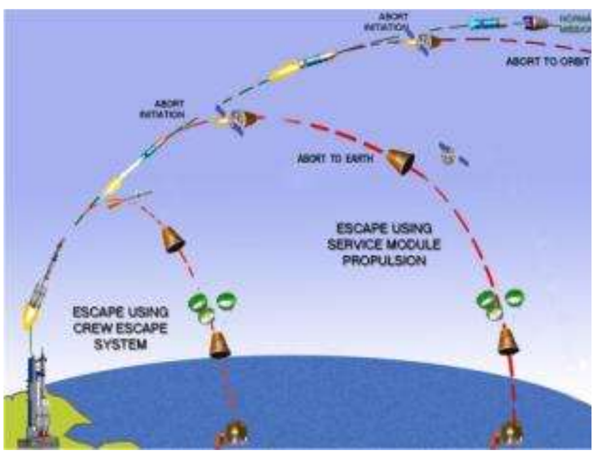

Figure-13 Crew Escape System Profile

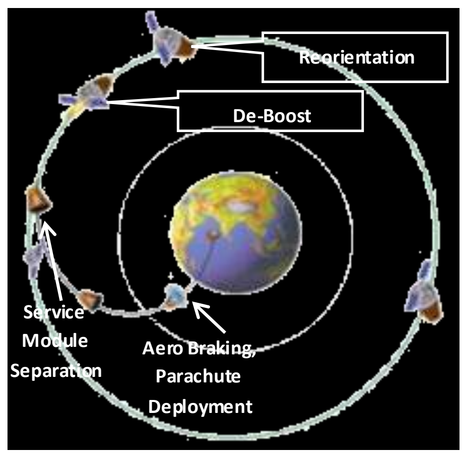

Figure-14 Deboost and Re-entry profile

Figure-15: HSP Orbital Vehicle

Scheduling operations: To fulfill the multi-mission support requirements, the ground network resources need to be shared optimally among the satellites. Scheduling the network resources for telemetry, tele-command and other operations involves visibility clash resolution for the ground stations taking into account the mission constraints and station capabilities. A software based system using genetic algorithm is implemented and is operational to meet the above requirements. For Multi Satellite Scheduling, inputs from Scheduling Guidelines, Visibilities of TTC network from Flight Dynamics Division and any special operations requests from operations team is taken and clash free schedules are prepared on weekly basis starting from Monday ending on Sunday. The weekly schedule forms the basic building block for generating of operation schedule and commands for the spacecraft. Figure 16 provides the flow of scheduling architecture for the TTC and Mission Control Centre operations.

Payload programming operations : The demands of multiple users for payload data have to finally culminate into command sequences that are to be uplinked to the satellite for payload operations. Payload programming is implemented using Payload Operations Planner (POP) software consisting of three modules namely User Order Processing System (UOPS) implemented at user end, Payload Programming System (PPS-NDC) implemented at NDC/NRSC, Hyderabad and Command Sequence Generator (CSG) implemented at SCC/ISTRAC, Bangalore. The payload requests are serviced based on criteria like priorities for different users, spacecraft constraints etc. Figure 17 depicts overall payload programming architecture.

Flight Dynamics operations *:*In order to keep track of the orbit of a satellite, it is essential to compute orbital parameters on daily basis, using the tracking data provided by TTC ground station network or using the SPS data downloaded from spacecraft.

Flight Dynamics Operations include

- Orbit determination using S-band tracking data or SPS data
- Visibilities generation for ground stations for tracking purpose
- Orbital Events prediction such as Eclipse entry/exit times, Pole crossing times etc.
- Orbit maneuver planning for ground track maintenance, local time maintenance and phasing requirements

The S-band tracking data contains the satellite's slant range from the station, range rate and look angles at different times. This information is collected and accumulated for a period of 60 hours (2.5 days) and orbit determination is carried out daily. For SPS based orbit determination, GPS measurements data stored onboard for around two orbits is downloaded and used. Preliminary Orbit Determination (POD) is one of the important tasks that are carried out during Launch. The POD results are disseminated to all the network stations 15 mins after spacecraft injection for further tracking.

Computer Network support: Distributed computer architecture has been implemented at Control Center in client server architecture configuration. The computer system will support all the missions in the multi-mission environment. Computers will provide prelaunch phase, initial phase, on-orbit phase and terminal phase support services for all LEO missions. Figure-18 shows overall computer architecture.

The computer configuration for a satellite comprises of:

- Work stations for health processing and display of spacecraft data
- File servers/Data base servers for data management
- Routers for interconnecting control center to ground stations
- Gateway systems for interconnecting control center with external agencies
- Virtual LANS for LAN connectivity of all the work stations, communication processors, file servers, Layer-3 switch / routers etc.,
- TCP/IP Data network is used to connect control center with other Ground stations

- On these systems, a unified software system will run consisting of a set of layered software products catering to the functions of data communication, data management and data flow monitoring.

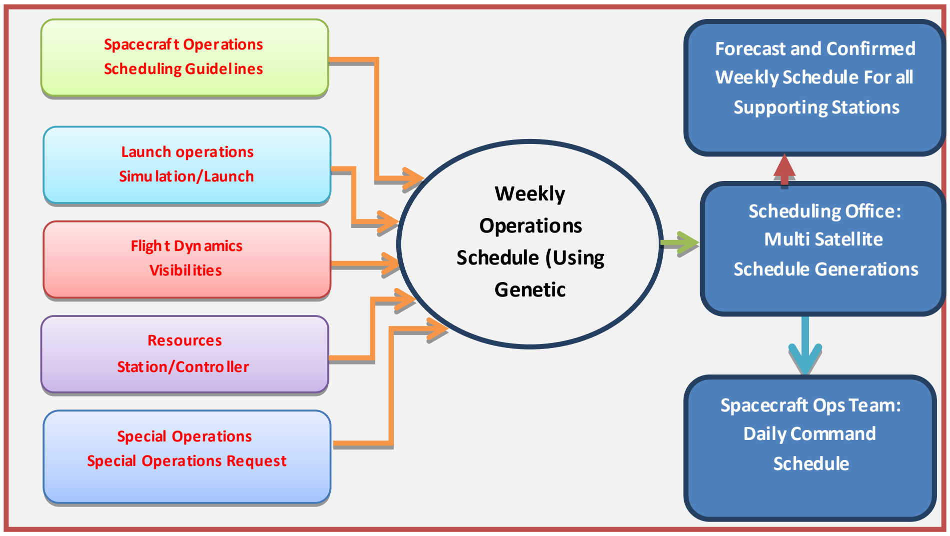

Figure-16: Scheduling Architecture

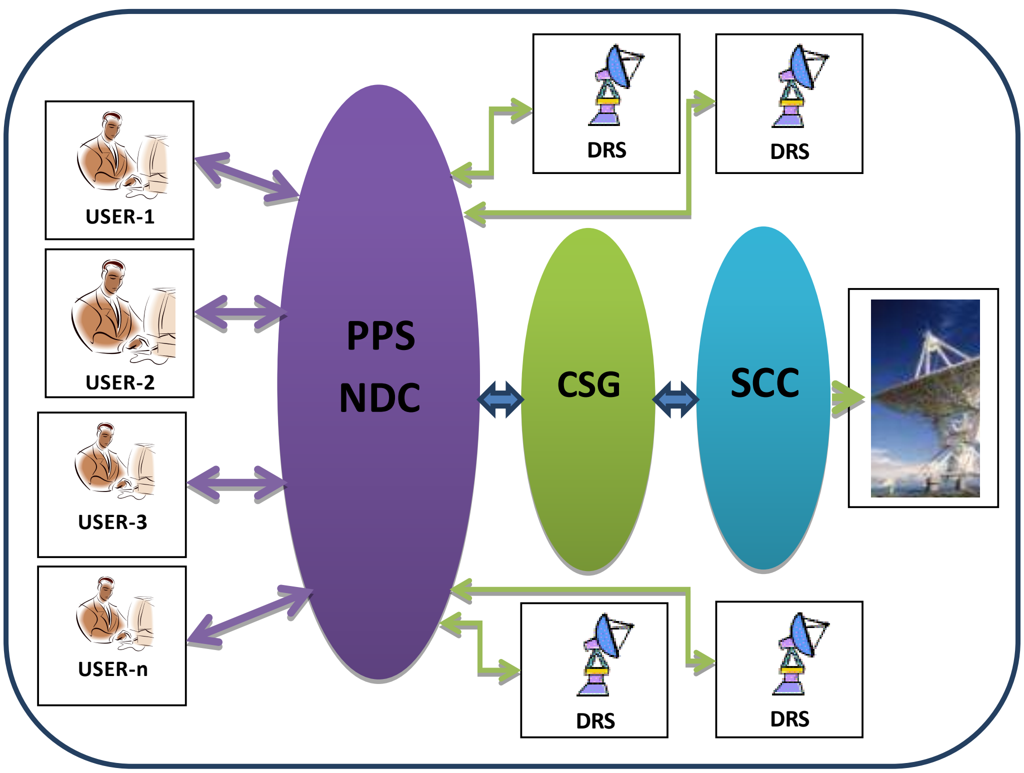

Figure-17: Payload Programming Architecture

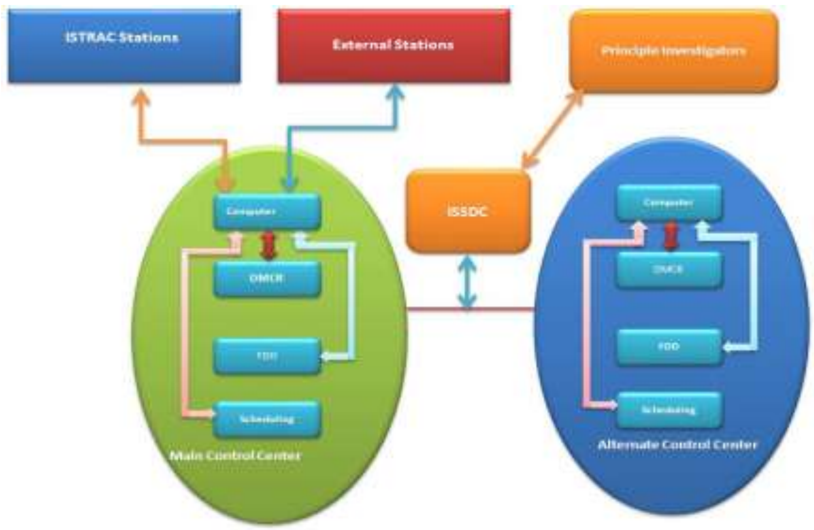

Figure-18: Computer Architecture

Communication Network Support: ISTRAC Communication Network provides real time voice/data/fax connectivity for TTC operation between Spacecraft Control Center (SCC), Bangalore / Vehicle Control Center (VCC), SHAR and other Network Stations both in India and abroad, supporting Launch Vehicle & Satellite during its launch phase, early orbit and normal phase of missions.

Sky Links: All the communications are provided with 128/256/384/512/768 kbps digital direct satellite links.

Terrestrial links: The terrestrial links are hired from communication providers. Terrestrial links are planned for redundancy wherever sky links exist. Two terrestrial links (main and redundant) are planned in an alternate route to avoid single point failures between VCC/SCC and TTC network stations not having connectivity through sky link. ISDN links are also established between BLR-MAU used as backup link. Figure 20 depicts the communication links for satellite operations.

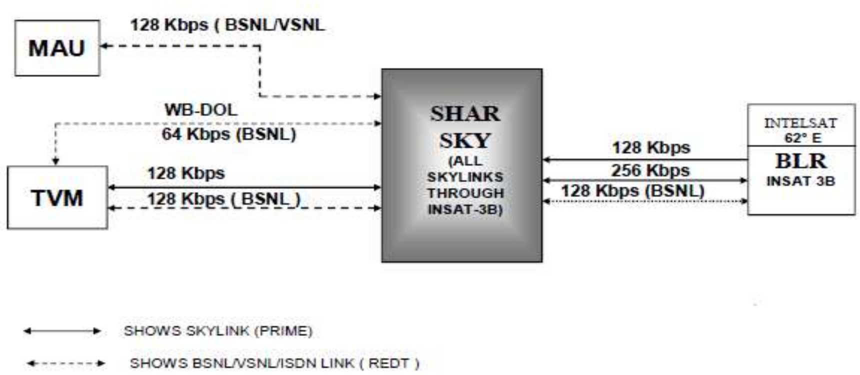

Figure-19: Communication Link Configuration for PSLV

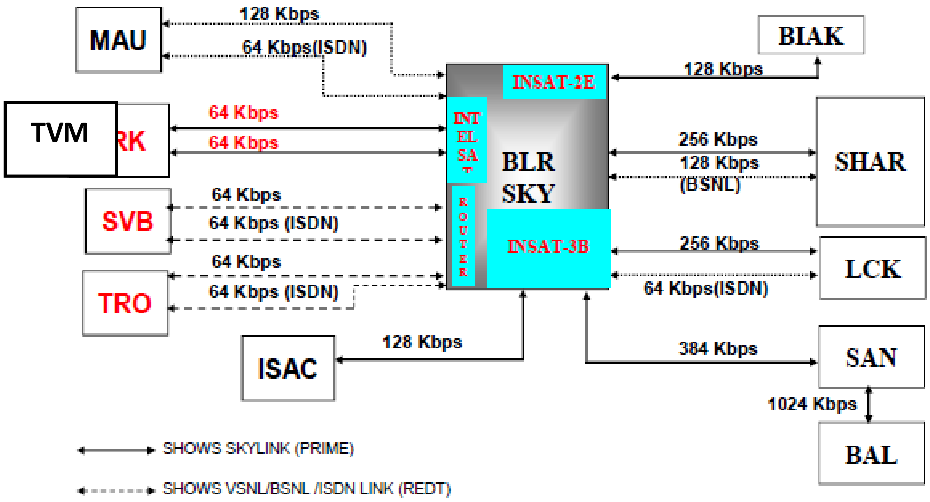

Figure-20: Communication links for satellite operations

Facilities Support: To support dual spacecraft mission launch and initial phase operations, two Control Centers (MOX-1 & MOX-2) are established in the Mission Operations Complex. Both MOX-1 and MOX-2 are integrated with each other (see Figures 21 & 22).

Mission control facilities at MOX-2 comprises of

- A Mission Control Room (MCR) to support Launch and Early Orbit Phase (LEOP) operations.
- A Mission Analysis Room (MAR) to support launch and early orbit phase (LEOP) operations.
- Dedicated Mission Control Room (DMCR) to support Normal Phase operations along with ongoing missions.
- Conference Hall

Mission control facilities at MOX-1 comprises of

- A Mission Control Room (MCR) to support Launch and Early Orbit Phase (LEOP) operations.
- A Mission Analysis Room (MAR) to support launch and early orbit phase (LEOP) operations.
- FDO area for supporting Flight Dynamics operations during the initial phase operations.
- Scheduling Office area to plan Payload and TTC operations.
- Conference hall.

Figure-21: View of Mission Control Room at MOX-2

Figure-22: View of Mission Control Room at MOX-1

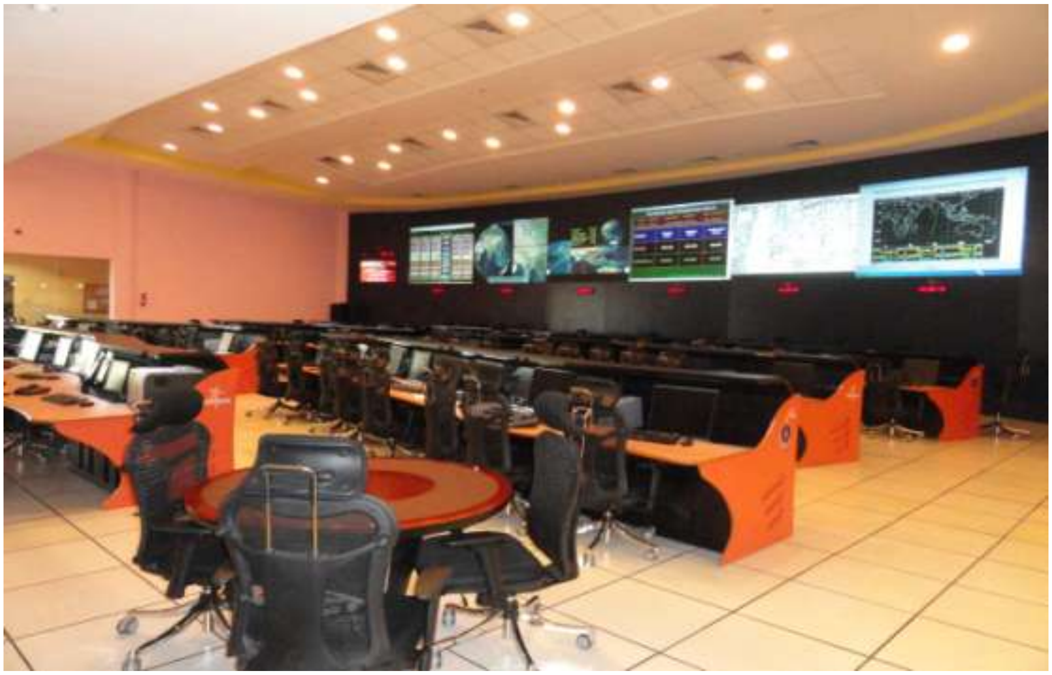

Figure-23: View of Mission Analysis Room

Figure-24: View of Dedicated Mission Control Room

Conclusion*:* Ground segment planning to meet the mission requirements has to consider all scenarios including contingency scenarios, which is a demanding task. Automation and autonomy is the topic of day and all ground elements have to meet these requirements. Various software and hardware interfaces are developed in-house and tested extensively before deployment.

Earth observation missions are increasing in number to meet the global remote sensing requirements. In order to provide seamless support for all the missions and to achieve the mission goals both ground and on-board autonomy have to be considered. Operations of Interplanetary mission calls for inducting Deep Space Network (DSN) into the ground segment and Indian Space Science Data Center (ISSDC) for payload data processing. It is necessary to interface with other global DSN network for getting continuous visibility. Health monitoring and commanding in an environment that is different from EOS missions have to be addressed for IPM.

Human Space missions are most complex in terms of ground segment and data exchange. Reliability plays vital role in planning ground segment and redundancies have to be built in the ground segment as well as operation scenarios. Unlike spacecraft missions, the ground segment has to address thoroughly for in-orbit abort scenarios, reentry and recovery including launch pad abort. The number of ground stations including SBT and ABT increase astronomically to provide near continuous support. To reduce the complexity and get maximum coverage, IDRSS concept that uses geo-stationary satellite can be planned to track crew module from space and relay the data to control center. This reduces the number of ground station supporting the manned mission leading to cost reduction.

TOWARDS NEAR REAL-TIME DATA SUPPLY OF INDIAN AND GLOBAL COVERAGE REMOTE SENSING DATA FROM INDIAN SATELLITES

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Introduction: There is a growing demand for the near real-time availability of satellite data for various applications and information retrieval algorithms. To meet these demands there are a few important factors that need to be considered for any earth observation satellite ground segment processing. To start with there is a need to enable the automated scheduling, acquisition and autonomous processing capability to minimize the gap between the data acquisition and processed data availability with required accuracies in usable form. There is also a need to maximize the availability of global coverage data by expanding the visibility and increasing the acquisition opportunities. It is also important to generate and publish the acquisition catalog and Off The Shelves (OTS) product catalog for selection, ordering and dissemination through electronic mode delivery service or through free product downloads through Open Earth Observation Data Archive (NOEDA) governed by ISRO data policies. Finally web based near realtime data/information delivery portals. At National Remote sensing centre there are continuous efforts to augment and improve the scheduling, acquisition, processing and dissemination facilities to meet the contemporary data supply demands as well as provide innovative applications to demonstrate utilization potential of remote sensing data.

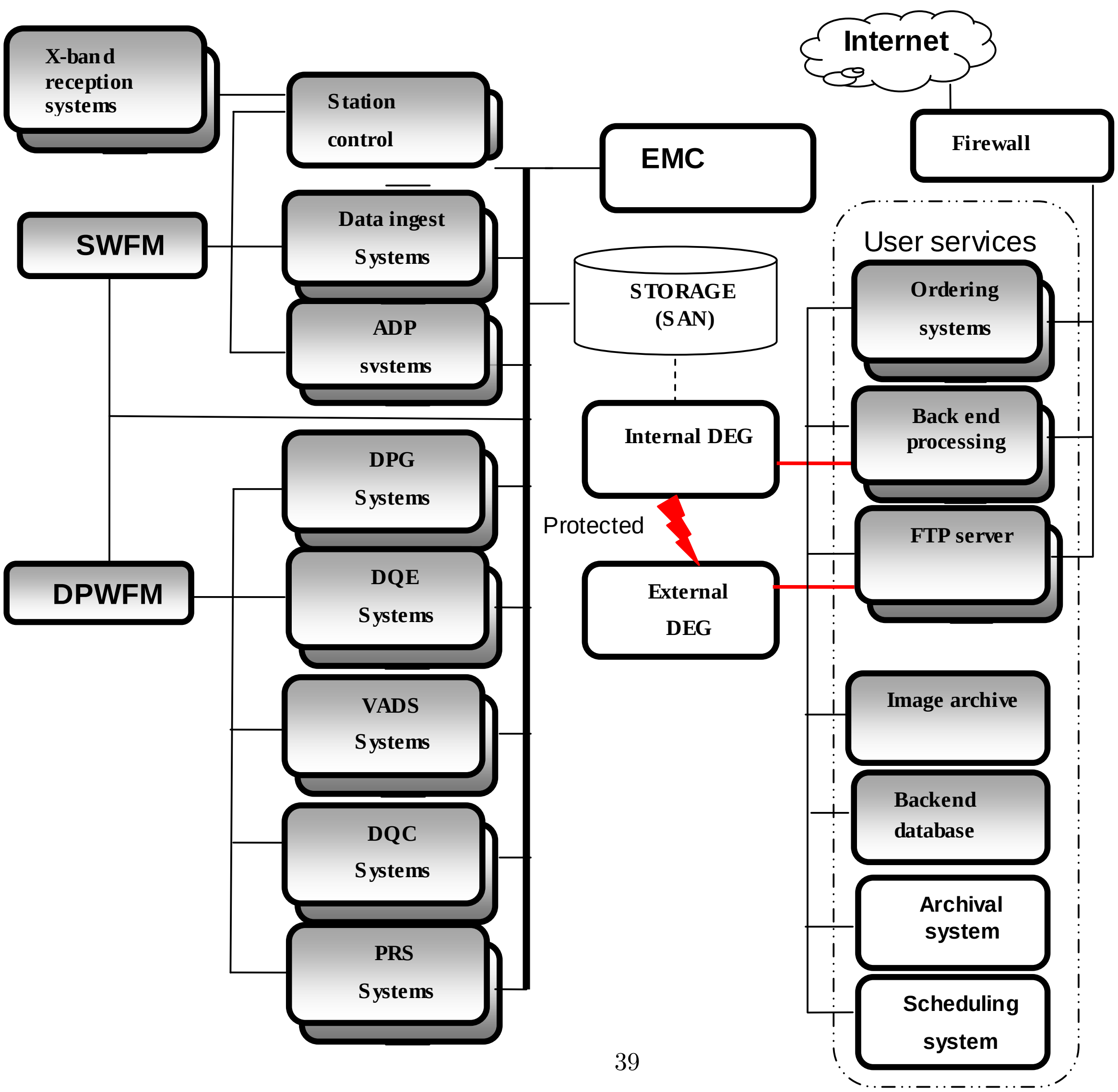
Evolution of Ground segment facility at NRSC : The ground segment facility in1988 when the first IRS satellite is launched was with standalone data recording on high density tapes and with a film based quick look images for offline data selection and using satellite specific custom made hardware units to interface and retrieve the data from the high density tapes at slower speed and processing using mini computers. The turnaround times for the product delivery achievable at that time are limited to 15 to 20 days. With Oceansat-1(1999) launch the mission specific hardware units are replaced by configurable front end processors enabling direct data acquisition on to computer storage exploiting the contemporary technologies. Generation and publishing of browse catalogs for web access is realized enabling online browsing for scene selection. The archival media is replaced with computer compatible high capacity digital tapes which eliminated the need for specialized hardware on data product generation system. The processing systems are configured with faster RISC based servers and the turnaround times for data supply are reduced to 3 to 7 days. With Oceantsat-2 (2009) launch the near real-time supply of data was realized by making the preprocessed data availability online and supplying the data through FTP mode is enabled. With ResourceSat-2 (2011) launch the acquisition and processing facility has undergone a total revamp and integrated multimission ground segment facility is realized with state-of-art technologies at Shadnagar ground station in Hyderabad to meet the near real time delivery of the data that is one hour for emergency products and 24 hours for regular products with online ordering and dissemination. This was feasible due to multi-core processor architectures and high speed storages and higher internet access bandwidths along with built-in contingencies.

Integrated multi-mission earth observation ground segment (IMGEOS): IMGEOS facility is designed and realized with a capacity to generate 1000 products per day with automated sequencing of majority of activities

The main focus was to meet the user demands in terms of product accuracies, timeline and volumes. This design caters for scalable and reconfigurable systems to meet the peak demands and maximize the reuse of the software while realizing the processing for future missions. The figure 1 below gives the block level description of the facility. The main features are:

- Autonomous mode of processing with no or minimum dependency on dynamic external inputs
- Data consolidation and shared file systems to ensure single instance of application installation with multiple and scalable processing nodes
- Automated preprocessing and catalog generations within 20 minutes to 60 minutes time based on the volume of the data acquired.
- Default Automated processing with improved system level accuracy integrated with terrain dependent inputs
- Building product off the shelves (OTS) based on user ordering patterns and profiles Built-in quality evaluation procedures to ensure the quality of the end product.
- Realization of Automated procedures end product
- Standard quality checks
- Provision for detailed quality verification for the end products based on the sensor related anomalies.

*ADP- Ancillary data processing: *DQE- Data quality evaluation
*PRS- Problem resolution systems; *DEG- data exchange



X-band reception systems: The reception facility comprises of four X-band reception chains starting with antenna subsystems to direct data ingest systems. The reception activity will be triggered by pass schedule file. Each chain will get automatically configured based on the mission to be tracked. Each antenna is associated with an antenna control computer and all the antennas are controlled through a station control computer. Data ingest system is interfaced with X-band acquisition system starting with antenna to demodulator and bit Synchronizer. Station control system also manages the connectivity for the closed loop simulation tests through Boresite.

Scheduling system: Scalable multi-mission interfaces for planning and scheduling the collections of IRS constellation of satellites. Enables provision for emergency tasking till the uplink of commands based on feasibility by preemption of earlier planned slots. Consolidates user requests based on mission/sensor rules and constraints and generates schedules

Direct ingest System (DIS): Direct Ingest System is a real time system for payload data acquisition for IRS satellites. This is a system for scheduling the various satellite passes for acquisition, acquiring payload data, archiving it on to RAID.

Ancillary data processing systems (ADP): Performs the preprocessing of data ingested by DIS and generates pass wise orbit, attitude data, scene framing parameters, browse catalog inputs, data quality reports based on schedule file and derived quality parameters.

Data product generation software generates : The data product generation systems handle data from optical and microwave payloads of IRS satellites and generate radiometrically and geometrically corrected products as the defined list for that sensor. It uses DEM data & ortho-rectified reference images for achieving the geometric accuracies.

Value added product generation: Value added product generation system generate Ortho rectified products, Multi sensor merged products, Multi-sensor co-registered products and large area mosaics

Product quality checking: It extends necessary automated and visualization tools to check the quality of the user demanded product before it is dispatched to the user.

Data quality evaluation system: Enables evaluation of geometric and radiometric quality of the products generated by DPGS. It uses the GCPs and the ortho rectified reference images to determine the accuracies of the products. Evaluates mission parameters like target accuracies, band to band registration, scene overlaps etc Assesses the detector performance degradations by comparing with lab measurements.

Secured data exchange: Enables secured data transfer between different networks by controlling the data transfer only from preregistered authorized applications

Storage system (SAN storage): The data consolidation happens through the storage systems with three tier hierarchy with high performance RAID, relatively low performance SATA storage and online tape library system. An additional facility of vaulting the data on to media for back up purposes is provided to maintain backups.

Problem resolution system: Single window for unresolved problem handling and providing recovery actions.

User services: User services include online browsing, data selection, ordering, electronic mode of data dissemination and ground station downlink scheduling.

Expanding acquisition opportunities through polar stations: Global coverage acquisitions are maximized by exploiting the onboard recording capabilities of the missions and by identifying polar stations which have capability for acquiring 10 to 14 orbits per day and establishing the link to transfer the data. This support ensures the availability of global coverage data within 6 to 12 hours from the time of data acquisition enabling near real time dissemination. This facility will enhance the capability to acquire more data enabling systematic global area coverage by IRS satellites in a quick turnaround time and respond to global disasters within few hours.

Svalbard /Tromso stations : Faster acquisition of global data is enabled by scheduling the playback passes at Kongsberg Satellite Services, Norway (KSAT) polar stations at Svalbard (78 deg N and 15 deg E approx) & Tromso (68 deg N 19 deg E approx). The data currently acquired from these stations is Cartosat-1, Resourcesat-2, RISAT-1 and global scatterometer data from Oceansat-2. To receive the data from Svalbard and Tromso stations 45 Mbits /sec link is established between Svalbard and Shadnagar. On either end of the link data exchange gateways are configure acquisitions at these stations are automatically scheduled and the acquired data is transferred to IMGEOS facility for processing. After processing the scat data is made available on oceansat-2 web portal within 40 to 30 minutes from the time of data downlink. Cartosat-1, RISAT-1 and Resourcesat-2 data is transferred to IMGEOS storage for subsequent processing. The diagram below shows the configuration and data flow between Svalbard/Tromso and Shadnagar/. The figure below shows the data flow.

Antarctica ground station : NRSC has established a Remote Sensing Ground Station at Larsemann Hills, Antarctica (69ºS and 76ºE approx) to receive data from Indian Remote Sensing Satellites in S/X-Band. 40Mb/sec Satellite communication link between the two stations is being established. Out of this 4Mbps is for full duplex communication available all the time. 36 Mbps is half duplex communication. This 36 Mbps link will be used to transfer the data acquired at Antarctica to Shadnagar IMGEOS facility. The system is capable of automatically scheduling acquiring and transferring the data from RISAT-1, Resourcesat-2, Oceansat-2 & Cartosat-1 satellites. The figure below shows the data flow. The system will be operational shortly.

Web based services: Different web based applications are hosted to extend online services to the users. They are services for data selection and ordering for all IRS missions, Oceansat-2 web portal for OCM and Scatterometer data products, for free download and information services realized using near real-time data.

Online services for data selection and ordering for paid service : The browse catalogs generated as a part of level 0 processing are archived as soon as they are ready and the user is enabled for online browsing, selection and ordering. The data ordered can be automatically uploaded to the NRSC FTP server with order/product specific login, for the users to connect and download from the public net through FTP service. The service also caters data download and ordering for Cartosat DEM data.

Oceansat-2 products web portal: Web hosting of Oceansat-2 ocean color monitor data pertaining to global coverage for free download service.

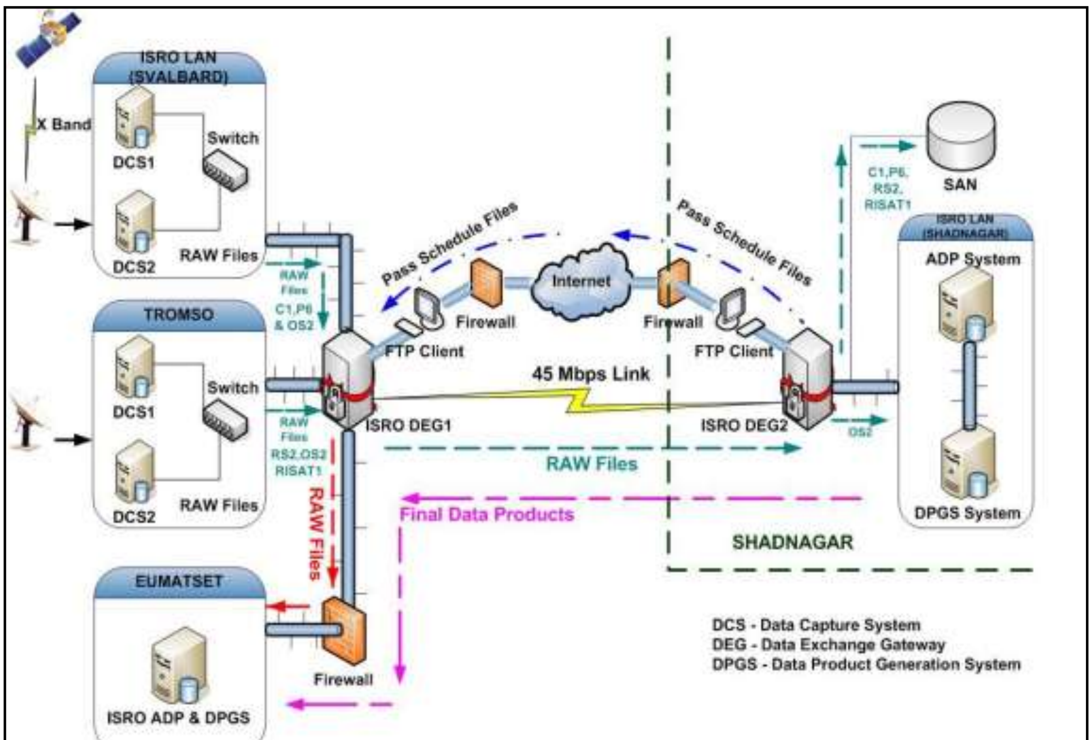
Web based Information services

India- Water resource information system: India-WRIS provides information on India's water resources data. India-WRIS allows users to search, access, visualize, the data. It presents all water resources and related data in a standardized GIS format in a national framework for Water Resource assessment and monitoring.

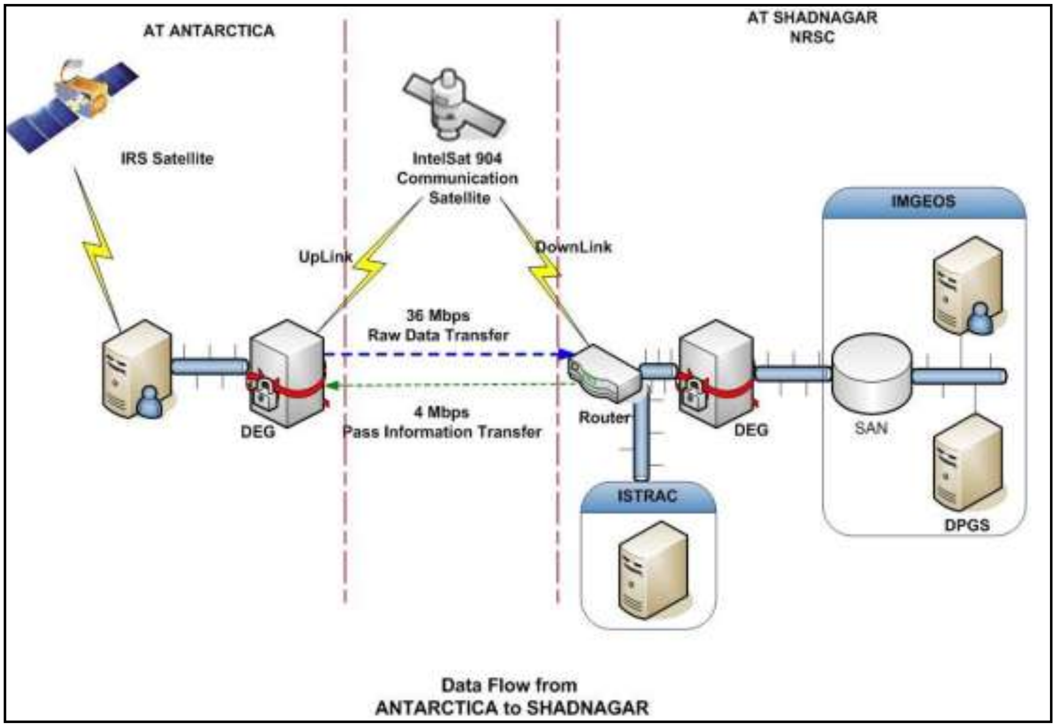
Other information services : The other services which are built using remote sensing data are Indian Forest Fire Response and Assessment System (INFFRAS) TERRA/AQUA – MODIS based active fire locations on daily basis within 1-2 hours of the satellite ground pass, Agricultural drought monitoring system using IRS data and Flood mapping system.

Scat products (25Km & 50Km)
Level 2B : Wind vectors for a given orbit
Level 3W : Global wind vectors
Level 3S (HH) : Global sigma – 0 values in HH polarization
Level 3S (VV) : Global sigma – 0 values in VV polarization

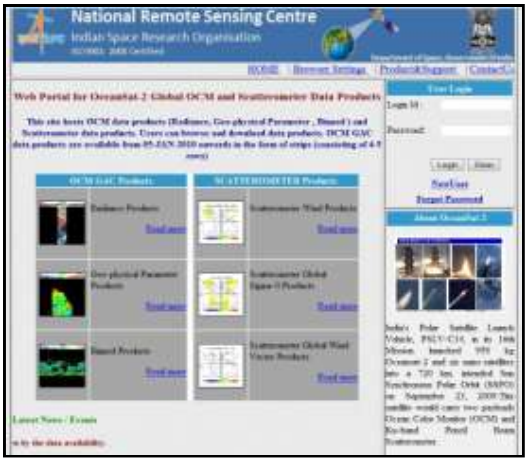
OCM products
Level-1B(Standard Products)
Level-2B(Geophysical parameters products) • Chlorophyll mapped • Sediment mapped • Aerosol optical depth at 865 nm • Diffused Attenuation coefficient
Level-3 (monthly and yearly Binned products)



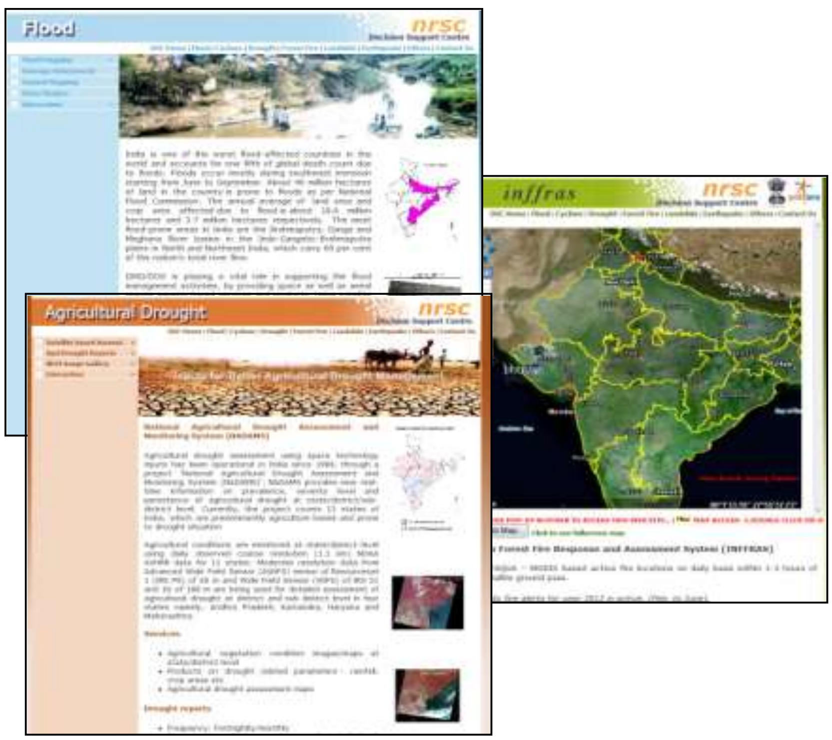
Data Flow from SVALBARD/TROMSO to SHADNAGAR


AT ANTARCTICA
AT SHADNAGAR
NRSC
IRS Satellite
IntelSat 904
Communication
Satellite
UpLink
DownLink
IMGEOS
36 Mbps
Raw Data Transfer
4 Mbps
Pass Information Transfer
DEG
Router
DEG
SAN
ISTRAC
DPGS
Data Flow from
ANTARCTICA to SHADNAGAR


Satellite Data Services
ional Remote Sensing Centre
Indian Space Research Organisation
Govt. of India ,Dept of Space


National Remote Sensing Centre
Indian Space Research Organisation


India-WRIS Wiki
Water Resources Information System of India


Flood
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MISSION DATA PROCESSING AND VISUALIZATION

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Introduction: Mission Data Processing is concerned with generation of software products for converting raw mission data in to meaningful and useful information. The raw mission data can be satellite telemetry data or payload data. Mission data processing is involved in development of software products to realize the visualization of Satellite Health Monitoring and Data Analysis. This article adresses Mission Data processing from telemetry (Satellite House Keeping) data processing, telecommanding and payload data pre processing point of view.

Data processing is a continuos process carried out during every phase of satellite, right from its inception to terminaton. The Data processing includes acquiring the data, storing and extraction, application specific processing and presentation using user friendly GUI (Graphical User Interface).

It has evolved over last four decades, got enhanced in function and features as well as in operation environment. Started as a near real time program on TDC 316 in late 70's grown and become a multi-mission package in use on Unix based system supporting realtime as well as offline activities for satellite operations.

In late 80's fully computerised operations started on Digital platform PDP11 with RSX11M and VAX/VMS.

In Mid 90's it was decided to move towards RISC based architecture with UNIX operating system for meeting requirement of support for multimission as well moving towards open architecture for portability.

The 21st century is an era of LINUX based operating system for enhanced features and flexibility in GUI design. New technologies are explored such as Web based satellite health monitoring and java based Integrated displays and Qt based Mimic Display system etc.

All the software are refined from time to time to serve the user community. The intended user community are subsystem experts, mission analysts, operational users at control centres.

The basic activities of Mission Data Processing can be listed as,

- Data Table Management
- Real time Data Acquisition
- Real time Processing of Parameters
- Real time Distribution of Processed data
- Real time Monitoring of Satellite Health and Critical events
- Support User Friendly Telecommanding
- Archival and Retrieval of Telemetry data for Analysis
- Support Offline Detailed Analysis
- Payload Data Pre Processing

Data Table Management : Satellites send telemetry data in the form of bits. On ground there should be some mechanism through which the data can be understood. The data table manager is the software used to define and maintain the processing definitions of these bits. These bits are grouped to form bytes thus forming a frame and master frame of data. A master frame contains the health of total spacecraft. The Individual subsystem health is available in certain frames with in the master frame. Each data is identified by a Parameter Identifier. The Parameter definition and processing logic is stored in this database. Further the processing software will make use of this database to process the data.

Real time Data Acquisition : Satellites send continuos health data to ground. They are in general low bit rates. This data is referred as Telemetry. This can be collected as frames and master frames. Each Frame is identified by frame sync words, satellite code, data type etc.

This telemetry is aquired from Telemetry Interface Unit (TIU).The acqusition programs acquire the telemetry data from number of TIU and baseband units as pre-configuration defined, at different ground stations.

In case of GEO (GeoSynchronous Earth Orbit) missions, ground stations and control centre are located in same place, as the satellite will be always visible to it.

In case of LEO (Lower Earth Orbit) missions, they are visible for couple of minutes over any ground station for only few orbits. Hence multiple ground stations, distributed across the globe are established or hired to manage the satellite and to carry out necessary operations. The health telemetry data for the non-visble period is obtained from the onborad recorded data, downloaded during visibility using playback stream.

Real time Processing of Parameters: At ground, database is maintained to identify each bit, word and combination of words in telemetry frame by a Parameter Idenfier (PID). Each PID has associated processing scheme attached to it. Ground calibration database and the parameter identifier enable to decode the data and arrive at status of various elements and their values. The Real time processing program processes all the parameters and update its values. Fig-1 depicts the architecture diagram of data processing.

The schemes required to process for most of the spacecraft subsystem parameters, fall under the generic categories, such as polynomial based evaluation, raw telemetry count, derivation of status etc. However some subsystem parameters require processing schemes involving higher bit data handling, complex arithmetic computations and look-up table based evaluation that could not be fit into any of the generic classes. They have to be processed using special processing software maintained separately for each mission. Spacecraft telemetry data processing is carried out using two approaches: *table driven* and *code driven*. In the former approach a centralized spacecraft parameter definition table is maintained for each mission. This database has restricted access and is maintained in conjunction with the mission team. This database contains the detailed scheme and definitions to process each and every subsystem parameter for the spacecraft. In the code driven approach, algorithms provided by subsystem experts to process spacecraft data are coded as special processing software specific to the mission.

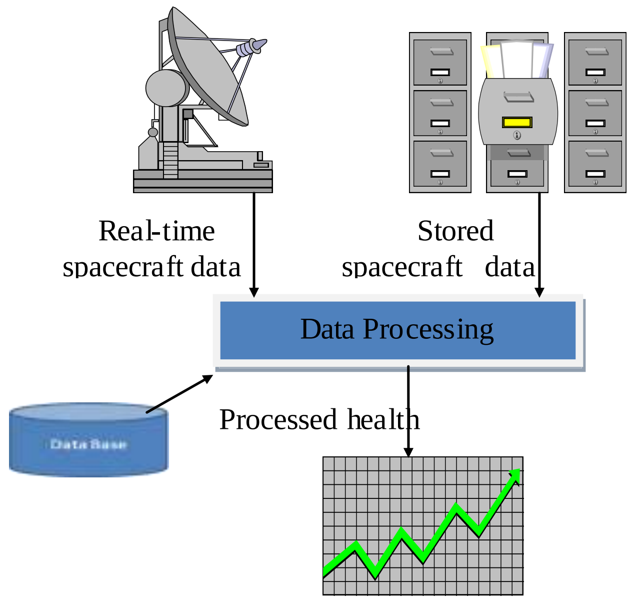

Fig -1 Data Processing

Real time distribution of processed data : The data is processed at fixed rate at the server and distributed to all the clients. The Server daemon posts the data to client and Client daemon acceptes the data and present it to the presentation software. Data is distributed using Client Server architecture. TCP/IP socket communication is used to make the client application independent of language and implementations.

Real time monitoring of PID and Critical events : All the processed information is presented in client Workstation by Real Time Page Display program and Real Time Graphics. Critical alarm monitor executes in background continuously looking for critical alarm signatures and generate alarm and recovery plans. There have been tremendous improvements in visualization of the information from generation to generation.

In early days Alpha Numeric Displays were used like in Fig-2, In this system the displays are not very user friendly. It was designed for the ANSI terminal with 24X80 display and only keyboard as input interface. To navigate between different pages one has to use the control keys and commands.

Fig-2 ANSI Display System

Second comes the X-Windows mode of displays, which are more user friendly as shown in Fig 3. All the parameters are displayed along with the values in a tabular fashion. It also provided enhanced features of navigation between different susbystem pages through click of button, navigating to exact page, previous page , next page etc. It also provides user monitor screens which allow the user to choose the PIDs he/she is interested in. But to maintain uniformity and compatability with earlier one the main display is limited with two column with each having 19 parameters. Only look and feel is improved and mouse also used for input.

Fig-3 X-Windows Display System

With the advent of technology, more and more information was brought under the single window called integrated display system (Fig 4) with advanced navigation features. Most of the currently operational software have evolved from terminal based display systems, and still considers different elements of visualization like graphs and alpha numeric display as different software entities. The new software integrates them all to a single window, In addition to an array of various widgets including dials and gauges, which altogether gives the user a comprehensive view on the state of the spacecraft.

Fig.-4 Integrated Display System

With time and technology and the increased number of spacecrafts to be monitored, it is necessary to make the monitoring reaching to the desktop with minimal environmental setup and beyond operational centre. Spacecraft controlling centre has the limitations of reachability, accessibility and security to make the desktop monitoring feasible. Web based technologies (Fig-5) is the appropriate solution which enables the spacecraft health monitoring & analysis system usable, interoperable over different operating system along with latest technology trends accommodated. This would allow the clients to be simple web browsers running on any computer through inter/intra centre network to access the spacecraft health data for analysis and operations.

Fig-5 Web Display System

Yet another revolution in the visualization is advent of Mimic Display System (Fig-6). This is pictorial representation of subsystem behaviour. In realtime it mimics the actual subsystem schematically which enables to capture the overall subsystem at glimpse.In conventional system to get the overall picture of a subsystem one has to navigate through multiple pages, where as, here it can be captured in single instance. Thus it enables early anomaly detection and correction. It uses different colour codes to depict the various states of the parameters. It can operate in real time and off line mode. This system presents more information compactly in a comprehensive and effective way.

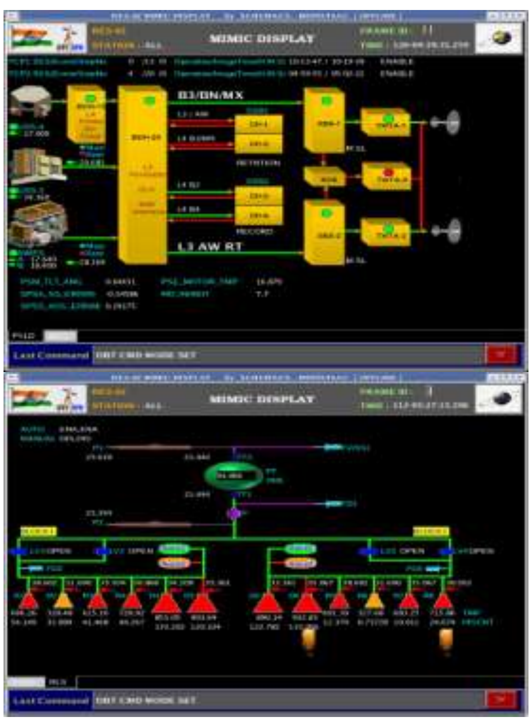

Fig-6 Mimic Display System

Support user for friendly telecommanding : Mission data Processing is also involved in telecommanding for controlling the satellite. Before the satellite contact time, the telecommands to be uploaded are decided according to the satellite mission schedule and listed in command plan. Using the list in the command plan, the actual telecommand to be transmitted are generated. The generated telecommands are packetized and transmitted to the satellite. After the transmission, the telecommand execution has to be verified by checking the telemetry value change. In IRS (Indian Remote Sensing) kind of satellites telecommands are divided into three categories depending upon the nature of the operation Real-Time Commands, Non Real-Time Commands, and Special Commands.

Real-Time Commands: The verification of the real-time telecommand can be accomplished in two phases. First phase checks the error free transmission of telecommand to the satellite by checking the telecommand frame acceptance. It only checks that the transmitted telecommand frame is received by the satellite and does not guarantee the its proper execution. Second phase check if the received telecommand is the same one transmitted from the ground control centre, by looking at the related value change in telemetry.

Special Commands: These commands are for the special operations, and the related telemetry value change has to be checked to verify its proper registration on-board. The on-board control software for performing the special operations mainly uses these commands. After verification, a pilot command is uplinked for the execution of these remote commands.

Non Real-Time Commands: It is stored in the buffer of the satellite after reception. Ground control system can guarantee its transmission by dumping command input buffer of the satellites on-board processor. To verify the telecommand reception only the telecommand frame reception will be used similar to real-time telecommand verification

Archival and Retrieval of Telemetry data for Analysis: The Telemetry data that is acquired during realtime has to be organized and stored in particular order for later analysis. User needs this data for performance analysis of certain subsystem during specific event of time. Once archived the data is extracted, processed and presented on user request.

In case of GEO the incremental archival takes place as continuous telemetry is available. The archival software has a capability to operate in real time as well as in offline. It validates the data, frames master frame and archives the data in circular file. It maintains various indexes to retrieve the data.

In case of LEO missions, the telemetry availbility is based on the visibility of satellite to particular supported station as it is restricted to station visibility. Only after the pass is over, the telemetry data is transferred from ground station to control centre. The data is then validated and archived. During non-visibility period the PB data is recorded onboard and played back later. This data have to be appropriately time tagged and archived. Once the data is archived it is retrieved based on the user request, eg. Orbit-wise or time-wise.

Tools For Offline Detailed Analysis : Various tools are provided for the user to analyse the data in offline. Grahical plots, parameter value generator, statistical value generator, offline display system etc are some of the tools.

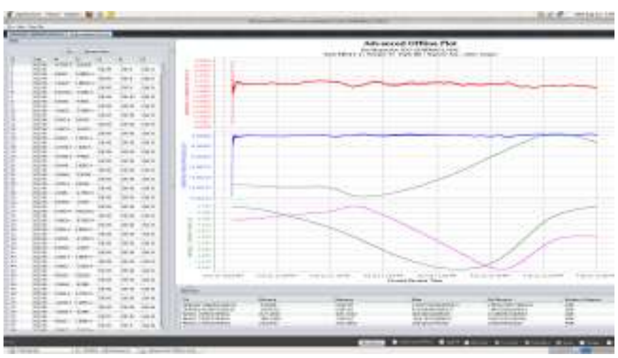

Fig- 7 Plot Generator

Payload Data Pre Processing : IRS series satellites carry various types of payloads such as scientific payload, remote sensing payloads and meteorological payloads. When ever a user wants satellite image over a region, they place request to NDC (NRSC Data Center) by choosing many parameters, viz. Satellite, resolution, Imaging geometry, date range, etc. An automated software called Payload Programming System (PPS) consolidates the inputs from all users and generates a data acquisition plan. This plan is provided to Command Generation software at ISTRAC which generates appropriate commands for acquiring the requested data. The commands are then uplinked to the spacecraft.

The requested payload data is either sent in real time or recorded onboard and sent to ground. In both the cases additional information about the related subsystems, position of satellite at the time of payload operation and orientation of the spacecraft are required for detailed processing. This information is made available through auxiliary data which is attached to payload data. All the requirement specific information are generated by number of programs for data extraction, validation, orbit computation, attitude determination and data formatting. The payload data is archived after pre processing so that it can be readily used whenever requried. In remote sensing satellites, radiometric and geometric corrections are carried out and final products are generated using number of image processing techniques.

Conclusion: This article gives the configuration, design details and salient features of Mission data processing. Mission Data processing plays a major role in Space craft health monitoring, analysis and controlling. Mission Data processing is involved in number of activities. It is evolved through various generations of software development. Health monitoring is carried out in real-time and offline modes. Various Analysis tools aid the users to realize the subsystem performance analysis in different forms and formats. The data visualization is provided on diverse technology base. User can have the complete statistic and performance report sitting on his desktop.

The LEO version of SCHEMACS (Space Craft Health Monitoring, Analysis and Control Software) is deployed at various ground control centres at Bangalore, Lucknow and Bhopal for this purpose.

The GEO version of SCHEMACS is deployed at Hassan and Bhopal ground control centres.

The payload data pre processing is done at all the stations that are configured to receive payload data.

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References:

- "Journey of SCHEMACS- Across computer system" , Paper by Eswar Prakash W.V,Sankar R, Pankaj joshi
- "In- Orbit Tele Command Verification System Of Indian Remote Sensing Satellites" , Paper by Pankaj joshi, Sankar R, Eswar Prakash W.V
- "Mimic Display for Spacecraft Health Monitoring Using Static and Dynamic data", Paper by Padmavathi.HJ, Vanitha E.
- "Web Based Spacecraft Helath Analysis and Operations", Paper by Nitin Bhardwaj, Vignesh Babu M.J
- "Integrated Presentation of Spacecraft Health with Enhanced Navigation", Paper by Sabari Sreekumar.

METEOROLOGICAL DATA RECEPTION SYSTEM FOR INSAT SENSORS

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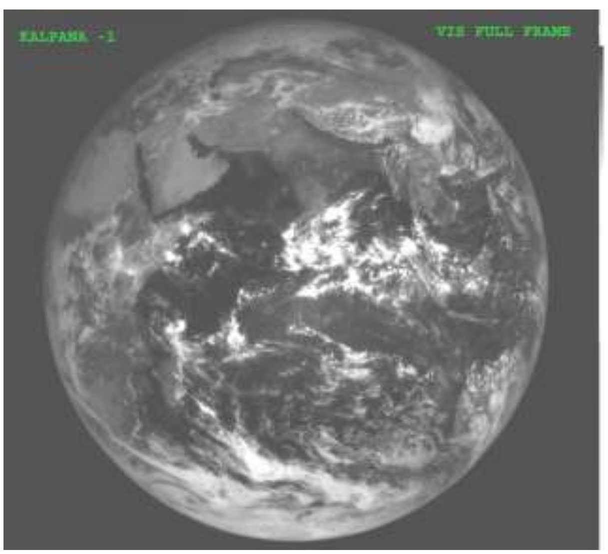
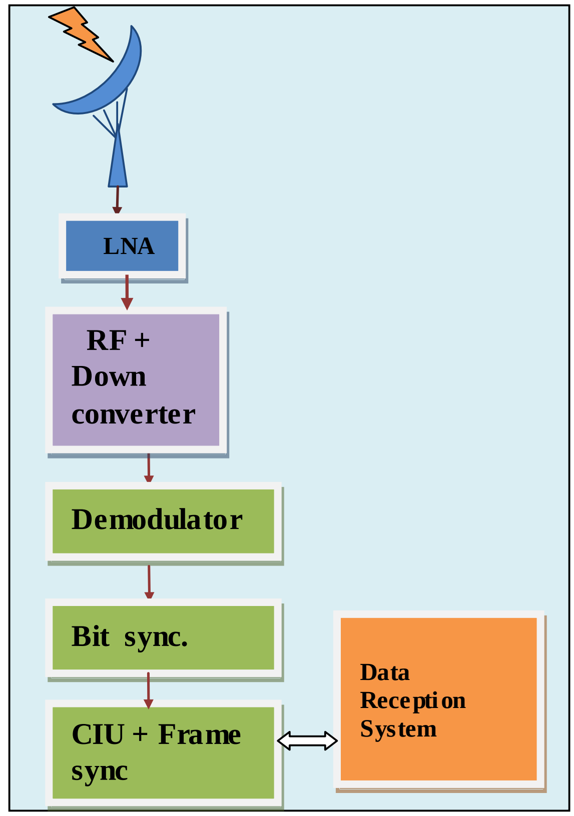
Intorduction: A complete Real-time Data Reception and Processing system is designed and developed to acquire and process all meteorological data transmitted by INSAT series satellites. The system acquires raw data from serial data streams, processes the data and generates various quantitative products from processed data for operational utilization by various users. The DR system receives the data from,

- 6 band IMAGER and 19 IR SOUNDER sensors of INSAT-3D
- 3 band CCD/VHRR sensors of INSAT-3A
- VHRR sensor of KALPANA-1

The methodology of the data acquisition and raw data storage is such that failure of acquisition-link elements does not result in the loss of raw data.





Data Reception Segment: The Data Reception (DR) system is the front-end system for data acquisition and processing chain. Each DR system receives base band serial data stream of one satellite sensor from RF demodulator. Raw data stream from each sensor (IMAGER, SOUNDER, VHRR and CCD) is handled independently.

Configuration / functional units of DR system RF Segment:

The RF segment includes:

- Outdoor Antenna with LNA and suitable steering mechanism and cable assembly along with structure
- Down converters for operation at INSAT satellite frequencies.
- IF segment instrumentation like demodulators and decoders

Base-band Data Reception System (DRS)

This includes:

- Bit Synchronizer Unit.
- Multi Format Frame Synchronizer Unit (Computer Interface Unit, CIU)
- DR Server, each data acquisition interfaces.
- Software for,
  - Data Acquisition, Archival
  - Processed Quick Look Display (QLD)
  - Data Transfer to Data Processing Computer
  - Online Telemetry Display
  - Raw data display
  - Archival Replay.

Description of DR system: Bit Synchronizer Unit receives the base band serial stream from the demodulator and provides the serial NRZ-L data along with synchronized clocks.

The CIU receives the serial base band data with clock from the Bit Synchronizer. It performs the functions of frame synchronization, de-randomization, and formatting the data. The main server controls the configuration and the data acquisition modes of the CIU.

Functions of real time data acquisition, disk archival, image-data transfer to Data Processing, QLD and raw data displays are implemented on the Server. A real time display of some telemetry parameters are also implemented on the same server. The software is implemented such that data ingest along with all applications will be operational simultaneously on the same Server.

Hardware elements of the DR systems like Bit synchronizer Units and Frame Synchronizer Units (CIU) are housed in instrumentation racks with proper signal distribution panels. All base band data-streams from the demodulators (RF section) are brought to these Racks. The DR servers are kept near these racks.

Bit Synchronizer Unit: It receives base band serial data from RF section (from demodulator), and generates TTL serial data along with synchronized 0 deg. and 90 deg. clocks. This output is connected to the CIU unit for frame synchronization and other functions for base band data acquisition. Independent bit synchronizer units are provided for all data streams with one to one redundancy for all chains.

Frame Synchronizer Unit (CIU): Multi format frame synchronization and data formatting functions are implemented as Computer Interface Unit (CIU) for VHRR, CCD, SOUNDER, IMAGER data acquisition into DR Server. CIU is a microprocessor-based unit capable of supporting two independent data streams. Each of the two chains of the unit can be configured for de-commutation of data stream selected for any of the specified sensors through remote commanding from the main server. These units have following features and functions.

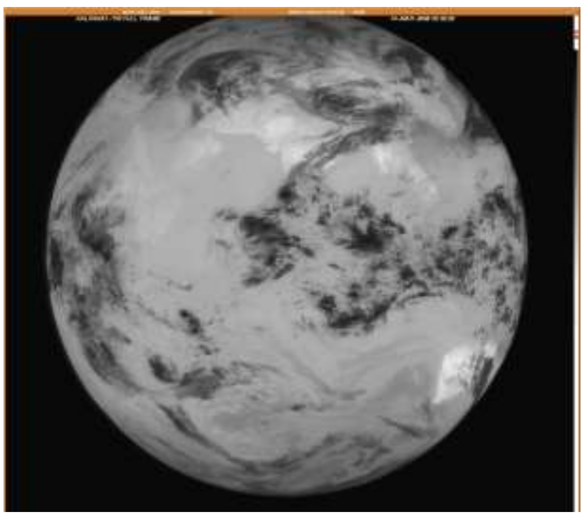
- Frame Sync Detection
- De-randomization of the serial data stream
- Serial to parallel data conversion on pixel word boundary
- Online data format checking
- Remote computer commanded automatic operations
- Computer data acquisition interface.

Computers Systems for Data Reception: The DR systems are configured on a dual CPU server. Each of the servers has capability to acquire and process data in real time from one/two independent base band chains. Each server consists of:

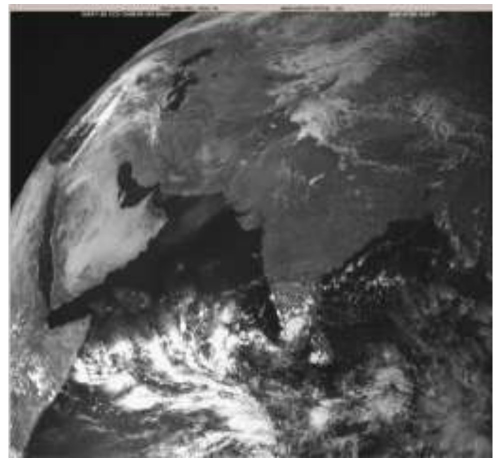
- Dual CPU configuration
- Dual data acquisition interfaces
- Dual system disk with operating system And DR system programs
- Data Archive Disks for each base band Chain
- Physical memory 2-4 GB as per Processing requirements of data stream
- Secondary archive drives LTO
- 21” console along with graphics Capability
- Giga Bit Network ports
- Redundant power supplies.

Additional display workstations to support online QLD are connected to the servers through network.

Processed Quick Look Display (PQLD): PQLD is implemented in all DR systems for all processing chains. For each sensor stream, QLD is displayed in real time in semi-processed mode for each band, e.g. for IMAGER 6 band QLD. The user interface is through GUI, which allows selection of the type of display mode. Displayed images can be enhanced in rushing a set of provided LUTs. The displayed image is automatically saved.. Multiple QLD screens can be activated at the same time with different modes. A typical P-QLD for Kalpana-VHRR for TIR band is shown here.



K1- VHRR, TIR PQLD Image.



INSAT-3A CCD, NIR PQLD Image

Installations: Several such Met. DR systems have been developed qualified, and installed at IMD-IMDPS system, New Delhi, and BES, Bopal, SAC. These are in operational use, since last four years. DR systems were also developed and installed at MCF, Hassan, for INSAT-3A and K1- VHRR, and are in use since 2001.

AWS DATA RECEPTION SYSTEM

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Introduction: The local weather is affected not only by the local atmospheric conditions but by regional and global systems, making forecasting in the tropics more complex and difficult. Weather forecasting in short, medium and seasonal scales require the adequate observational data such as temperature, humidity, atmospheric pressure, wind speed, wind direction, radiation and rainfall over temporal and spatial scales at local, regional and global level. Observational data with appropriate spacing is crucial for running mesoscale and high resolution weather models. Satellites provide data at synoptic scale, the ground based observations are essential for proper definition of the initial field required for the models. In India, considering the emerging requirement of automation in weather observation, Indian Space Research Organization (ISRO) undertook development of Automatic Weather Station (AWS), which could be linked to the satellite for real time data collection. AWS are installed all over the country to take meteorological observations every hour and transmit it to the satellite. INSAT and KALPANA series satellites carry Data Relay Transponders, which receives data from remote platforms and retransmit it to Delhi Earth Station of IMD and Bopal Earth Station(BES). Where these data is received and processed to extract meteorological data in the required format.

Automatic Weather Station (AWS): The indigenous AWS was conceptualized as an integrated system of meteorological sensors, data logger, transmission of data and receiving system. The main components of AWS system consist of *Field measurement unit, Space segment* and *Ground Data reception and processing.* The *field measurement unit* mainly includes sensors, Signal Conditioning Unit, digital system, transmitter and antenna unit.

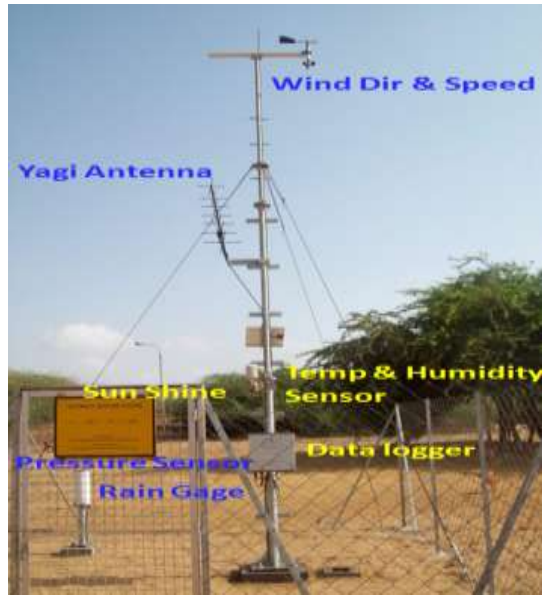

Figure-1 AWS Field Unit

The field unit is housed in a weatherproof housing as illustrated in Figure-1. The *space segment* consists of UHF receiving antenna, down converter, filter, amplifier and transmitting antenna. *Receiving station* consists of antenna (2.4 m), Low noise Block down Converter, L-band down converter, BPSK burst demodulator and Data Reception and Processing System. The indigenous AWS Data Reception System (AWSDRS) is designed and developed to collect data on a continuous 24x7 basis and to provide the automated unattended operations as illustrated in Fig.-2.

AWS DATA RECEPTION SYSTEM (AWSDRS): Automatic Weather Station Data Reception System (AWSDRS) is front end real time data acquisition and processing system designed and developed to cater 4 (Maximum) different carriers.

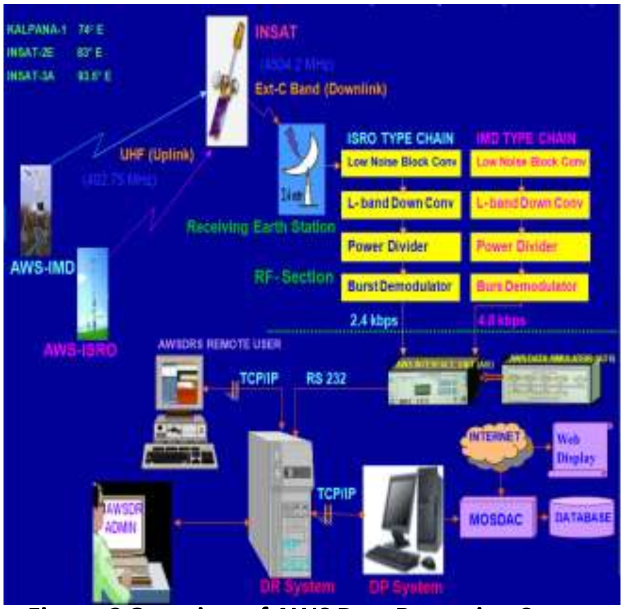

Figure-2 Overview of AWS Data Reception System

The AWSDRS system consists of Hardware element, Computers, Software and their integration. The system provides graphical user interface for AWS data reception in near real-time, retrieval of sensor observations and allows automatic archival of every half an hour data. The AIU receives the signal from demodulators or simulators. Output of AIU is connected to the AWS Data Reception systems through RS-232.

Figure-3 AWS Data Reception System Configuration

Each AWSDR Server acquires AWS data, process and displays it online on the screen. It creates a file of processed AWS data received during a half an hour period as illustrated in Figure-3. Data Processing (DP) system fetches the file from AWSDR Server using FTP for further processing and storage. This system provides the automated unattended operations and is installed at IMD, New Delhi as part of IMDPS project and Bopal Earth Station.

There are two types of data format supported by AWSDRS.

(A) IMD FORMAT AWS DATA: IMD type AWS sends three times the hourly observed meteorological parameters to the satellite in its prescribed 10 minute time slot within the next 60 minutes before the next observation takes place. The IMD type AWS are divided into 6 groups with each AWS group allotted a 10 minute transmission window i.e. 0-10, 10-20, 20-30, 30-40, 40-50 and 50-60 min, starting from full hour U.T.C. There is no transmission during the first minute of the 10 minutes window. The remaining 9 minutes are divided into 3 time slots of 3 minutes each. Every AWS transmits the 422 bits of data in a burst at a data rate of 4.8 kbps, once during allotted each time slot of 3 minutes.

(B) ISRO FORMAT AWS DATA: This type uses Time Division Multiplexing Access (TDMA) mode of transmission of data to the INSAT/KALPANA. ISRO type AWS is tuned to transmit the same observation data twice at a pre-decided time slot (of a fixed second) within the hour to ensure redundancy in reception of data. The TDMA scheme helps in avoiding data loss due to simultaneous transmission by AWS. Towards time keeping with accuracy of milliseconds, a GPS is integrated to the AWS, which corrects the local clock of the station everyday. Each AWS transmits data packet in the allocated 1-second time slot. AWS interface unit receive 4 synchronous input channels simultaneously and it provides output on single channel in asynchronous format and supports both existing IMD transmission format as well as ISRO AWS transmission format.

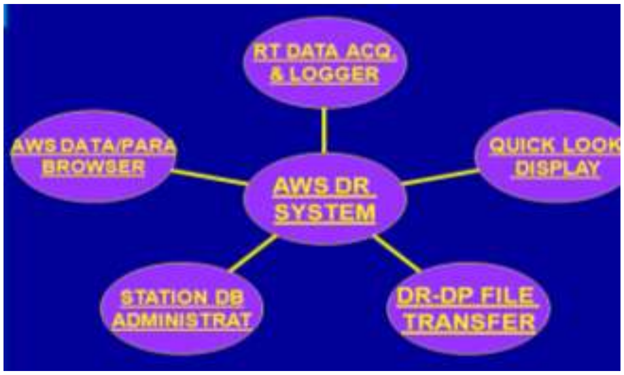

Figure-4 AWS Data Reception Software Configuration

Real time AWS data acquisition, processing and displaying on the screen are implemented on the HP Alpha server (DS-25). Software is developed using FORTRAN, C, PHP and X-Windows programming. Secure Web Application (SWA) software is developed on **O**pen**V**MS operating system with **A**pache – Web server, **M**ySQL–Database server and **P**HP – Scripting language (OVAMP). It displays engineering values for received AWS packet in real time. These outputs are available online on main computer monitor or at networked personal computers. AWSDRS (see Figure-4) consists of following software components

AWS Data Acquisition and Processing Software suite: AWS data acquisition and processing software suite provides near real time continuous data acquisition in HP Alpha (DS-25) server without manual intervention. It runs continuously on server throughout the project life on 24x7 basis. Module is designed and developed to acquire continuous asynchronous AWS data in real-time mode from AIU via serial RS-232C port without missing any single bit. AWD data packets for each station are of size of 35 bytes, for each data packet data acquisition module separate IMD and ISRO type of AWS station and also check for Start of transmission (SOT), End of transmission (EOT) ,Station ID, Sensor ID, parity, Range, GMT and CRC errors. The verified and validated AWS data packet is further converted from digital count in to engineering units (meteorological parameters) as per the specific conversion equations. Data archival is implemented as a formatted file on disk. Each archive file is written for 30 minutes of AWS data, additionally Online processed AWS data packets are continuously written into the MySQL database table in a predefined format. Formatted half hourly files are transferred to Data Processing System in a pre defined format.

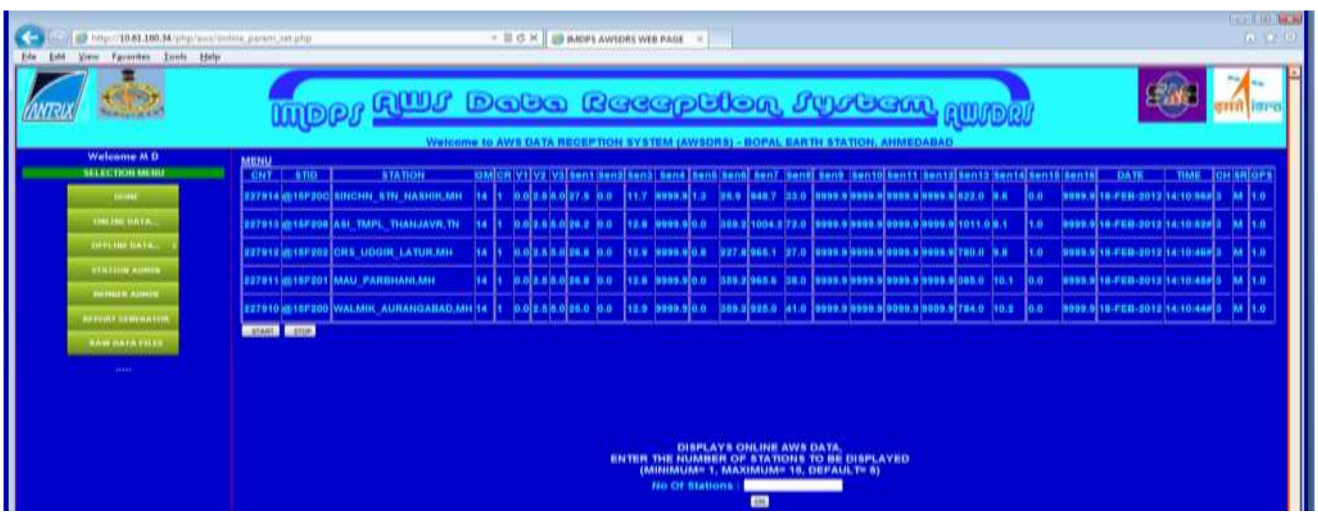

Figure-5 On-line AWS Data Display (Web based) screen

Secure Web based Application (SWA) for online & offline AWS Data monitor suite: This software is developed using Apache – Web server, **M**ySQL – Database server, **P**HP – Scripting language and HTML. Suite supports online, offline data display module and report generation module. This software can be accessed across the network using any standard browser. Online data display module is capable of displaying last fifteen processed AWS station data packet as illustrated in Figure-5. Display is updated and scrolled online automatically for each AWS data received. Offline data display (browser) module provides facility of retrieval of AWS station data from Mysql database using selection criteria based on Sensor ID, date and time, sensor parameters etc. Report generation module generates different reports like no of station received, new station received, station with parity errors, CRC errors etc. These reports can be generated at every half hour.

Station Id & User Administrator suite: Administrator software suite provides the facility to add/ modify /delete / block the particular Station ID. This suite is developed for controlling the ongoing processing of the AWS data and provides administration function for Station ID and AWS user registration. Station Data base manager module is capable of registering new station by administrators, changing parameters for existing station and blocking the processing of irritating station. User Administrator suite enables registration by a new user and facility for user authentication, modification and removal by User Administrator.

AWSDRS software is developed as per ISRO Software Process Doc. (ISPD) guidelines in compliance to IEEE12207 standards.

Conclusion: At present AWSDRS is installed as a constituent of INSAT-3D Meteorological Data Reception System (IMDPS) project at Delhi Earth Station of Indian Meteorological Department (IMD) and also as Meteorological and Oceanographic Satellite Data Archival Centre (MOSDAC) at Bopal Earth Station of Ahmedabad. It provides near real time data on a continuous basis with weather parameter statistics on hourly, daily and monthly basis to the scientific users in table or graph form. These systems acquire/ process/ archive and disseminate Meteorological and Oceanographic satellite data products through web services (www.mosdac.gov.in and www.imd.gov.in). The acquired data provides information and alerts with its effective use to improve weather forecasting models, disaster preparedness and minimize damages caused by disasters.

Acknowledgements: We are thankful to Shri Saji A Kuriakose Deputy Director SEDA, Shri R. Ramakrishna Project Director IMDPS, Shri K.N.Mankad Group Director EOSG under whose guidance this work was carried out. We are also thankful to Dr. R Nandkumar for his valuable suggestions. We are also grateful to Shri A. S. Kiran Kumar Director, Space Applications Centre who reviewed the activity and provided valuable technical insights.

Reference:

- Plummer, N., Allsopp, T. and Lopez, J.A. 2003. *Guidelines on climate observations networks and systems.* The WCDMP “Guidelines” series. WCDMP52, WMO/TD No. 1185.
- Street, R.B., Allsopp, D, Durocher, Y. 2007. *Guidelines for managing changes in climate observing programs.* WCDMPNo.62, WMOTD No. 1378. 24pp.
- World Meteorological Organization. 2001. *Guide to climatologically practices.* Commission for Climatology.
- Wright, W. 2008. *Observing the climate – challenges for the 21st century.* In preparation.
- World Meteorological Organization. (1970). Guide to hydro meteorological practices. 2nd Edition, WMO No. 168, Technical paper 82.
- Test and evaluation document for IMDPS-AWSDRS(SAC/MPCED/PCEG/IMDPS-AWSDRS-01)
- Software Design Document for Automatic Weather Station Data Reception System (SAC/SEDA/PCEG/MPCED/IMDPS/AWSDRS/DES-IGN)

HWQLP/NRTP System for Quick Look Browse and Near Real Time

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Introduction : RISAT-1 Synthetic Aperture Radar (SAR), India's first and indigenous C-band active antenna based multi-mode microwave radar sensor in Low Earth Orbit (LEO), has recently completed one year of successful in-orbit operation in space. All its SAR operating modes viz. Stripmap, ScanSAR and Sliding Spotlight, have been successfully invoked and tested during this journey. A multi-mode system like RISAT-1 SAR generates an enormous and varying volume of data, in view of different swath coverages (10-225 kms) and imaging resolutions (1 to 50 meters), which necessitates high performance signal and image processing for final product generation. Onboard Block Adaptive Quantizer (BAQ) based SAR Data compression and Variable data rate Formatting before SAR data transmission further adds to the complexity and computing power requirements of ground data processing chains for RISAT-1 SAR mission. SAR has an unique role to play in mapping and monitoring of large areas affected by natural disasters especially floods, owing to its unique capability to see through clouds as well as all-weather imaging capability. Also, for various civilian and strategic applications, the utility of SAR sensor is primarily governed by its capability to generate radar images of the terrain under observation, in real or near-real time with very fast turnaround times. Considering these user requirements, a Hardware Quick Look SAR Processor (HWQLP) / Near Real Time SAR Processor (NRTP) has been built by MRSA/SAC team, Ahmedabad. It has been installed at 'Integrated Multi-mission Ground segment for Earth Observation Satellites' (IMGEOS) Facility at NRSC, Shadnagar, Hyderabad, which carries out the automated execution of entire ground processing tasks for RISAT-1 mission beginning with SAR Payload programming, data acquisition and SAR signal & image data processing to SAR raw data and data product dissemination with fast turn-around-times.

HWQLP/NRTP System Configuration for RISAT-1 : The real time or near real time RISAT-1 SAR image generation necessitates Block Adaptive Quantiser (BAQ) decoding, two-dimensional radar matched filtering, motion compensation and post detection image processing tasks to be performed on raw data received in real time or during recorder playback mode. A Hardware Quick Look SAR Processor (HWQLP) / Near Real Time SAR Processor (NRTP) system has been built as a constituent of RISAT-1 Ground segment. This HWQLP/NRTP is based on Commercial-Off-The-Shelf (COTS) Digital Signal Processor (DSP) and other hardware plug-in modules on a Compact PCI (cPCI) platform. A Multi-DSP architecture has been configured and suitable algorithm development and optimization activities have been carried out to fulfill the mission goals. Figure-1 gives HWQLP/NRTP system configuration for RISAT-1 ground segment.Table-1 gives the major specifications of HWQLP/NRTP system for RISAT-1 SAR. The major functions performed by it are as follows:

- Dual channel 8-bit I/Q data reception from Front End Hardware (FEH)
- Raw Data Storage/Archival on two JBOD Recorders
- Pre-Processing of Raw SAR data involving Extraction of SAR data from BDH frames, Online Block Adaptive Quantizer (BAQ) decoding and data distribution to DSP Clusters
- Digital Range compression and data distribution to Azimuth DSPs
- Azimuth Compression using DSP Clusters
- Post processing tasks like Slant range to Ground range conversion & Geocoding
- Real time display of processed image on monitor
- Online recording of the image to an appropriate storage device

Table- 1: Major Specifications of RISAT-1 SAR HWQLP/NRTP System

Parameter	RISAT-1 SAR Operating Mode		
	Spotlight Mode	Stripmap Mode	ScanSAR Mode
Range Pulse Compression Ratio	5000	1667-834	417
Resolution (Ground Range x Azimuth)	1m x 1m	(2.4–9.4 m) x 3m-FRS1 (4.9-18.8 m)x 9m-FRS2	(9.8-37.7m)x21m -MRS (9.8-37.7m)x52m- CRS
Hardware Quick Look Processor (HWQLP)			
Input Data	Two Chains of 16-bit (8I + 8Q) LVDS @ 20 MHz each in RT Mode		
Swath Coverage	-	12.5 Kms	25 Kms (One sub-swath in real time)
Product Turn Around Time	-	Real Time	Real Time
Sustained Throughput	-	3 GFLOPS	3 GFLOPS
Near Real Time SAR Processor (NRTP)			
Input Data	Two Chains of 16-bit (8I + 8Q) LVDS @ 1-2 MHz each in PB Mode		
Swath Coverage	Full Swath		
Standard Scene Size	10 Kms x 100 Kms	25 Kms x 25 Kms	113 Kms x 113 Kms 225 Kms x 225 Kms
Product Turn Around Time	90-120 Minutes	3-4 Minutes	12-20 Minutes
Sustained Throughput	4 GFLOPS	4 GFLOPS	3 GFLOPS
HWQLP / NRTP Hardware Configuration			
Host Computer and Housing	Intel Core2 T7400 @ 2.16 GHz SBC – PC cPCI @ 33 MHz, 64-bit, 500 GB or Higher HDD,16 Slot cPCI Chassis		
Multi-Processor DSP	HWQLP/NRTP : 80 TigerSharc (TS201S) DSPs @500 MHz		
Additional Storage for NRTP	RAID or JBOD, 7200 rpm or Higher Capacity : 4 TBytes, Fiber Channel interface External Housing capacity 16 disks		
Display Monitor	21" SVGA / TFT / LCD		
Weight and Power	30 Kgs, 2000 Watts (HWQLP/NRTP) ; 15 Kgs, 500 W (Recorder)		

The various operating modes of HWQLP/NRTP are as follows:

(a) Quick Look Processor (QLP) and Data Archival Mode: QLP mode is exercised during the satellite pass over India. In this mode, RISAT-1 raw SAR data available from the Ground segment Front End Hardware (FEH) is directly received by HWQLP & archived on dedicated JBOD recorder and SAR image generation is accomplished in real time. Additionally, the QLP processed image is transferred immediately to ISTRAC after each pass on operational basis over a dedicated link (2 Mbps). An application installed at ISTRAC decodes and displays images at the Mission Control Centre.

(b) Near Real Time Processor Mode (NRTP): In this mode, the data archived during the satellite pass is played back from the archival system to the NRTP at a slower rate. In this mode, NRTP may utilize the BDH Aux. data available onboard to generate GEOTIFF format SAR images.

(c) Payload Performance Evaluation (PPE) Mode: QLP/NRTP system is also used to monitor the health of the payload and to evaluate the quality of data received at the Shadnagar earth station from the SAR sensor. It is possible to perform payload performance evaluation both online (i.e. during a satellite pass) and offline (i.e. after the satellite pass). In online mode, the QLP performs real time range compression on the received data and displays the processed data along with the auxiliary parameters on a sampled basis. The Offline mode, the recorder data after the pass is downloaded to host and the parameters related to Data Acquisition and Compression Subsystem (DACS), Payload Controller (PLC) of the payload are extracted, evaluated and sent to ISTRAC after converting it in predefined format for each pass on operational basis in an automated way for further analysis. Also, during the Onboard-Calibration (CAL) mode of the sensor, the gain and phase of all 576 TR modules of the active antenna is evaluated after range compression and compared with a pre-stored ground measured reference and TR modules status values is sent to ISTRAC.

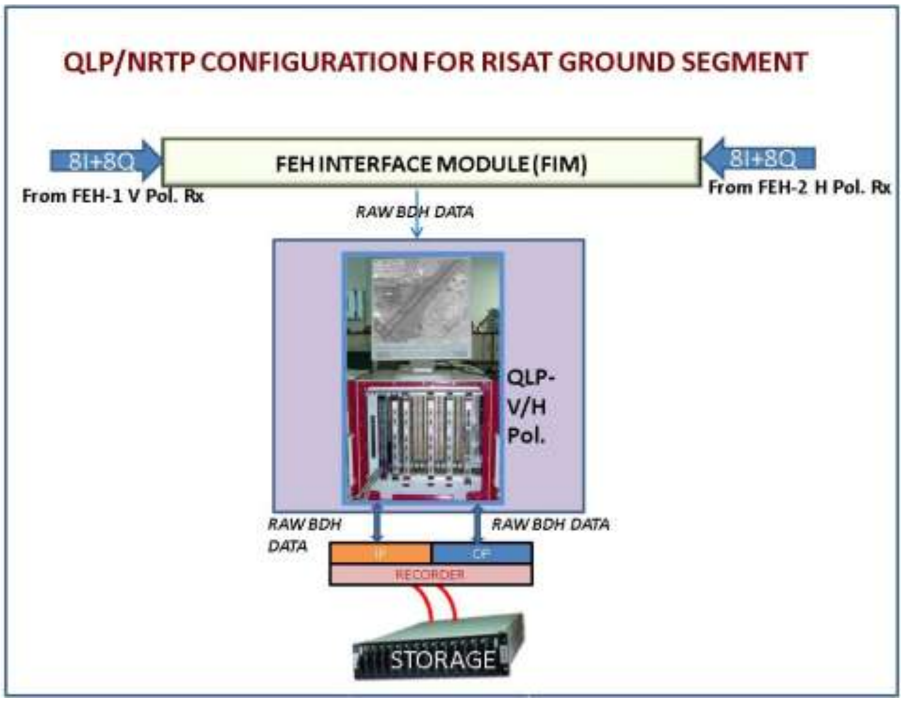

Figure-1: HWQLP/NRTP system configuration for RISAT-1 ground segment

HWQLP/NRTP Data processing & Products: HWQLP/NRTP system is configured around a 16-slot Compact PCI (cPCI) chassis with a host SBC and 80 Analog Devices' TigerSHARC, TS201 processors. Additionally, HWQLP/NRTP has its own archival system consisting of a cPCI recording blade along with a total 4 TByte JBOD/RAID based disk array. HWQLP/NRTP system caters to various RISAT-1 spacecraft data transmission modes namely Real time (RT) transmission mode, Stretch mode and SSR PlayBack (PB) mode. SAR processing algorithm and other software utilities for HWQLP/NRTP have been coded using VC++, Visual DSP++, DSP assembly language. One of the challenging aspects in

HWQLP/NRTP system is the development of real time DSP software for inter-processor communication between processing modules without the use of any centralized Real Time Operating System (RTOS). The HWQLP software is a fully automated system where in, it automatically reads the Pass Schedule file and configures itself for real time data archival and processing.

HWQLP/NRTP can operate in any of the following five SAR processing modes:

- FRS-1 Stripmap Mode
- FRS-2 Quad-Pol mode
- MRS/CRS ScanSAR Mode
- HRS Sliding Spotlight Mode

For FRS-1 stripmap mode, FRS-2 Quad-pol mode and MRS/CRS conventional ScanSAR imaging modes, Deramping/SPECAN algorithm has been employed for real time HWQLP image generation. For near real time SAR image generation in FRS-1 and MRS/CRS modes, frequency domain Range-Doppler algorithm is employed. Individual sub-swaths of MRS/CRS are processed by zero-padding in the burst gaps in azimuth direction and all the bursts are processed at once using a full-aperture matched filter. Therefore, the compression algorithm is similar to that of continuous case and additionally includes Scalloping removal and Range Mosaicing. Spotlight or Sliding Spotlight SAR processing algorithm for near real time high resolution SAR image generation, is a variant of the Range Doppler algorithm with additional processing steps like time domain bulk RCM correction and reverse RCMC.

Figure-2 shows the photograph of HWQLP/NRTP system currently installed and operational at Shadnagar, NRSC. This HWQLP/NRTP can process SAR data from one Pol-chain (H or V) depending on the cable selection. It is also planned to install two such HWQLP/NRTP units to cater to processing of SAR data from both V- & H-Polarization chains simultaneously. Figure-2 also shows RISAT-1 images for different SAR operational modes, which were generated using this HWQLP/NRTP system.

Conclusions : Considering the growing user demand and inevitable necessity of real or near-real time SAR data processing, the design and development of a Hardware Quick Look SAR Processor (HWQLP) / Near Real Time SAR Processor (NRTP) was pursued as one of the mission goals of RISAT-1 Ground segment. HWQLP/NRTP currently installed at Shadnagar, NRSC ground receive station is mainly used for data archival, SAR sensor performance evaluation and Real / Near real time browse product generation. The real time Hardware SAR signal processor's development had been a technologically challenging and very fulfilling experience and it will surely help in our endeavors in configuring real time full swath configurable onboard SAR processors for ISRO's future spaceborne SAR missions.

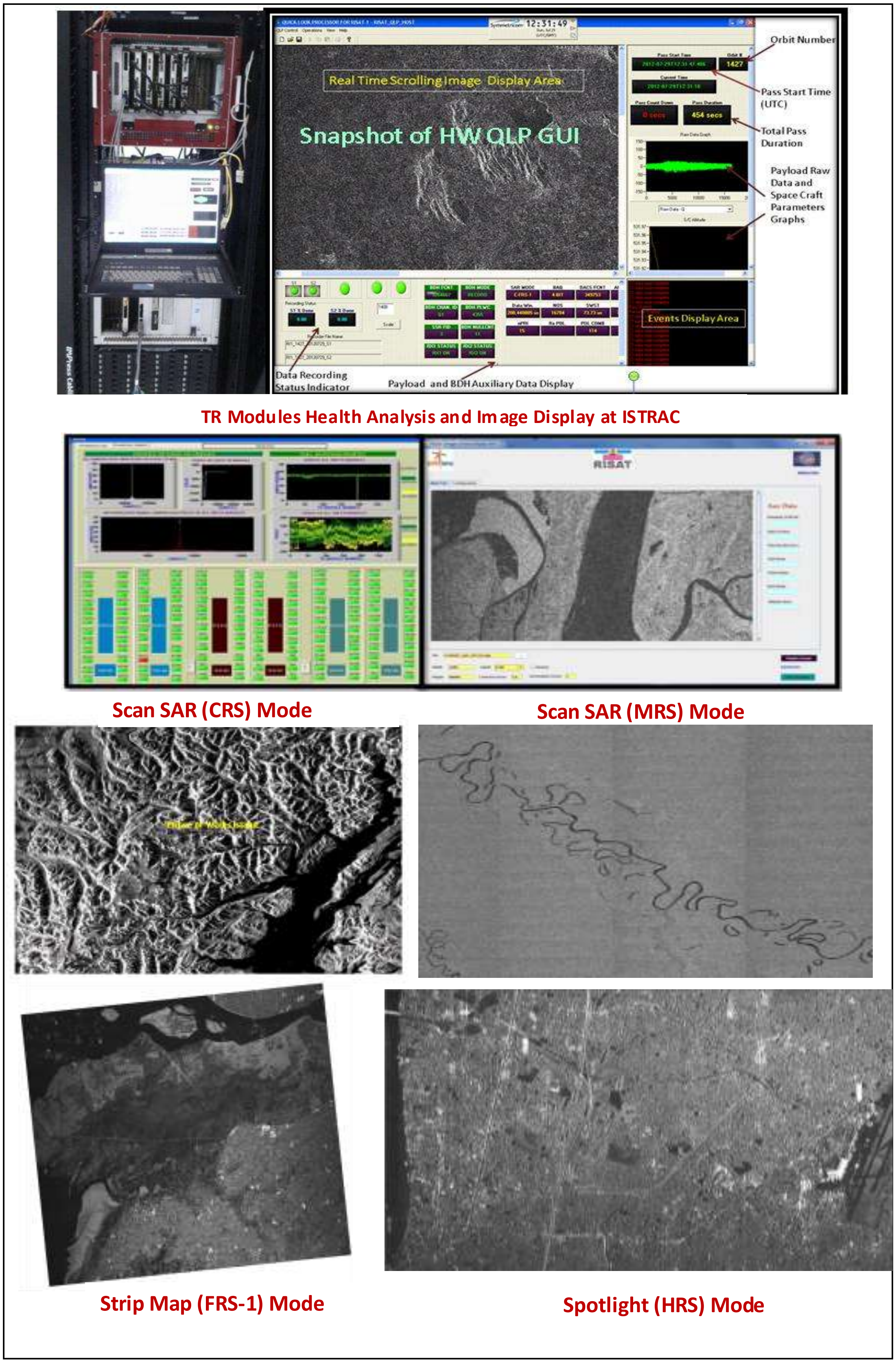

Figure-2: RISAT-1 SAR HWQLP/NRTP and SAR Image Products

EVOLUTION OF IRS DIGITAL DATA PRODUCTS FORMAT

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Abstract : Since launch of IRS (Indian Remote sensing Satellite) 1A to current IRS series Resourcesat-2 there is widespread application of Geographical Information System (GIS) packages worldwide, which needed standardization of remote sensing satellite digital image data products' formats and its contents. During IRS-1A (Launched in March, 1988) we started with LGSOWG (Landsat Ground Station Operators Working Group) digital data products format which was very exhaustive.

Then we moved towards EOSAT Fast Format, GeoTIFF and HDF4/HDF5/HDFEOS. Although currently various data formats like PGM, GIF, BMP, TIFF are in use for storage of raster image data, they have a common limitation in the data that they can store. To overcome this limitation and to store any information into a file in generic way was the requirement. The design of Hierarchical Data Format (HDF) is an attempt to define a generic general purpose scientific data format which can store any data types. We are using HDF5 for our meteorological satellite data products (both basic data products and Geo-physical products). This technical paper gives evolution and brief description of digital data products format for Indian Remote sensing satellites and some common satellite digital data formats.

Introduction : The space borne remotely sensed images in digital form have gained wide popularity over the last decade with the advances in the field of Digital Image Processing, Geographical Information System (GIS) and evolution of computer hardware and software. The data format for multiband image data has been classified into three main categories namely BSQ (Band sequential), BIL (band interleaved by Line) and BIP (Band Interleaved by Pixel). Irrespective of file format the internal layout is in form of BSQ/BIL/BIP.

Table-1: Digital data products format supported

Digital Product Format	Satellite Name	Suitable Processing Level	Remarks
Super Structure (LGSOWG)	IRS-1A,1B,1C,P3, P4,1D,P6, Resourcesat-2, OCEANSAT-1, Cartosat-1/2/2A/2B	Level-1 Level-2	Supports both Radiometrically and geometrically corrected products
EOSAT Fast Format	IRS-1C/1D/P6	Level-2	Radiometrically and Geometrically corrected
GeoTIFF	IRS-1C/1D/P6/Resoucesat2 Cartosat-1/2/2A/2B	Level-2	Most suitable for Geo-referenced products
HDF-EOS	IRS-P6	Level-2	Most suitable for Geo-referenced products
HDF4	OCENSAT-2 OCM	Level-1,2	Suitable for all levels of products
HDF5	IMS-1 Ocensat-2(Scatterometer), Resourcesat-2	Level-1,2	Suitable for all levels of products

The digital data products from IRS series of satellites, which are provided in various formats, are summarized in Table 1.

Super Structure Format (LGSOWG format) [9]

This is a very exhaustive Data Products Format suitable for Level-0(RAW i.e. no correction applied), Level-1(RAD i.e. Radiometric Correction Applied) and Level-2(GEO i.e. Both Radiometric and Geometric correction applied) products. Though all categories of products can be supplied in this format, Level-0 and Level-1 are the most preferred. For detailed understanding of LGSOWG format, the corresponding format document can be referred.

Super Structure Digital Data File Format consists of five files namely, Volume Directory File, Leader File, Image File(either in BSQ or BIL) Format, Trailer File, Null Volume Directory File.

A logical volume is a logical collection of one or more files recorded consecutively. All logical volumes have a volume directory as the first file and null volume directory as the last file. When a logical volume is split between physical volumes the volume directory is repeated at the start of the next physical tape with some updated information.

Fast Format [10] : Fast Format is a comprehensive Digital data Format that is suitable for Level-2 Data Products. It consists of two files namely 1) Header File, 2) Image File(s).

Header File : The first file on each volume, a Read-Me-First file, contains header data. It is in American Standard Code for Information Interchange (ASCII) format.

The Header File contains three 1536-byte ASCII records. The first record is the **Administrative Record** which contains information that identifies the product, the scene and the data specifically needed to read the imagery from the digital media (CDROM, DAT or DISK). In order to retrieve the image data, it is necessary to read entries in the Administrative Record. The second record is the **Radiometric Record**, which contains the coefficients needed to convert the scene digital values into at-satellite spectral radiance. The third record is the **Geometric Record** which contains the scene geographic location (e.g. Latitude, Longitude etc) information. In order to align the imagery to other data sources, it will be necessary to read entries in the Geometric Record.

Image Files : Image files are written into CDROM, DAT or DISK in Band Sequential (BSQ) order i.e. each image file contains one band of image data. There are no headers records within the image file, nor are there prefix and/or suffix data in the individual image record or scan lines.

GeoTIFF and IRS Data Products [3] : Since GeoTIFF has become a de-facto standard among Satellite Image data users, it has been adopted as a format of choice for IRS data products. The geographic data of a GeoTIFF file can be used to position the image in the correct location and geometry on the screen of a geographic information display. The GeoTIFF specification[2] defines a set of TIFF tags provided to describe all "Cartographic" information associated with TIFF imagery that originates from satellite imaging systems, scanned aerial photography, scanned maps, digital elevation models, or as a result of geographic analyses. Its aim is to allow means for tying a raster image to a known model space or map projection.

Basic Features of GeoTIFF : GeoTIFF format fully complies with the TIFF 6.0 specifications, and its extensions do not in any way go against the TIFF recommendations, nor do they limit the scope of raster data supported by TIFF.

It uses a small set of reserved TIFF tags to store a broad range of geo-referencing information, catering to geographic as well as projected coordinate systems needs. Projections include Universal Transverse Mercator (UTM), US State Plane and National Grids, as well as the underlying projection types such as Transverse Mercator, Lambert Conformal Conic, etc.

It uses a "MetaTag" (GeoKey) approach to encode dozens of information elements into just six tags. These keys are designed in a manner parallel to standard TIFF tags, and closely follow the TIFF discipline in their structure and layout. New keys may be defined as needs arise, within the current framework, and without requiring the allocation of new tags from Aldus/Adobe. GeoTIFF format uses numerical codes to describe projection types, coordinate systems, datums, ellipsoids, etc. The projection, datums and ellipsoid codes are derived from the EPSG list compiled by the Petro technical Open Software Corporation (POSC), and mechanisms for adding further international projections, datums and ellipsoids has been established. The GeoTIFF information content is designed to be compatible with the data decomposition approach used by the

National Spatial Data Infrastructure (NSDI) of the U.S. Federal Geographic Data Committee (FGDC).

GIS and GeoTIFF : A large number of commercial GIS and Image processing packages now support GeoTIFF because of its embedded georeferencing information. The major GIS/Image Processing packages those who support GeoTIFF are: ARC/INFO, ERDAS IMAGINE, PCI's EASI/PACE, MAP INFO and Python Imaging Library

HDF5- as IRS Data Products Format : Since HDF5 is a general purpose scientific data format, it has been chosen as one of the Digital Data Products format for future IRS missions. IRS data products are supplemented with a lot of ancillary, ephemeris, attitude, calibration and mission related data along with digital image. These supporting data along with digital image data can be well accommodated in HDF5. The new data types (Point, Grid, Swath) added by HDF-EOS are specifically very useful to store satellite data.

HDF (popular HDF4) : It is a library and multi-object file format for the transfer of graphical and numerical data between machines. It is freely available. The distribution consists of the HDF library, the HDF command line utilities, and a test suite (source code only). It is versatile, self-describing allowing an application to interpret the structure and contents of a file without any outside information. It is flexible. With HDF, you can mix and match related objects together in one file and then access them as a group or as individual objects. It is portable. HDF files can be shared across most common platforms, including many workstations and high performance computers.

HDF5 [7] : HDF5 is a library and file format for storing scientific data. HDF5 is a completely new Hierarchical Data Format product consisting of a data format specification and a supporting library implementation. HDF5 is designed to address some of the limitations of the older HDF product and to address current and anticipated requirements of modern systems and applications. HDF5 includes the following improvements.

- A new file format designed to address some of the deficiencies of HDF4.x, particularly the need to store larger files and more objects per file.
- A simpler, more comprehensive data model that includes only two basic structures: A multidimensional array of record structures and a grouping structure, with better-engineered library and API, with improved support for parallel I/O, threads, and other requirements imposed by modern systems and applications.

Note that HDF and HDF5 are two different products. HDF is a data format first developed in the 1980s and currently in Release 4.*x* (HDF Release 4.*x*). HDF5 is a new data format first released in *Beta* in 1998 and designed to better meet the ever-increasing demands of scientific computing and to take better advantage of the ever-increasing capabilities of computing systems

HDF-EOS [8] : The HDF has been selected by the EOSDIS Project as the format of choice for standard product distribution. To bridge the gap between the needs of EOS data products and the capabilities of HDF, three new EOS specific data types – point, swath, and grid – have been defined within the HDF framework.

The Point interface is designed to support data that has associated Geolocation information, but is not organized in any well-defined spatial or temporal way. The Swath interface is tailored to support time-ordered data such as satellite swaths (which consist of a time-ordered series of scan lines), or profilers (which consist of a time-ordered series of profiles). The Grid interface is designed to support data that has been stored in a rectilinear array based on a well defined and explicitly supported projection.

Other Common Digital Data Formats

- **CEOS Superstructure Format**: The Format Subgroup of the Committee on Earth Observation Satellites (CEOS) established the CEOS Superstructure Format for Earth observation product delivery a number of years ago.
- **Common Data Format (CDF/netCDF)**: The Common Data Format (CDF) is developed and maintained by NASA. A variation of the format that was designed for transfer across networks was developed by Unidata and called Network Common Data Format (netCDF).

- **FITS (Flexible Image Transport System**) is a data format designed to provide a means for convenient exchange of astronomical data between installations whose standard internal formats and hardware differ. The format is unlikely to be used significantly for EO data.
- **Spatial Data Transfer Standard (SDTS):** General Spatial Data Transfer Standard (SDTS) is a method for transferring spatial data, such as geographic and cartographic features, between heterogeneous computer systems.

Stereo Image File Formats

- MPO: The Multi Picture Object (.mpo) format consists of multiple JPEG images (Camera & Imaging Products Association) (CIPA).
- PNS: The PNG Stereo (.pns) format consists of a side-by-side image based on PNG (Portable Network Graphics).
- JPS: The JPEG Stereo (.jps) format consists of a side-by-side image format based on JPEG.

Planetary Data System : In 1972 the USA's National Aeronautics and Space Administration (NASA), sent their first mission to explore an outer planet of the solar system, Pioneer 10. A data representation format that would allow long term storage was developed in order to guarantee its usability long after the mission architects had retired. The standard that was adopted is called the Planetary Data System or PDS standard, (pds.jpl.nasa.gov). The PDS standard requires that all metadata files be in an ASCII or 'human-readable' format. This metadata is stored in text files using a simple keyword/value structure separated by new lines known as the Object Description Language (ODL, see the PDS Standards reference, pds.jpl.nasa.gov/documents/sr). This allows for an easy, 'human-readable', structure that does not require special software in order to read and understand the data stored in the PDS dataset. The data itself can be stored either in ASCII or binary formats, such as text tables, JPEG images files, or more complex 3-dimensional QUBE structures (appendix A.23 of PDS Standards reference, pds.jpl.nasa.gov/documents/sr/AppendixA.pdf)

Conclusion : GeoTIFF and HDF5 has become standard digital data products format for IRS series of satellites.

As almost all standard GIS and Image Processing packages support GeoTIFF, it has emerged as a standard image file format for various GIS applications worldwide. The TIFF flexibility to add new Tags and portability has given a lot of scope for GeoTIFF expansion in future. Now major GeoTIFF data providers are Department of Space (DOS) India, Space Imaging, and SPOT. Since major remote sensing data providers in the world today provide data in GeoTIFF format it has high potential user base for GIS applications where spatial data is one of the major input.

Since HDF5 is a general purpose scientific data format with potential to store and disseminate virtually all types of data, it is gaining wide spread popularity among scientific community. HDF-EOS with special data types like Point, Swath and Grid has added advantage in storing Satellite Data. HDF5 and HDF-EOS has been adopted by IRS-P6 (RESOURCESAT), HDF5 for RESOUCESAT-2 as a Digital Data Products Format.

References

[1] TIFF 6.0 Specifications

[2] GeoTIFF Specification (Revision 1.0)

[3] GeoTIFF Format Document for IRS-1C/1D/P6

[4] ftp://mtritter.jpl.nasa.gov/pub/tiff/geotiff/

[5]ftp://ftpmcmc.cr.usgs.gov/release/geotiff/jpl_mirror/

[6] HDF Specifications and Developer's Guide, Version 4.1r4, January 2001.

[7] HDF5 User Documentation, Release 1.4.2, July 2001.

[8] HDF-EOS Interface Based on HDF5, Volume 1,2: March 2001.

[9] IRS-1C/1D/P6 DIGITAL DATA PRODUCTS FORMAT FOR REVISION C FAST FORMAT PRODUCTS, May 2003.

[10] IRS-P6 LGSOWG (Super Structure) DIGITAL DATA PRODUCTS FORMAT, May2003.

EVOLUTION OF METEOROLOGICAL DATA PRODUCTS FORMAT FOR INSAT-3D

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Introduction : The meteorological world is full of information exchange. All kinds of weather messages are continuously created, transmitted and stored all over the globe. These messages have very different contents, manual observations on the land and oceans, upper air soundings, satellite and radar observations, observations from aero planes, drifting buoys, constant level balloons, automatic weather stations etc. All these different observation reports contain different kind of data and traditionally there has been a huge variety of different ways to code them. WMO manual on code [1] describes nearly hundred codes like SATOB, SYNOB, RADAR etc for observational data exchange. As long as only ground observations were transmitted, message size was small and formats were tailored for human interpretation. But with the broadcast of satellite and weather forecast numeric model data, data flow volume has increased and binary formats like BUFR, GRIB have been defined to optimize data transmission and other scientific purposes. Apart from this to account scientific variability of geophysical parameters [2] estimated from meteorological payloads, HDF-5 has became operational data format and it is used extensively.

History : Meteorology means the study of the atmosphere and its phenomena. International community started aligning towards the global meteorological needs by establishing an intergovernmental organization named International Meteorological Organization, IMO in 1873, which later became World Meteorological Organization, WMO, in 1950 specialized agency of the United Nations. Exhibiting scientific advancement for meteorology, first meteorological satellite (Tiros-1) was launched on 1st April 1960 by NASA (see Fig 1).

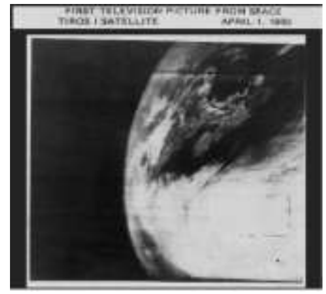

Figure-1

In Indian context 1875 was the important year when Government of India established the India Meteorological Department (IMD), Calcutta being its headquarter, bringing all meteorological work in the country under a central authority. Later headquarter of IMD was shifted to Simla from Calcutta, then to Poona (now Pune) and finally to New Delhi.

The IMD has strong international linkages with and through the World Meteorological Organization (WMO). IMD is a founder member of the International Meteorology Organization (IMO) later, reconstituted as the World Meteorological Organization (WMO). For Satellite Meteorology ISRO is the main companion of IMD. ISRO (set up in 1969) is the primary agency in charge with the responsibility of executing space related research and development programs and schemes in accordance with the directives and policies laid down by the Space Commission and the Department of Space.

Meteorological Satellites from India : INSAT-2E (1999) was first geostationary satellite to put meteorological payload (CCD) into the orbit. Afterwards, KALPANA-1 also known as K1/Metsat, launched in 2002 followed by INSAT-3A in 2003. INSAT-3D, future mission of India, proposed to carry two meteorological payloads named Imager and Sounder designed to cater to the meteorological needs of the country. INSAT-3A/K1 are operational till date, whereas INSAT-3D [3] is planned to be launched in 2013.These satellites work on the principle of measuring the geophysical phenomenon by the sensor mounted on satellite platform. The goal is to produce estimates of geophysical parameters. These geophysical parameters correspond to corrected and calibrated data or retrieved environmental variables and hence needed to be stored for scientific applications, transmitted to be accessed globally and for Nowcasting in suitable format.

Different Meteorological Format : As long as only ground observations were transmitted, message size was small and WMO alpha-numeric formats were tailored for human interpretation. But with the broadcast of satellite and weather forecast numeric model data, data flow volume has increased and binary formats have been defined to optimize data transmission. WMO Binary format like BUFR and GRIB is the answer to that. This binary format gives portability in data transmission and allows to cope up with the scientific variability of meteorological data. HDF-5 has been chosen as general purpose data format. Table -1 shows list of geophysical parameters and their proposed format for different Indian meteorological sensors. Details of these entire formats will be discussed in subsequent section.

HDF5 : HDF5 is a general purpose scientific data format. IRS data products are supplemented with a lot of ancillary, Ephemeris, attitude, calibration and mission related data along with digital image. These supporting data along with digital image data can be well accommodated in HDF5. The new data types (Point, Grid, Swath) added by HDF-EOS are specifically very useful to store satellite data.

KML

KML, Keyhole Markup Language, is a file format used to display geographic data in an Earth browser such as Google Earth, Google Maps, and Google Maps for mobile. KML uses a tag-based structure with nested elements and attributes and is based on the XML standard. All tags are case-sensitive and must appear exactly as they are listed in the KML Reference. The Reference indicates which tags are optional. Within a given element, tags must appear in the order shown in the Reference.

Table-1 Geophysical parameters and proposed formats

S. No	Sensor	Geophysical Parameter	Data Format
1	INSAT-3A CCD	Himala-yan Snow Cover Analysis System (HSCAS)	HDF-5
		Normal-ized Differential Vegetative Index (NDVI)	HDF-5
2	Imager/VHRR	Outgoing Long-Wave Radiation (OLR)	HDF-5
		Quantitative Precipitation Estimate (QPE)	HDF-5
		Hydro-Estimator (H-E)	HDF-5
		Sea surface Temperature (SST)	HDF-5
		Snow Cover	HDF-5
		Fog identification	HDF-5
		Fire, Smoke and Aerosol identifica-Tion	HDF-5/KML
		Atmospheric Motion Vector(AMV)	HDF-5/BUFR
		Water Vapour Wind Vector (WVWV)	HDF-5/BUFR
		Upper Tropospheric Humidity(UTH)	HDF-5
3	Sounder	Geo-potential Height (GH)	HDF-5
		Layer Precipitable Water (LPW)	HDF-5
		Total Precipitable Water (TPW)	HDF-5
		Lifted Index(LI)	HDF-5
		Wind Index(WI)	HDF-5
		Dry Microburst Index (DMI),	HDF-5
		qe-Differential	HDF-5
		Ozone estimate	HDF-5

GRIB format

GRIB (GRIdded Binary) has been primarily designed to broadcast grid generated by numerical weather forecast model, but it is also used for meteorological satellite images [5].

A GRIB message is a sequence of six parts (or sections):

- Start of message (section 0)
- A product definition section which describes content of message (date and time, source, parameter and unit, etc.)
- A grid definition section specifying data geometry (projection, grid size, extension).Although a lot of projections are listed in GRIB tables, latitude–longitude projection seems to be the only one used for forecast model output. To avoid oversampling on poles, grids are often thinned: the number of grid nodes on a parallel is latitude dependent.
- An optional bit map section used to mask missing

or not relevant data

- The data section itself. Various compression algorithms are proposed: the most used relies on integer increments from a minimum value. Number of bits for each value can be freely specified on the beginning of this section.
- End of messages

In the simplest situation (a satellite image without compression) GRIB format is only a header before raw raster data.

BUFR BUFR format (Binary Universal Form of Representation of meteorological data) is in fact a very general fomat which could support any type of data asuming we could get the corresponding tables

A BUFR message is also defined as a sequence of sections:

- Start of message
- A product definition section indicating mainly originating centre, date and time
- A data definition section
- The data as defined by the previous section
- End of message

Other useful WMO formats

SYNOP Report of surface observation from a fixed land station

SHIP Report of surface observation from a sea station

SYNOP MOBIL Report of surface observation from a mobile land station

METAR Aviation routine weather report (with or without trend forecast)

SPECI Aviation selected special weather report (with or without trend forecast)

BUOY Report of a buoy observation

RADOB Report of ground radar weather observation

RADREP Radiological data report (monitored on a routine basis and/or in case of accident)

PILOT Upper-wind report from a fixed land station

PILOT SHIP Upper-wind report from a sea station

PILOT MOBIL Upper-wind report from a mobile land station

References

[1]WMO, ”Manual on codes” International codes VOLUME I.1, 1995 edition, WMO- NO. 306.

[2]INSAT Geophysical Parameter Retrieval System, ATBD document February, 2007 Space Applications Center Indian Space Research Organization, Ahmedbad.

[3]INSAT-3D Meteorological Data Processing System, Design Document, SAC/IMDPS/TN-03/Version-1

Meteorology and Oceanography Information and Data Sharing: MOSDAC

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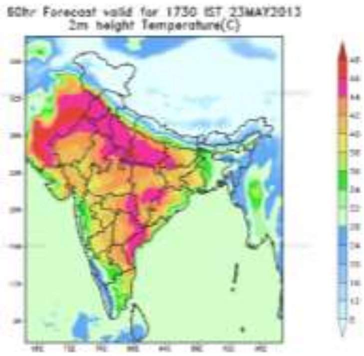
Introduction: Since ages scientists have been studying oceanographic and climate patterns to understand the **vagaries** of nature. Extreme conditions of climate and drastic variations in ocean current systems lead to gross destruction of property and human beings. Continuous studies in ocean and climate sciences have brought the awareness of global warning. This awareness has now led to strategies and policies and plans for combating global warming and thereby save Mother Earth. Conclusive results in these fields of climate and oceanography are possible only when respective parameters are measured from varying platforms, at different scales and in continuous mode. Many models are built around datasets of almost hundred years to interpret and understand climatology and oceanography. Hence, it becomes extremely essential to continuously generate and archive oceanographic and climate related data.

MOSDAC Objectives: Meteorological and Oceanographic Satellite Data Archival Center (MOSDAC) has been established in March 2006 at Space Applications Centre – ISRO, Bopal campus, Ahmedabad, to cater to the needs of research community in the country from meteorological and oceanographic fields. The major objective is the application of Space Technology for the benefit of the common man. MOSDAC has been driven by applications of societal interest like cyclogeneis and cyclone track prediction, weather forecasts at 5km grid resolution and providing all meteorological and oceanographic data to the scientific community in near real time. Archived data is also made available to users for studies and research in climatology.

Meteorology and Oceanography related data is acquired at data reception facility established at SAC – Bopal campus. This data then get archived at archival and dissemination facility established in the same campus. These data products are disseminated to the users through its web based service http://www.mosdac.gov.in and ftp://ftp.mosdac.gov.in. The home page is a store house of a good quantity of weather related information. Actual data sets are made available to only registered users. The registered users are put under various categories. Depending on the policy, the user has access to specific data sets and he/she can put the request. The requested data is made available on an FTP server through individual accounts. For launch campaign users and under special observation periods the data is made available “on-line” i.e. without putting any request, the data is made available on FTP server.

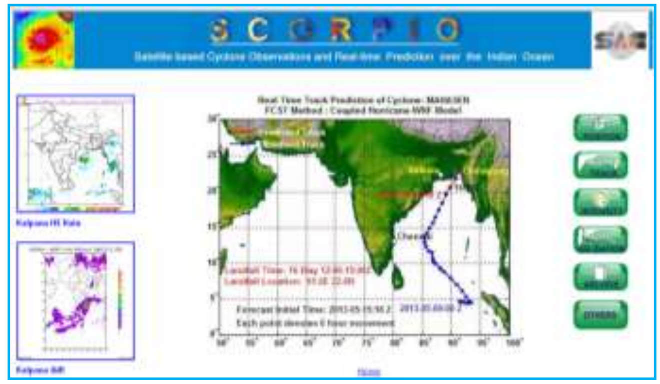
EUMETCAST data is also received at MOSDAC and disseminated over FTP to authorized users. This data is currently being used for simulating INSAT3D data products from FY2 data received from EUMETCAST.

MOSDAC Services: Weather Forecasting Services: Procedures developed using satellite data assimilation and observed data in the Weather Research and Forecast Model have resulted in local area specific forecast in 5Km resolution at 24, 48 and 72 hours. The forecast is disseminated from MOSDAC at major metro and city level as well as locations with high density populations across the country. Several government and public agencies like Govt. of Gujarat, Govt. of Karnataka, Madhya Pradesh Forest Department and so on use these weather forecasts for planning, resource management and disaster management. Typical forecast for Ahmedabad City and country wide synoptic forecast of temperature are depicted below.



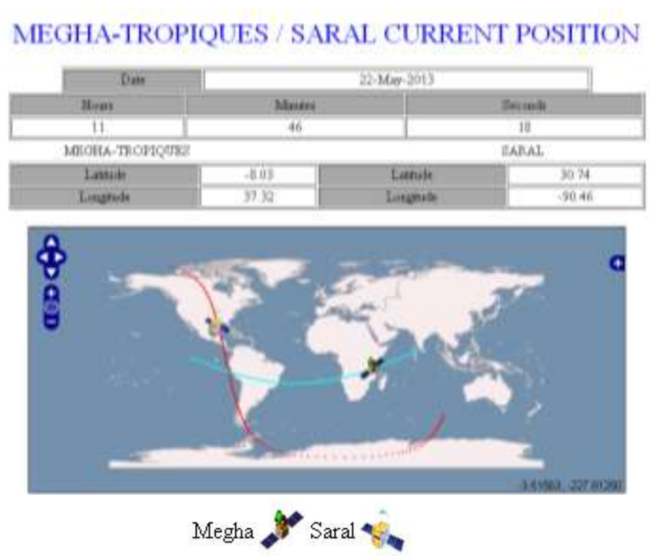
MOSDAC Cyclogenesis and Track prediction Services:

Satellite observations (from Indian satellites Kalpana, Oceansat-2 and Megha-Tropiques) are used effectively for skillful prediction of genesis, movement and landfall of tropical cyclones. Independent techniques have been developed to predict the tracks of these systems. Several key parameters like position, intensity, and structural details of cyclone are monitored by satellite observations throughout the lifetime of the cyclone. These models not only predict the cyclone tracks accurately but also provide detailed spatial distribution of rainfall and winds across the cyclone which is crucial for disaster management exercises.

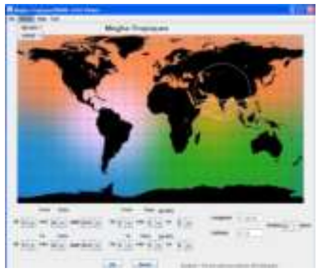


Data Handling Utilities – Free Downloads: In the interest of the scientific community many applications and tools are developed and hosted for free download from MOSDAC web site. The applications deal with handling data from each of the satellite data released and exporting to user convenient formats.

User-friendly Applications: Applications like the current position of both SARAL and Megha-Tropiques Satellites and the Orbit predictor for both the missions are hosted through links on the home page.



The Orbit Predictor application is used to plan CAL/VAL activities and collecting ground measured data synchronous to the satellite pass.



Data Visualization Services: Visualization of full day products of MEGHATROPIQUES SARAL and SCARAB sensors is necessary for first cut analysis and inference from the data. INSAT and KALPANA products are displayed as jpeg images under weather gallery on a daily basis.

Data & Metadata Services:

Metadata: All the products are supported with WMO compliant metadata and a powerful search engine with a multi-filter and multi-combination search mechanism.

Data Products: The data products available at MOSDAC as on May 14, 2013 are tabulated below. Data from each of the missions is released on MOSDAC in near real time. A cooperative agreement has been signed with EUMETSAT for using meteorological data from Meteosat-5 at 63 degree East in exchange for weather pictures collected by INSAT. These data sets are made available for internal consumption through MOSDAC.

OCEANSAT2-SCATTEROMETER PRODUCTS

Short Name	Begin Date	End Date	Items
O2-SCT-HWV	16-05-2010	14-05-2013	6449
O2-SCT-DAILYAWV50	01-01-2012	03-04-2013	457
O2-SCT-AWV50	01-01-2012	13-05-2013	935

MEGHATROPIQUES DATA PRODUCTS

Short Name	Begin Date	End Date	Items
MT1SAPSL1A	20-02-2012	14-05-2013	2427
MT1SAPSL1A2	20-02-2012	14-05-2013	2424
MT1SAPSGPL2A	24-01-2013	14-05-2013	1798

Short Name	Begin Date	End Date	Items
MT1SCASL1A	20-02-2012	14-05-2013	2466
MT1SCASL1A2	20-02-2012	14-05-2013	2456
MT1SCASGPL2A	24-01-2013	14-05-2013	1447

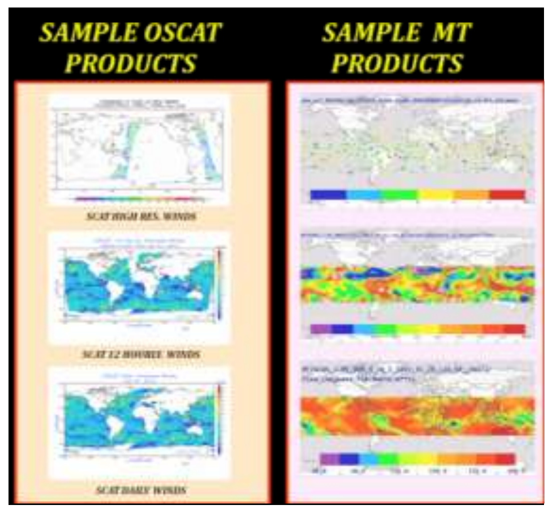
INSAT-3A PRODUCTS

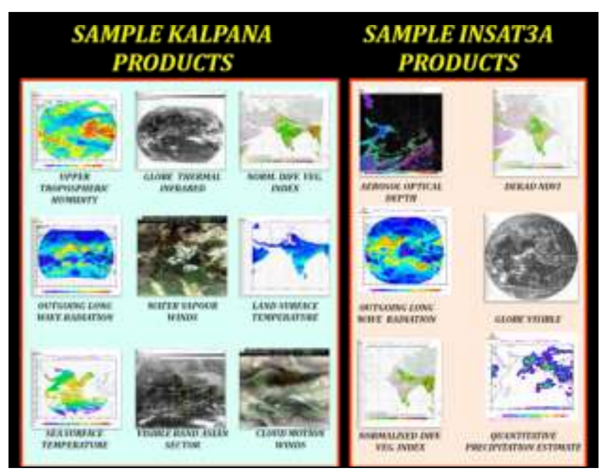
Short Name	Begin Date	End Date	Items
3A-CCD-COMPOSITE-NDV	22-08-2008	10-05-2013	1722
3A-CCD-L1	22-08-2008	14-05-2013	8408
3A-CCD-NDV	22-08-2008	14-05-2013	7062
3A-CCD-AOD	23-04-2010	14-05-2013	3203
3A-CCD-GPS	23-04-2010	14-05-2013	6580
3A-VHR-L1-INDIAN SECTOR	27-05-2009	14-05-2013	17885
3A-VHR-L1	27-05-2009	14-05-2013	18128

KALPANA PRODUCTS

Short Name	Begin Date	End Date	Items
K1-VHR-OLR	06-05-2008	14-05-2013	73796
K1-VHR-WVWV	01-06-2008	06-07-2010	26067
K1-VHR-CMV	01-06-2008	08-09-2010	29517
K1-VHR-DAILYSST	01-06-2008	13-05-2013	1562
K1-VHR-DAILYOLR	01-06-2008	13-05-2013	1587
K1-VHR-L1	01-06-2008	14-05-2013	73884
K1-VHR-UTH	01-06-2008	14-05-2013	73812
K1-VHR-L1-INDIAN SECTOR	01-06-2008	14-05-2013	72542
K1-VHR-DAILYQPE	01-06-2008	14-05-2013	1558
K1-VHR-QPE	01-06-2008	14-05-2013	56244
K1-VHR-SST	01-06-2008	14-05-2013	73466
K1-VHR-AMV	03-11-2009	06-08-2012	8721
K1-VHR-BRT	03-11-2009	14-05-2013	25177
K1-VHR-BTW	03-11-2009	14-05-2013	25132
K1-VHR-CMK	04-05-2010	04-01-2011	13466
K1-VHR-SGP	05-05-2010	14-05-2013	44491
K1-VHR-IMR	19-05-2010	14-05-2013	11148
K1-VHR-SGP-CMV	06-07-2010	14-05-2013	34652
K1-VHR-SGP-WVWV	12-08-2010	06-05-2013	30998
K1-VHR-LST	30-08-2010	14-05-2013	41769
K1-VHR-DAILYINS	17-07-2011	13-05-2013	479
K1-VHR-INS	17-07-2011	14-05-2013	25161
K1-VHR-AMV-VIS	21-02-2013	14-05-2013	2791

Other than satellite based data products MOSDAC also receives in-situ data from data collection platforms like Automatic Weather Stations and Agro Met Stations. There are more than 1100 AWS stations installed across the country and 23 AMS towers installed for primary experiments. The data is received on an hourly basis and disseminated in real time to prime users.





MOSDAC Setup: MOSDAC setup consists of many components such as satellite tracking systems, data reception systems, data processing software and systems, data flow over leased lines and the web server setup for final access of data from the Internet

(Figure_1). The Satellite data reception at MOSDAC is in two different modes. A meteorological data reception system (MDRS) is set up at Bopal Earth Station to track both INSAT3A and Kalpana1 satellites and receive the data from them. The raw data acquired is then subjected to various data processing algorithms for generating standard products as well as geo physical products. Scheduler software is in place to monitor and manage the routine data processing operations. The acquisition of MEGHATROPIQUES data is at ISSDC and SARAL and OSCAT2 is at NRSC. The level0 products are generated at respective locations and the same is fetched over dedicated leased lines. The next level data processing is carried out at MOSDAC. All products are disseminated from MOSDAC with corresponding metadata compliant to WMO standards, thumbnails and image previews to authenticated users. The entire chain from data acquisition / reception to dissemination through MOSDAC is executed in an automated process, established through many interface softwares and scripts.

Figure 1: MOSDAC SETUP

Future: The INSAT3D mission is envisaged to provide an operational, environmental & storm warning system to protect life & property and also to monitor earth's surface and carryout oceanic observations.INSAT –3D has following payloads on-board the spacecraft.

- Meteorological (MET),
- Data Relay Transponder (DRT) and
- Satellite Aided Search & Rescue (SAS&R)

ISRO missions will provide valuable data to the scientific community in the field of Oceanography and Meteorology.

Conclusion: A detailed study of the usage of MOSDAC data and services indicates a good response in the number of registrations (1793 till date) and the average monthly logins which is around 4011. Again the monthly data downloaded by users is around 1177GB. With the INSAT3D in pipeline and the expected release of SARAL data it is expected that the utilization of MOSDAC data and services will grow proportionately.

Acknowledgements: Author thanks the team members who successfully realised the MOSDAC system. I gratefully acknowledge the encouragement provided during the system realization and implementation phases by the SIPA data products team members, AOSG Megha-Tropiques and SARAL team members and SAC management.

NEW SET UP OF HIGH PERFORMANCE COMPUTING (HPC) AT SIPA LAB, SAC BOPAL

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Introduction: Signal and Image Processing Area (SIPA) at SAC has recently executed compute solution offering Image Processing symmetric multiprocessor (SMP) Server System, rack mounted configuration with Intel Xeon E7 enterprise series servers in a single system image for developing software program for optical and microwave sensors data - Satellite Image processing. It can be used as three independent 32-sockets system or different combination of 24X4 / 48x2 as well as all together to work as SMP of single OS image to handle large data size of the raw images and deliver the processed image in near real time or minimum TAT.

HPC: ScaleMP vSMP has emerged as a new solution in virtualization for high-end computing, providing higher performance. The innovative Versatile SMP (vSMP) architecture aggregates multiple x86 systems into a single virtual x86 system, delivering an industry-standard, high-end symmetric multiprocessor computer. vSMP Foundation is a software-only solution that eliminates the need for proprietary hardware components in developing high-end x86 systems, reduces overall end-user system cost and operational expenditures (Fig. 1A &1B). Software interception engine creates uniform execution environment.

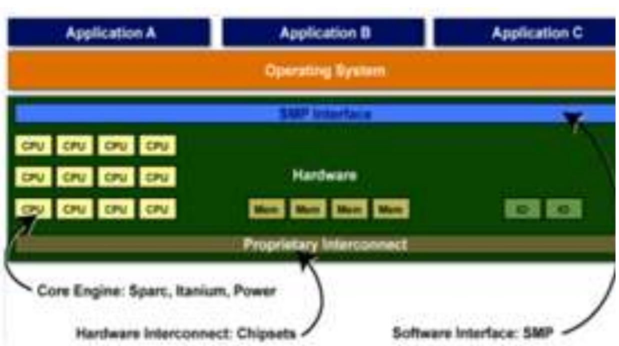

Figure -1A. Traditional H/W based SMP

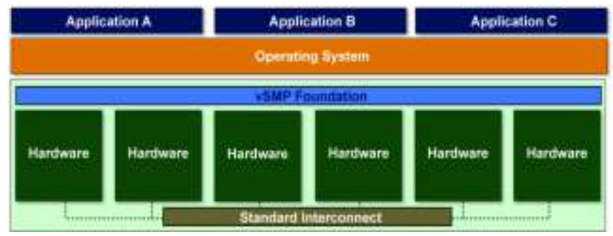

Figure -1B. SMP VSMP software based SMP.

Design Architecture:

- The SMP systems (aggregated 24x Dell R910 nodes) run a Novell SUSE Linux x86_64 distribution (Figure 2).
- It has a total of 576 cores running @ 1.86GHz offering a theoretical peak performance of 4.185 Tera FLOPS. The SMP system has a total of 3,072GB RAM installed.
- It has an internal raw scratch capacity of 115.2 TB for the single large 24-Node SMP and 28.4TB for each smaller 8-Node SMP with10K RPM SAS drives configured in RAID 6. The SMP system has a fully redundant and highly available, active-active memory backplane. Storage size can be configured for scratch and persistence storage for price & performance.
- It has a fully redundant and highly available high speed ultra low latency Infiniband Network backbone with 2 Switches and each Switch with Redundant Power Supply & 2 HCA/node.
- It runs vSMP Foundation software from ScaleMP with the partitioning feature allowing for remote reconfiguration of the system into separate SMP.
- Support components: Torque Scheduler 3.0.6 for 8-Node vSMP, Intel cluster studio, Altair Pbs Pro for 24-Node vSMP are installed for initial exercise

Fig.-2.HPC compute set up at SAC Bopal.

HPC system sub component connection detail (Figure 3 and Figure 4)

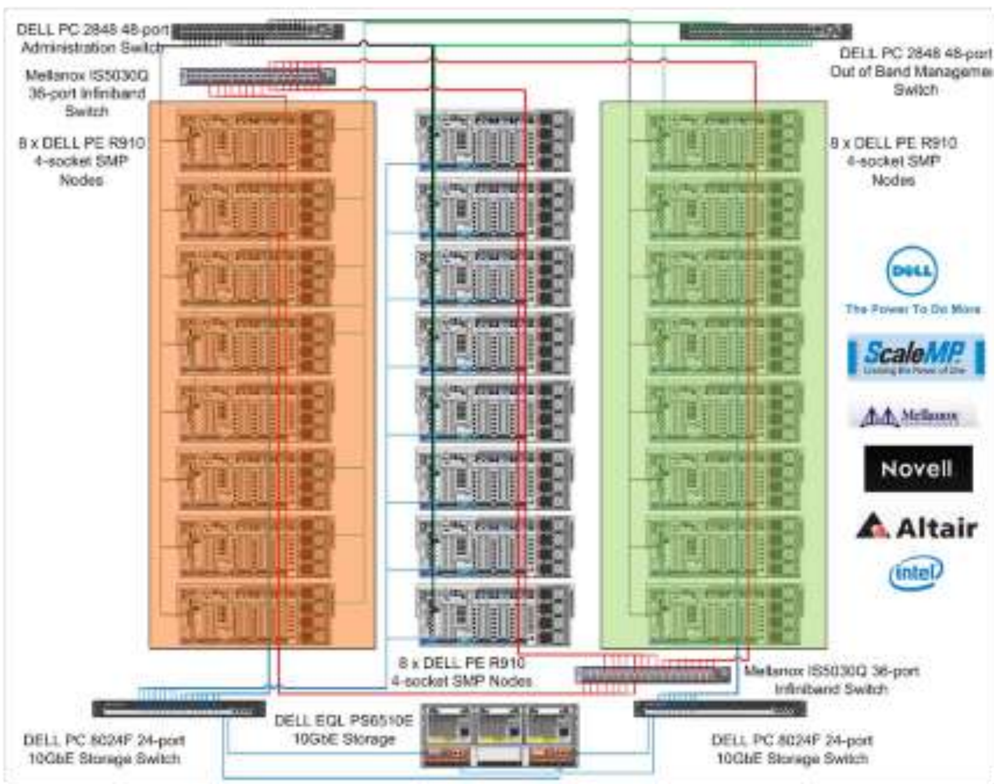

Figure 3

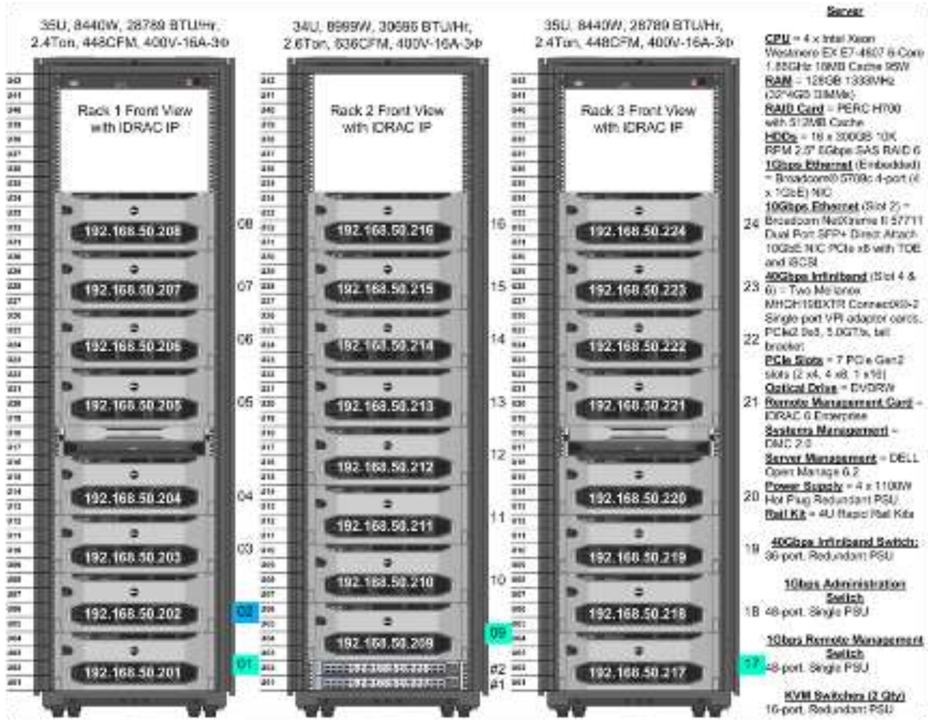

Figure 4 HPC foot print, SMP vSMP Racking Front View with iDRAC IP and HPC Configuration

HPC features:

Open Standards	Open Standards based x86 Processors, Chipsets, High Speed Interconnect, Operating System, Development Tool Kit and Job Scheduler.
Cache Coherency	Architecture maintains cache coherency between the individual Server boards using multiple advanced coherency algorithms. The algorithms operate concurrently on a per-block basis, based on real-time memory activity access patterns, binary code scanning, and other predictive techniques.
I/O Aggregation	Aggregates I/O resources across all Server boards into a unified PCI hierarchy and presents them as a common pool of I/O resources to the OS and the application. The OS is able to utilize all the system storage and networking controllers to provide aggregated high-I/O system performance and capabilities.
Storage Aggregation	Leverages the internal disk expandability to offer high throughput scratch storage space without the need for an external storage array & file system for scratch.

Scalability	Scalable to 512 sockets and 64TB RAM with present available technology. Along with Compute & Memory power, user also gets scalability in high throughput storage
High Availability	Redundant IB Backbone Network, Redundant Hot Swappable Power Supplies, Redundant Hot Swappable Cooling Fans. Redundant Hot Swappable Disks, RAID 6 offering Protection up to 2 Disk failure
Manageability	Easy to Use, Simple to Manage.
Flexibility	Without need for advanced resource management tools & without complex system reconfiguration or setup, Flexibility to run different types of Applications like Multi-Threaded, Multi-process Throughput (no message between processes), Multi-process cooperative (MPI Applications) & Single-threaded large memory applications.

HPC test results:

- With three runs of HPCC benchmark on three 8 nodes virtual machines; ~1 TFlops (Rmax) is achieved in all the virtual machine showing efficiency > 70%.
- In 24 Node virtual machine, with linpack standard & limited use cases RMax of 2.2 TFlops is achieved. Figure 5 & 6 are showing the Teraflops values achieved using various problem sizes and block sizes combinations. In 24 node virtual machine, IOZone is showing a lot more than 2 GBps throughput.

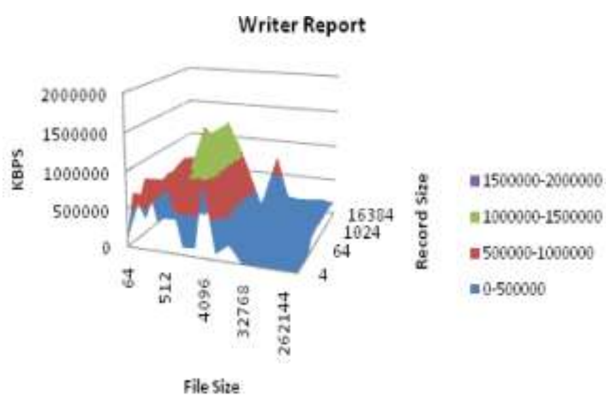

Figure 5 IOZONE Results – 24 Node VM

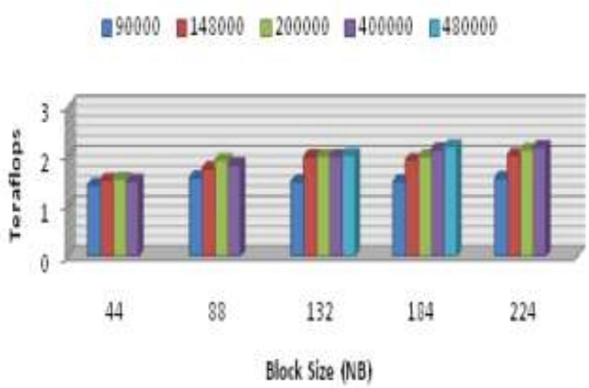

Figure 6 HPL results on 24 Nodes

- Application having three cases were tested on HPC.
  - Execution without any I/O.
  - Execution with I/O on /ramfs.
  - Execution with I/O on RAID drive
- In the application, 16K FFT was used for 32K such records. Apart from this, the application was also containing the complex multiplication for 16K x 32K times. In case of execution without I/O, memory space was filled up using some trigonometric functions. 4 GB data was read using threads for execution with I/O. This total processing was repeated for 16 iterations and the results were noted with varying number of threads on the HPC machine.

- Results were noted for two configuration of the HPC.
  Four VM containing 6 boards of 24 cpu core each.
  One VM containing 24 boards of 24 cpu core each.
  Results for different combination of the above cases are shown in the following tables:
  Case 1: HPC machine configuration with 4 virtual machines containing 6 boards each.
  Case 1.1: Execution without any I/O activity.

S. No.	N Threads	Time (in seconds)
1	16	118
2	32	63
3	64	38
4	128	20

Case 1.2: Execution with I/O activity on /ramfs.

S. No.	N Threads	Time (in seconds)
1	16	60
2	24	42
3	32	34
4	64	20
5	128	14.5
6	144	13.8

Case 1.3: Execution with I/O activity on RAID drive.

S. No.	N Threads	Time (in seconds)
1	16	66.8
2	32	44.6
3	64	42.9

Case 1.4 Execution of applications running simultaneously on different boards with 24 threads.

S. No.	Application State	N Threads x N Boards	Time (in sec.) /board
1	Without I/O	24 x 6	80 seconds
2	With I/O on /ramfs	24 x 6	234
3		24 x 5	160
4	With I/O on RAID DRIVE	24 x 2	91
5		24 x 4	160
6		24 x 5	205
7		24 x 6	250

Case 2: 1 VM HPC configuration with 24 boards. Execution of applications running simultaneously on different boards with 24 threads each. While using the ramfs, it was taken care that the data was kept on respective boards for execution on that board.

S. No.	Application State	N Threads x N Boards	Time (in seconds)/board
1	Without I/O	24 x 24	80 seconds
2	With I/O on /ramfs	24 x 6	70
3		24 x 12	70
4		24 x 23	85
5	With I/O on RAID DRIVE	24 x 6	85
6		24 x 12	108
7		24 x 18	166
8		24 x 23	170

The above results in case of I/O, represents the results only for reading purpose. Writing part of the I/O was tested separately with a single thread. Writing of 4 GB memory was done by executing different applications on different boards simultaneously.

S. No.	N Boards x N Threads	Time (in seconds)
1	6 x 1	7
2	12 x 1	8.7
3	23 x 1	15

Hybrid computing

a. GPGPU: SIPA had test experiment for few basic image processing algorithms with latest NVidia GPGPU S 2070, 1U rack mounted units. It slashes the cost of computing by delivering the same performance of a traditional CPU-based cluster at one-tenth the cost and one-twentieth the power. Tesla S2070 GPU Computing Systems has 448 per GPU CUDA Cores (Total 3584 cores), Dedicated Memory*: 6GB/ GPU (Total 48GB). It Delivers up to 515 Gigaflops of double-precision peak performance in each GPU.Advanced training was also imparted. CUDA actually works from an application's perspective.

b. Intel® Xeon Phi™ Coprocessor: HPC set up has 24 node which can be upgraded with this card for performance improvement as same code can be used.

Conclusion: This article gives the configuration, design details and salient features of state of art technology for High Performance Computing (HPC). The scheduler is required to bifurcate the HPC load and GPU load and also requires CUDA program for GPGPU.

Acknowledgements: Authors thank the ATP team members, SAC CPSPC & CFC committee who successfully realised the HPC system. We gratefully acknowledge the encouragement provided by the management, Shri A S Kirankumar, Director-SAC, Technical guidance by Shri Santanu Chowdhury, DD, SIPA, Dr R R Navalgund - Ex Director SAC and the SIPA scientists / engineers during the system realization and implementation phases.

References:

- ATP Report on High Performance Computing
- SITC of HPC PO No AHRS 2010001239
- http://www.dell.com
- http://www.scalemp.com

SPACE SCIENCE DATA MANAGEMENT TECHNIQUES & DESIGN CONSIDERATIONS

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Introduction: This paper describes the design and techniques for Science data management & design considerations adopted at Indian Space Science Data Center (ISSDC). In the current scenario of advancement of technological trends, there are several data centers available in order to facilitate one or more services to the user community. The services hosted by data centers are very definite to achieve the specific goals. Data center services for the scientific applications are mission critical and time bound. Indian Space Science Data Center (ISSDC) is designed to host wide variety of scientific data with several types of retention policies necessary to meet the ever-growing data storage requirement of all the science missions of ISRO. ISSDC has a multi-layered architecture where each and every layer is scalable, resilient and flexible enough to accommodate requirements of current & future science missions of ISRO where each layer has a specific functionality to deliver mission defined goals. ISSDC is designed to support the data ingestion, data processing, data archival and data dissemination needs of all the science missions of ISRO [1].

ISSDC Data Management Techniques: When one thinks about the science data management requirements and techniques, it will generally open up a wide variety of challenges in organizing the data sets for a limited as well as longer period, qualifying the data sets for various levels of processing and dissemination to different category of people, maintaining the integrity and providing on-demand access. To cater such needs, ISSDC has designed the data management techniques in such a way to make it more flexible and scalable for multi-missions environment.

The following major parameters are considered while designing the science data management techniques -

1. *Data Identification*
2. *Data Storage*
3. *Data Archival*
4. *Data Backup*
5. *Data Processing*
6. *Data Dissemination*
7. *Data Integrity*
8. *Data Security*
9. *Data Migration*

1. Data Identification

To start with science data management techniques, it is a mandate to identify all the types of data sets for inventory control and monitoring. It is recommended to have an estimate of volume of data, the number of files, type of files, the file size histogram, the data traffic flow, compression technology used for all the data assets which has to be stored. These parameters plays major role in gathering the requirements and designing the data management architecture.

2. Data Storage

Data assets have to be carefully handled and to be supplied to all the processing and archiving services within stipulated time. This needs meticulous planning to achieve effective file layout. The design has to identify the file system and file areas as per the performance and data availability requirements for each and every mission. The nomenclature and design of all the storage areas should be in such a way that the users and administrators should be able to identify it uniquely and quickly without degrading the system reliability, accessibility, availability and performance standards.

3. Data Archival

It is one of the key parameters which have to be planned based on the life of the data sets. Generally data sets are fed for archival in two modes –

a. For a limited period
b. For a longer period

It is recommended to perform the data quality checks and qualify all the data sets by executing valid evaluation procedures before it is fed to permanent or longer period archives.

The distinct feature of science data is that it will become further useful and significant as the time evolves. More and more applications/ models/ algorithms will be developed by referring to the multiple sources of science data sets. Long-term-archives (LTA) of the science data sets are stored with the compatible software, libraries, metadata, documents, data definitions, data descriptions and information about usage/compatible systems required to interpret the data at any point of time in future.

The LTAs are also designed in such a way to incorporate all the internationally acceptable archiving standards like PDS, HDF, FITS etc as well as the custom designed archiving formats in order to exchange the data with different sect of users i.e. general public or domain experts.

4. **Data Backup** [6]

Each and every bit of science data is highly valuable for the global scientific user community and it requires efficient planning of data protection mechanisms.

Following several data backup strategies are considered to evolve a very efficient data protection mechanism -

I. *Backup Infrastructure*
   a. *Software Infrastructure*
   b. *Hardware Infrastructure*
II. *Backup objective*
   a. *Recovery Point Objective (RPO)*
   b. *Recovery Time Objective (RTO)*
III. *Design Consideration*
   a. *Identifying the Datasets*
   b. *Understanding the Data Environment*
   c. *Deciding the Backup Window*
   d. *Deciding the Type of Backup*
      i. *Full Backup*
      ii. *Incremental Backup*
      iii. *Differential Backup*
   e. *Deciding Backup DataPath*
   f. *Backup Capacity Planning*
   g. *Backup on Disk or Tape*
   h. *File level or Block Level Backup*
   i. *Verification*
   j. *Backup Security*

To realize the data backup strategy, the administrator has to consider aforementioned parameters which can transform into an effective data backup technique.

5. Data Processing

Different applications and services require different computational and throughput requirements. To meet these requirements for any specific project, the following factors are considered for system configuration–

a. *Number of files and file sizes*
b. *Time to process the ingested files*
c. *Time taken to generate the product*
d. *Multithread/Multicore processor requirement*
e. *System memory requirement*
f. *Total turn-around time requirement*
g. *Graphics/Display requirements*
h. *Platform requirements*
i. *Input/Output throughput for deciding the data path*
j. *Data Product Regeneration*

To meet the computing power requirements & throughput requirements, ISSDC has various classes of servers configured with different combination of processors, memory and interfaces which comprises of xeon & itanium based processors ranging from dual core upto octacores & RAM varying from 4 GB to 32 GB expandable upto 128 GB. As per the aforementioned requirements, ISSDC is flexible to allocate the computing resources to carry out the pre-defined task. Trade-off between the allocation of proper resources and its utilization has been considered at the time of planning & designing. If in case, any new hardware/software needs to be deployed to meet the specific project requirements, the IT infrastructure of ISSDC is scalable enough to adapt such hardware/software components into the ISSDC architecture.

6. Data Dissemination

Final aim of any scientific data - processed & archived is to make it available to the user community. Keeping this into view, a separate data dissemination network has been designed at ISSDC to acts as an interface to external users, principle investigators, guest observers, payload operation center (POC) team, external ground stations for accessing the intended data sets.

The data dissemination network of ISSDC provides the following services -

a. *Policy based Data Dissemination*
b. *Data hosting facility*
c. *Web services*
d. *SFTP/FTP services*
e. *Email Notification facility*

The aforementioned services are being extensively used by a large group of users landing over private or public communication links.

7. Data Integrity

One of the critical parameters to be ensured in science data archives is data integrity. Different mechanisms are adopted to maintain the accuracy and consistency of the data over its life cycle. ISSDC has developed its own custom defined applications to carry out data integrity checks at various levels and reporting mechanisms for finding inconsistencies promptly. This involves usage of various existing algorithms like calculation of md5 checksum as well as custom defined mechanisms like generating metadata information, caching and versioning.

8. Data Security

Data Security has got the paramount importance in data management. ISSDC has different security mechanisms like maintaining multiple copies of data both in disk & tape, vault copy in data safes, file transfer across multiple layers using custom built one-way gateway, which is a combination of hardware and software components, policy based data access, authentication and authorization mechanisms.

9. Data Migration

Due to the fast advancement in the storage technology, it is a very challenging task for the administrator to adapt to the new technologies without affecting the operational systems and services. This has to be looked into at regular intervals to maintain the state of the art infrastructure. Also any hardware system has a life during which it can provide services and it can be maintained by specific agencies. Whenever there is a hardware refresh, the data migration poses a major challenge and the design of entire storage and backup infrastructure plays a vital role in doing the same.

ISSDC Data Management Configuration: Storage is the vital resource of a data center. Planning the storage resources for a data center includes estimation of volume of storage, type of storage, storage access paths, storage performance and scalability [1]. The storage infrastructure has to be configured with redundancy in disk drives, access ports, storage controllers, and storage access paths to the clients [2]. The efficient storage solution should be complemented with an effective backup strategy [2] [4].

The storage infrastructure at ISSDC is realised using different storage architectures for providing various services. Storage access is provided over Storage Area Network (SAN) for core storage infrastructure and Network Attached Storage (NAS) for access storage infrastructure in meeting different storage requirements.

A. ISSDC Core storage architecture

The core storage architecture at ISSDC is based on a Hierarchical Storage Management solution. It consists of three tiers of storage with various disk drive types of different capacities and performance figures. The first tier of storage is configured with multi-ported Fiber Channel drives, second tier with SATA drives and third tier with LTO4 & T10K tapes. The storage solution in ISSDC is configured to ensure zero data loss incorporating redundancy at different levels and automatic backups.

The capacity, performance of these storage tiers are mentioned in Table 1:

TABLE 1: ISSDC Core Storage features

Tier	Storage Type	Specifications	ISSDC Configuration
1	High Performance Storage: Hitachi 9990v with 146 GB and 300 GB FC drives	Disk Drive Slots:1152 Virtual Storage Machine: 32 Cache: 256 GB	Disk Drives:888 Virtual Storage Machine: 1 Cache: 160 GB
		IOPS: 3.5 million I/O per sec Internal Bandwidth: 106 GB/s Scalable upto 247 PB	
2	Medium Performance Storage: SUN 6540 with 500 GB SATA	Disk Drive slots: 448	Disk Drive slots: 310
		IOPS: 0.575 million I/O per sec Cache: 16 GB	
3	Tape Library: StorageTek SL8500 with LTO4 & T10K tapes	Media Slots: 1448. Scalable to 100000. Tape Drive Slots: 64. Scalable to 640. Robotic Arms: 8	Media: 552 Tape Drives: 12 Robotic Arms: 8

The three tiers of storage are configured in a Hierarchical Storage Management (HSM) structure and are connected over SAN. Hierarchical Storage Management (HSM) is a data storage technique which automatically moves data between high cost and low cost storage media [5]. The Tier-II storage systems has been virtualized with the Tier-I storage system so as to get efficient performance and effective management capabilities using both the tiers. The application data is written in Tier-I storage using the high performance storage path over SAN. The Tier-II and Tier-III contains the copy of the Tier-I data taken at different backup intervals.

There is a policy-based data migration across the three tiers of storage. This enables high flexibility in managing the storage infrastructure by maintaining frequently used data in the high performance Tier-I and releasing less frequently accessed data to moderate performance Tiers. The end user application gets the best performance in accessing the storage over SAN even if the total volume of data is distributed across different tiers.

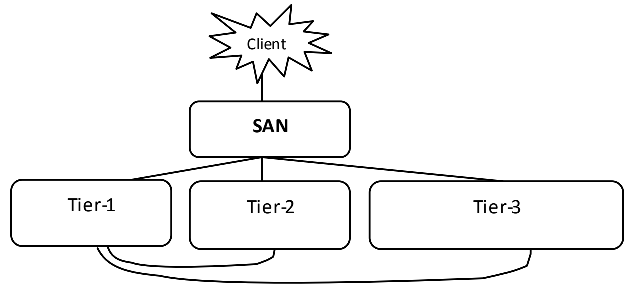

Fig. 1 ISSDC Hierarchical Storage Management

The File systems are served by a cluster of metadata servers which host Storage Archive Manager Quick File System (SAMQFS) services to the data processing servers over SAN. The QFS clients access the metadata from the QFS servers over LAN and access actual data over SAN from the respective storage. The QFS servers also provide NFS service which is available over LAN to all the NFS clients. The SAMQFS servers are responsible for data backup and automated data migration between different tiers of storage as per the policy configured [1].

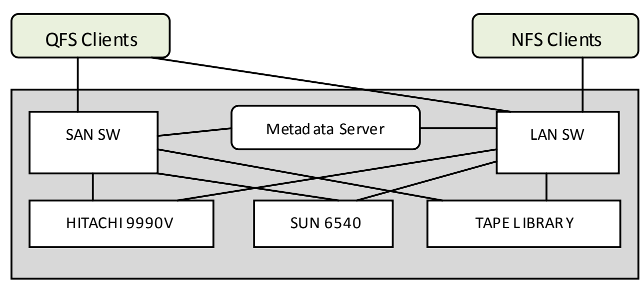

Fig. 2 ISSDC Storage Architecture

It is completely transparent for the end user where from the data is being accessed.

The servers running applications with high input output operations requirement are configured with dual 4 Gbps Host Bus Adapters (HBA) and are connected over SAN for data access.

B. ISSDC Access storage architecture

One of the most important services provided by ISSDC is data dissemination to the scientific community & general public. In order to maintain the sanctity of the archives, an independent NAS storage solution is deployed to provide data access to the end users via

SFTP/FTP, Web through public and private links. The NAS storage controllers are in high available mode with Fiber Channel drives configured in RAID DP.

C. Spacecraft Data Management at ISSDC:

ISSDC has successfully supported Chandrayaan-I & YouthSat in all phases of the mission. Currently, ISSDC is supporting Megha Tropiques, SARAL, AIS-SB payload of RS2 and also ready for supporting Mars Orbiter Mission and Astrosat. ISSDC has hosted the complete Long Term Archival of Chandrayaan-I and selective data sets of Youthsat on web.

Megha Tropiques data management - a case study: The payload data received from ISRO and external ground stations is successfully being ingested in a pre defined format. The payload data ingestion happens in two modes – real-time mode and offline mode. The real-time mode is used for providing quick look display (QLD) facility at ISSDC as well as at MOX (Mission Operation Complex) by multicasting UDP packets. The offline mode is based on store and forward mechanism, where ground station system acquires the payload data into a file and then transfers to ISSDC through FTP services. ISSDC has established an exclusive QLD pipeline for all the payloads. QLD has played a vital role in ensuring the quality of valuable data received in various operational modes and gave initial assessment of the payload data to the principle investigators & mission team.

The data sets received in offline mode by ISSDC are subjected to level-0 processing on high-speed servers with multi-core Xeon processors connected using NIC/HBA interfaces. All the data sets required for level-0 processing are ingested in automatic chain. The computing resources and network configuration of ISSDC have met the L-0 product generation requirements.

Level-1 processing is specific to payloads and ISSDC has provided the environment and resources to carry out Level-1 processing. ISSDC has also supported regeneration of level-0 and level-1 data products in order to produce the more accurate and complete data products.

ISSDC successfully exercised its file transfer and data dissemination service in order to achieve 100% objective. The required data sets generated at internal layers of ISSDC are made available to principle investigators, payload operations centers, and general public through SFTP and Web interfaces.

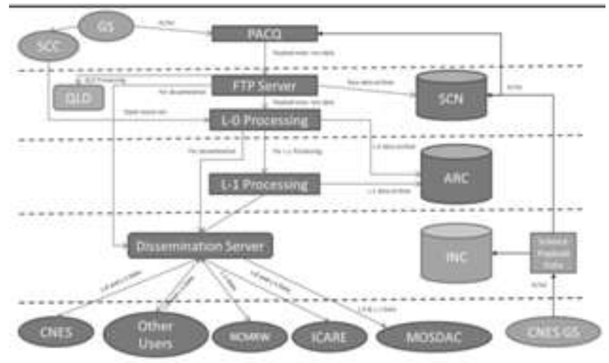

Fig. 3 Data Pipeline

As per the current scenario, ISSDC is receiving approximately 25 GB of Raw data per month and is subjected to level-0 & level-1 processing. Subsequently, 25 GB of Level-0 products and 150 GB of level-1 products are getting generated at ISSDC on monthly basis. In order to fulfill the above requirements for entire mission, ISSDC has planned suitable storage and archival areas with appropriate backup policies in place.

With the experience of Megha Tropiques and CH-1, the data management techniques and design considerations adopted at ISSDC were tested exhaustively and proven that it is scalable to provide multi-mission environment of ISRO.

Conclusion: ISSDC has considered the various techniques and modes to design effective science data management heuristics in order to meet the data ingest, processing, archive and dissemination requirements of all the science missions of ISRO.

Acknowledgements: We thank the ISSDC team members who successfully realised the data center and supported all the missions smoothly. We gratefully acknowledge the guidance provided by the senior management during the data center realization and implementation phases.

References:

1. Indian Space Science Data Center (ISSDC) Architecture for Multimission Support, ID141, Computer Technology for Space 2011.
2. Critical Design Review Document of ISSDC for Chandrayaan-1, ISRO Documentation 2008
3. Ying-Guo Zhu, "Design and Realization of Data Center Based on SAN" IEEE 2010
4. Montri Wiboonrat, "An Empirical Study on Data Center System Failure Diagnosis," IEEE 2008.
5. K. Vaidyanathan S. Narravula P. Balaji D. K. Panda., "Designing Efficient Systems Services and Primitives for Next-Generation Data-Centers", IEEE 2007.
6. Backup Strategy for Mission Critical Data, ID184, Computer Technology for Space 2011.
7. "Indian Space Science Data Centre for planetary and space science missions", B0.9-0007-12, COSPAR-2012.
8. www.Wikipedia.org

DATA PROCESSING TECHNIQUES

OVERVIEW OF DATA PRODUCTS SOFTWARE FOR EOS & PLANETARY MISSIONS

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Introduction: Space Applications Centre is engaged in the design & development of data products (DP) software (S/W) for optical (e.g. CCD/APS based PAN, multi-spectral & hyper-spectral sensors and Optical Radiometers) and microwave sensors (e.g. Synthetic Aperture Radar(SAR), Scatterometer, Radiometer & Radio-Occultation Payload) catering to ISRO missions (Oceansat(OS), Resourcesat(RS), Cartosat(CS), INSAT(IN), RISAT(RI), Megha-Tropiques(MT), Chandrayaan-1(Ch-1), etc.). Level-1 (L-1) products are radiometrically and geometrically calibrated radiances/ brightness-temperature/ sigma-naught parameters and Level-2 (L-2) products are derived geo-physical parameters. DP S/W has been operational at various data centres, e.g. NRSC, ISSDC, MOSDAC, INCOIS, IMD, M-NCCF and several International Ground Stations (IGS) and is maintained professionally throughout mission life cycle. Algorithms for providing improved radiometric and geometric specifications, S/W design paradigms and programming languages, processing architecture, software engineering practices, data products formats, delivery mechanisms, etc have continuously evolved with time in order to meet contemporary user requirements.

Data Processing Algorithms: *Basic Parameters :* Raw Payload data along with ancillary information is acquired in ground stations for a given payload and processed in the data centers to generate calibrated L-1 parameters. Optical Cameras (Hyperspectral, Multi-spectral & PAN sensors) provide radiances, which is a measure of reflected energy in a given state of sun-sensor geometry & atmosphere. Optical & Microwave radiometers provide brightness temperature, which is a measure of apparent temperature at two polarizations at target incident angles for different channel frequencies. The Scatterometer, Altimeter & Synthetic Aperture Radar (SAR) payloads are active microwave payloads and provide sigma-naught parameter, a measure of surface roughness at different transmit-receive polarizations.

Radiometric Correction : Radiometric correction procedures to derive basic parameters are different for different payload types. Photo-response-non-uniformity of detectors is inherent in CCD/APS sensors and individual detectors are characterized in the laboratory to enable estimation of radiances. Optical radiometers (e.g. Imager & Sounder payloads on Insat-3A/3-D & K-1 and SCARAB on Megha-Tropiques) acquire data corresponding to earthview & cold space and generate brightness temperature/radiance parameters using the calibration equation. Microwave radiometers (e.g. MADRAS & SAPHIR on Megha-Tropiques) acquire data corresponding to earthview, cold space and hot load and brightness temperature parameter is computed using calibration & antenna pattern correction algorithms. Signal & Noise counts acquired for a Scatterometer footprint along with antenna pattern gain & range information is processed to obtain slice-level & composite-level sigma-naught parameter using the radar equation. The return waveform from a microwave altimeter is analyzed to obtain corrected range, sigma-naught parameter, significant wave height, etc. Two dimensional processing steps, e.g. range compression, azimuth compression and range-cell migration correction are carried out for SAR image formation. Pseudo-ranges and Carrier Phases measured by the radio occultation payload (e.g. ROSA on Oceansat-2 & MT) are converted to derive excess phase, bending angle and refractivity profiles.

Geometric Corrections : Orbit and attitude information obtained from onboard GPS and Earth/Star/Gyro sensors at sensor-viewing time along with various payload alignment angles & Digital Elevation Models (DEM) are used to derive geometric parameters e.g. latitude, longitude, Incidence angles, Sun Pointing angles, etc. Accurate ortho-products are generated for Cartosat-1 & Resourcesat-1/2 payloads by using reference images, GCPs and DEM. For Resourcsesat-2 Liss4 payload and Hyperspectral payloads on IMS-1 & Ch-1, where bands are not inherently registered, scene-based band to band registration is carried out. For active microwave payloads, Doppler centroid frequency is estimated from data to derive accurate geometric parameters.

Geo-Physical Parameters : L-2 geo-physical parameters are derived from L-1 basic parameters using physical model based or empirical model based retrieval algorithms. Typical geo-physical parameters for INSAT based imagers are Atmospheric Motion Vector Winds, Sea Surface Temperature, Upper Troposphere Humidity, Hydro-Estimator, Quantitative Precipitation Estimates, Outgoing Longwave Radiation, Fire, Smoke, Fog, Snow Cover & Aerosol Optical Depth, whereas Sounder based parameters are temperature, humidity & Ozone profiles. Precipitation, water vapor, cloud liquid water vapour, ocean surface wind speed are derived from MT MADRAS payload, Humidity profile from MT SAPHIR payload and Shortwave/Longwave flux from MT SCARAB payload. The scatterometer payload provides wind vectors over oceans. Radio Occultation payloads provide humidity and temperature profiles over land and oceans.

Derived Products: Various derived and value added products have been generated. CARTODEM & Lunar DEM Software for generating DEM from Cartosat-1 stereo pair & Chandrayaan-1 TMC triplets have been used to generate DEM for Indian landmass and lunar surface. FASALSoft S/W for estimation of crop yield has been operationalized at M-NCFC for crop forecasting using RS-2 AWiFS & Radarsat/Risat-1 SAR data. Software has been developed for generating vegetation index products for the Indian landmass using AWiFS, INSAT CCD & OCM data. Software for generating fused products using multi-spectral RS-1/2 Liss4 data & high resolution Cartosat-2 PAN data as well for RS-1/2 Liss-3/4 & RISAT FRS/MRS data has been developed.

Data Processing Software: DP S/W is developed using ISRO recommended software engineering standards. System Requirements Document, S/W Design Document and Test & Plan documents guide software implementation. DP core software is implemented in object oriented language C++ and GUIs are often implemented in JAVA. In order to improve turnaround time, S/W is installed in multi-CPU multi-core systems and improvement of turnaround time is carried out using process level or thread level parallelization. Schedulers & Job Controllers are designed to handle execution of concurrent jobs (scenes/segments/orbits) and to control the sequencing of multiple processes for a given job. High end work stations are configured along with high performance storage units at the data centers to accomplish data processing in near real time. Products are automatically generated in operational data centers without any operator interface.

Data Dissemination Requirements : INSAT products are required to be made available to users within half an hour of acquisition. Systems are sized so that Scatterometer & MT products reach the modelers at Eumetsat/France within 3 hours of data acquisition.

Data Formats : Resourcesat & Cartosat data products are provided in geotiff, orthokit(with RPC) and HDF format. Data Products for Optical & Microwave Radiometers (IN, MT), Ocean Color Monitor & Scatterometer payloads (OS2) are generated in HDF5 format. INSAT, Scatterometer & MT products are also provided in BUFR format. SAR slant & ground range products are provided in CEOS format whereas geocoded products are provided in CEOS & geotiff format. Data products of RO & Altimeter payloads are provided in netCDF format. CH-1 data products are provided in PDS format.

Data Quality Evaluation (DQE) Software: DQE S/W has been developed and installed at NRSC to provide a quantitative characterization of platform, payload & data products. Geo-location accuracies are estimated for selected scenes using reference images and attitude residuals are indicated. Onboard calibration data is acquired periodically for optical & SAR payloads and analysis reports are generated.

Future Challenges : Data Products Software has to be developed for new payloads in MARS & Chandrayaan-2 missions. Atmospheric corrected data products for optical payloads and climate quality data products for microwave scatterometers & radiometers and radio occultation payloads are to be developed.

Acknowledgements: The authors are thankful to Shri DS Kamat, former Head, Image Processing & Analysis Division, SAC for initiating activities related to data processing & retrievals, Dr. George Joseph, former director, SAC for streamlining radiometric analysis activity, Dr. AKS Gopalan, former Director, SAC for evolving methodologies for radiometric & geometric corrections, Shri AR Dasgupta, former Deputy Director, SIIPA for introducing GIS components and value aided products, Dr. KL Mazumder, former Deputy Director, RESIPA for operationalization of various data products software, Dr. RR Navalgund, former director, SAC for his emphasis on calibration & validation and Dr. PK Srivastava, former Deputy Director, SIPA for providing solutions related to stereo photogrammetry.

OPERATIONAL DATA PRODUCTS SYSTEM FOR IRS & SPECIAL EMPHASIS ON INSAT MDPS - AN OVERVIEW

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Introduction: Indian remote sensing programme started way back in early 1970's, only photographic processing was carried out to analyze the data at that time. Earth observation data as it is acquired from orbiting satellite platforms are affected in terms of brightness and contrast as well as in truly representing the shapes and sizes of objects observed. These are due to the imaging characteristics, as well as the various motions that occur, and the earth undulation, which warrant data processing as a necessary prerequisite before the earth observation data are made into user products by improving the radiometry and geometry and make them ready to use.

Operational Data Products Generation System – IRS: Experiences gained with data from TV cameras placed onboard the Bhaskara satellites, , the first operational data products generation system was realized with the launch of IRS-1A , Quick look, Browse, Standard, Precision and Special products were generated. Data products were generated based on *Path-Row* basis defined as per the satellite ground referencing scheme outlining the ground coverage of the sensor data. The turn-around-time specified for delivery of products in digital form is 3 hours to 3 days at the Shadnagar earth-station. Data products generation systems were configured started with VAX-11/730 and/or 780 based computers with a special purpose FPS array processor for number crunching. Currently faster system with SAN the high throughput of about one thousand data products are generated in an IMGEOS environment in Near Real Time using multi processor, multi threaded applications. High Speed Storage and Data Visualization hardware and software solutions, tools are deployed so as quality data products are produced.

Optical data Products Generation: The first category evolved with the multi-spectral data products generation with data from LISS sensors onboard IRS-1B, IRS-P2, IRS-1C, 1D, ResourceSat-1 and ResourceSat-2 as well as the Indian Mini Satellite IMS-1. The second category evolved with the 8-band OCM sensor data products onboard OceanSat-1 and the OceanSat-2 for ocean applications, with the ready-to-use geo-physical parameter products as standard products and time-integrated binned products. The third category flourished with the PAN sensor data processing onboard IRS-1C and 1D and subsequently with TES, CartoSat-1 and CartoSat-2 series of satellites with better than one meter spatial resolution. Stereo data processing emerged as a result of the tilt capability provided in IRS-1C/1D for the PAN sensor and the operational stereo data acquisition with the two PAN-Fore and PAN-Aft sensors onboard CartoSat-1, 2 satellite. The fourth category of full-globe and sector data products for meteorological applications were operationally generated with the data from VHRR and CCD sensors onboard the geo-synchronous satellites INSAT-2E, Kalpana-1 and INSAT-3A.

RESOURCESAT multi-spectral data processing saw the development in multi-band registration capabilities to a finer level. There has been a gradual shift towards more use of digital products and the turn-around-time saw a reduction to a few hours from the data reception with the archive mode of processing approach adopted. Multi-sensor fused data products merging low resolution multi-spectral products with high-resolution panchromatic products are also generated, involving complex algorithms to precisely register the two data sets and to retain the tonal variations while preserving the high spatial resolution.

Microwave Sensor Data Products Generation: This activity was initiated with data products generation from microwave radiometers such as SAMIR, MSMR and MADRAS onboard the ISRO-CNES Meghatropiques satellite and involves internal instrument calibration, correction for antenna patterns and generation of brightness temperatures. Data for vertical sounding instruments such as SAPHIR onboard Meghatropiques are processed with a similar processing approach as above. Further, the wind vector generation processing from scatterometer data onboard OceanSat-2 involves data compression, sigma-naught estimation and deriving the wind vectors employing an empirical model. Currently, data products are being generated from the synthetic aperture radar (SAR) sensors such as onboard RISAT-1. SAR signal processing involves range and azimuth compressions, range cell migration correction, and intensity detection. Product generation covers the different modes of data acquisition including Strip-map mode, Scan-SAR mode and Alternate-Polaraisation mode.

IRS Data Product System development: Data Products generation System activities start with understanding of payload systems, detector characteristics, attitude, orbit and control systems, and coverage schemes. **Study phase** is followed by identifying and grouping computational elements patterns to evolve architecture for the data products generation systems. In parallel, host of techniques, models and approaches to be used are explored, necessary R&D efforts are initiated. System requirements and **software requirements** are specified in a formal language that design and implementation teams will use throughout the development and maintenance cycle. Many ISRO centres participate and develop sub systems in the realization of the data products generation system, early identification interfaces is necessary for ease solution integration. **Preliminary design** is evolved after numerous ground segment deliberations subjected to an independent and stringent peer review conducted by a team drawn from multiple centres. Lacunae and gaps if any are identified during the preliminary design reviews and communicated to the design teams to rectify, improve and complete the design before it evolves in to **detailed design** and further reviews. Design activities are always accompanied by data simulation and utility developments to complement the software testing activities. Implementation and testing go hand in hand till centre level formal test and evaluation conducted by separate teams constituted by the project. Teams would have achieved package level integration by then, completed unit level and package level **testing by the designers**. **Pre launch simulation** activities assume importance, to iron out interface issues related to data formats, databases, reports and work order information. Pre launch simulation activities are performed by participating centers together, able to mimic many operational scenarios, in terms of telemetry data formats, ephemeris, work order, payload data and work flow data. The entire operation chain could be rehearsed as if the mission is live and operational. Many of the actual scenarios involving real data remain untested till mission starts. However, this preparation helps greatly to test

INSAT Meterological data Processing system : INSAT-3D is a three axis stabilized geo-stationary satellite and has two payloads; 6 channels (VIS, SWIR, TIR1, TIR2, MIR, WV) Imager – optical radiometer for Meteorological applications and 19 channels (LWIR, MWIR, SWIR and VIS) Sounder. Sounder will be used to generate temperature and humidity vertical profile of the atmosphere for weather (Mid & Long Range) forecasting, disaster warnings.

INSAT-3D Data Processing System will cater to the requirements of INSAT-3D Meteorological Data Processing System (**IMDPS**), which includes real time Data Acquisition and Quick Look Processing (DAQLS), near real time Data Processing (DP) and Geo-Physical Parameter Retrieval (PR) of all data transmitted by the Imager and Sounder payloads of INSAT-3D. As a precursor to INSAT-3D, IMDPS is currently processing VHRR and CCD payloads of INSAT-3A and VHRR payload of KALPANA-1 satellites on 24X7 basis. IMDPS also includes the Image Analysis System, Ancillary Data Processing, Data Dissemination, AWS data processing, archival and Retrieval.

IMDPS consists of three major Sub-systems:

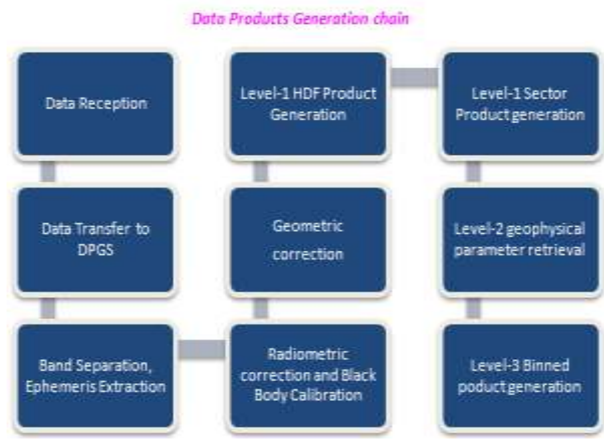
- Data Acquisition &Quick Look System (DR)
- Data Products Generation System (DP)
- Geophysical Parameter Retrieval (PR)

IMDPS software has been indigenously designed, developed, installed and commissioned at IMD, New Delhi with Mirror Site at SAC - BES, Ahmedabad. It is operational 24X7 for INSAT-3A & Kalpana-1. IMDPS will cater to forthcoming INSAT-3D IMAGER and SOUNDER data processing. The data archival and dissemination is through IMD Delhi and SAC - MOSDAC websites.

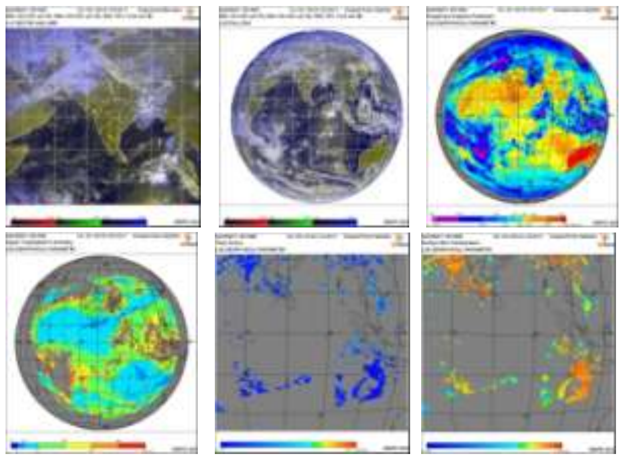
All Hardware (Computer Servers, SAN Storage, customized special Hardware Bit Synchronizer, Computer Interface Unit, serial data simulators) are operational at IMD and SAC

Data Reception (DR): Raw data from de-modulator output of the ground station for IMAGER, SOUNDER data streams is input and performs Hardware and Software pre-processing. Dual data-stream per transmission is available and the differential decoding of the data, where required, is part of the demodulator hardware. Major DR functions are Bit synchronization , Frame synchronization , De-randomization , De-commutation of data-stream into band-separated, bit-parallel-word-serial format , Correction for alternate line-reversal of bi-directionally scanned data, Display of the Satellite Instrument HK data, as required for DR activity, Quick look display, Raw data Archival, Transfer of pre-processed Image File to Data Processing Computers in Near Real Time to Data Products Chain. DR chains have been tested with baseband data simulators and all units are in place at IMD after T&E and QC.

IMAGER **SOUNDER**



Data Products Software: INSAT-3D Processor is designed and developed indigenously based on service oriented architecture to cater multiprocessing. The core Data Processing consists of Algorithms for radiometric correction including Black Body Calibration, geometric correction to generate per pixel geo-location (for navigation) information, Servo correction and Image Motion compensation. The new elements of INSAT-3D are Bi-annual Yaw Flip, IMC/MMC to achieve better navigation accuracy. Geophysical Parameters are generated using standard products as input. Sounder and Imager data simulation activities are carried out. Similarly, Geo-physical parameters retrieval algorithms are tested by using simulated data of both Sounder and Imager. Sample Imager sector, full disk, OLR, UTH products generated shown below.



Sector Full Disk (RGB) OLR
UTH OZONE SKIN SURFACE TEMP

Simulated Imager and Sounder Data Products

The geometric correction, resampling is performed on the radiometric corrected pixel-data based on static and dynamic models of the instrument and satellite as well as orbit and attitude parameters available simultaneously with the imaging data and produces various levels of data products. A further precision/improved accuracy is necessary which requires in registering the image-pixels on fixed lat-long grids would be achieved through image navigation and registration algorithm in an automatic/interactive approach. The Data Products Software provides capability for generation of products on the user requested media and in the required formats HDF and also in the generic binary format.

The various types of products generated by the Data Products System are

- LEVEL - 0 (Raw) – for internal use and archival
- LEVEL - 1 (Full Globe)
- LEVEL - 2 (Sector)
- LEVEL - 3 (Geo-Physical)

Image and Mirror Motion Compensation (IMC/MMC) have been incorporated in INSAT-3D. However the effect of this will be reflected only in the mirror position. This will be available as part of Auxiliary data to Data Products System. The DTM will contain twenty samples of the fast scan mirror positions for every frame. Polynomial fit through these twenty points and this curve will be used to interpolate the fast scan mirror positions at other locations. Similar interpolation will be done to calculate the slow scan mirror positions. Another new element in INSAT-3D is the half yearly yaw flip – the satellite will be rotated by 180 degrees once in six months. The DP software is taken care for the yaw flip.

Geophysical parameter retrieval: Two types of Geophysical parameters are generated from INSAT-3D (see Table-1)

Image based products {e.g. Atmospheric Motion Vector Winds, Outgoing Long wave Radiation (OLR), Upper Troposphere Humidity (UTH), Sea Surface Temperature (SST), Quantitative Precipitation Estimates (QPE), Fire, Smoke, Fog, snow cover and Aerosols}. The algorithms for all products are ready, and the Algorithm Theoretical Basis Definition for these products has been finalized. The above image based products are being generated in Data-Products chain using simulated INSAT-3D radiances based on real-time observations from visible, infrared regions data available from contemporary satellites.

Sounder-based: Algorithms and products (e.g. temperature, humidity profiles, and total ozone) are tested using simulated INSAT-3D sounder radiances based on hyperspectral sounder data sources. Thousands of fine spaced spectral channels that are convolved over the INSAT-3D spectral response function curves to obtain equivalent INSAT-3D sounder radiances. The robustness of this approach has been tested, basic & derived sounder products are generated. A detailed bias-correction procedure is applied to make the simulated radiances consistent with radiances simulated by forward radiative transfer model. The Radiometric calibration as part of data pre-processing is carried out based on the extensive ground calibration data supported by ground and on-board calibration techniques, which tracks changes in the instrument response due to in-orbit thermo-mechanical environment, radiation effects and aging.

Table -1 List of Geo-Physical Parameters

Sr. No.	Sensor	Geo-Physical Parameters
1	INSAT-3A CCD	Snow Cover Analysis
		Normalized Differential Vegetative Index (NDVI)
2	IMAGER/VHRR	Outgoing Long-Wave Radiation (OLR)
		Quantitative Precipitation Estimate (QPE)
		Hydro-Estimator (H-E)
		Sea surface Temperature (SST)
		Snow Cover
		Fog identification
		Tropical Cyclone Position and Intensity Estimation
		Fire, Smoke and Aerosol identification
		Atmospheric Motion Vector(AMV)
		Water Vapor Wind Vector Lifted Index
		Upper Troposphere Humidity(UTH)
3	Sounder	Geo-potential Height (GH)
		Layer Perceptible Water (LPW)
		Total Perceptible Water (TPW)
		Lifted Index(LI)
		Wind Index(WI)
		Dry Microburst Index (DMI),
		θ_e-Differential
		Ozone estimate

Data Dissemination Server: Many Products are planned as part of data dissemination activity

- Transfer of Imager to the web site.
- Conversion of products to GTS format and transmission to Meteorological communications computer.
- Encoding of products and AWS data in WMO format and transmission to Meteorological Communications Computers (MCC).

Database Management System: The Database Management System is using ORACLE 10g as a backend Database server and will contain Metadata of all processed products available on the central store. This database will also contain information about the permanent databases such as GCP and boundary database, Ingested Auxiliary Data i.e. data from GTS and AWS and other information, which are used during the Data Products Generation and by Image Analysis software.

Ancillary Data Processing System (ADPS):The Ancillary Data Ingest system is cater to the requirements of ingesting data from other sources and conversion of the data to the required format for archival of the same at the central data storage. This archived data will then be used by Data Products/Parameter Retrieval system for processing.

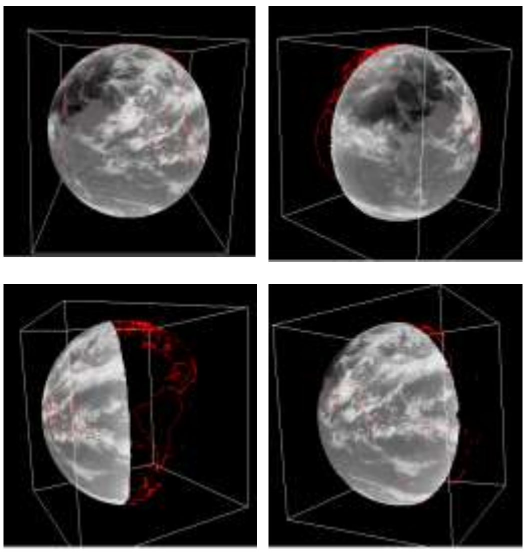
Satellite Imagery Display System (SIDS):SIDS monitors, system are installed at different locations. SIDS has provision of 20 channels including DD News channel. It has the capability of displaying imagery from all INSAT Meteorological payloads with boundary overlays in near real time.

GIS package for INSAT-3D System: This GIS package handles Vector, Raster and TIN data and has access to the data available on the central storage. It will have following capabilities.

- Distance and Area Measurement
- Buffering
- Map Algebra
- Boolean, Polygon Operations, Terrain Analysis

Image analysis & Visualization

The image data received from the satellite is in the form of a sequence of bytes, which is converted to a 2 dimensional matrix for display represented by scan lines and pixels. For earth observation data received form geo-stationary satellites, this 2D data can be projected on the globe to give a feeling as if earth is being viewed from a distance, this form of display is called as globe display. The advantage of such a projection is that the data can be visualized from different view angles as shown below.



INSAT Data visualization

Conclusion: IRS Data Product System is operational at NRSC, ISTRAC, INCOIS, International Ground Stations. The activities started with understanding of On-Board payload systems, attitude, orbit, control systems, and evolved over three decades The Ground Segment is well matured and ready to easily plug and play the necessary software with huge collection of Signal & Image Processing Modules and library to cater to IRS Optical, Microwave and Non-Imaging instrument data Processing to generate high quality and high throughput data products .

As part of IMPDS on 24 x 7 at SAC-Bopal, Ahmedabad and IMD, Delhi, end to end system is realized to acquire, pre-process, post processing and generation of Geo-Physical Data Products from INSAT Data on an operational basis almost in Near Real Time (NRT). The Meteorological Data Products are produced before the next set of Data Acquisition of the Satellite data. The visualization techniques help in better interpretation and analysis of INSAT data products.

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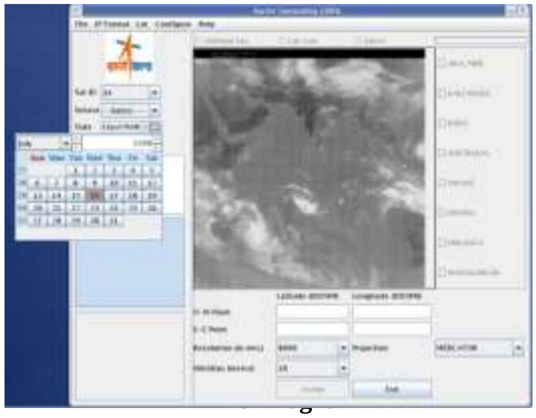
References

[1] INSAT-3D Meteorological Data Processing System Design Document (Data Processing Elements), Doc. No. SAC/ IMDPS/ TN-03/ Version-1 January 2007.

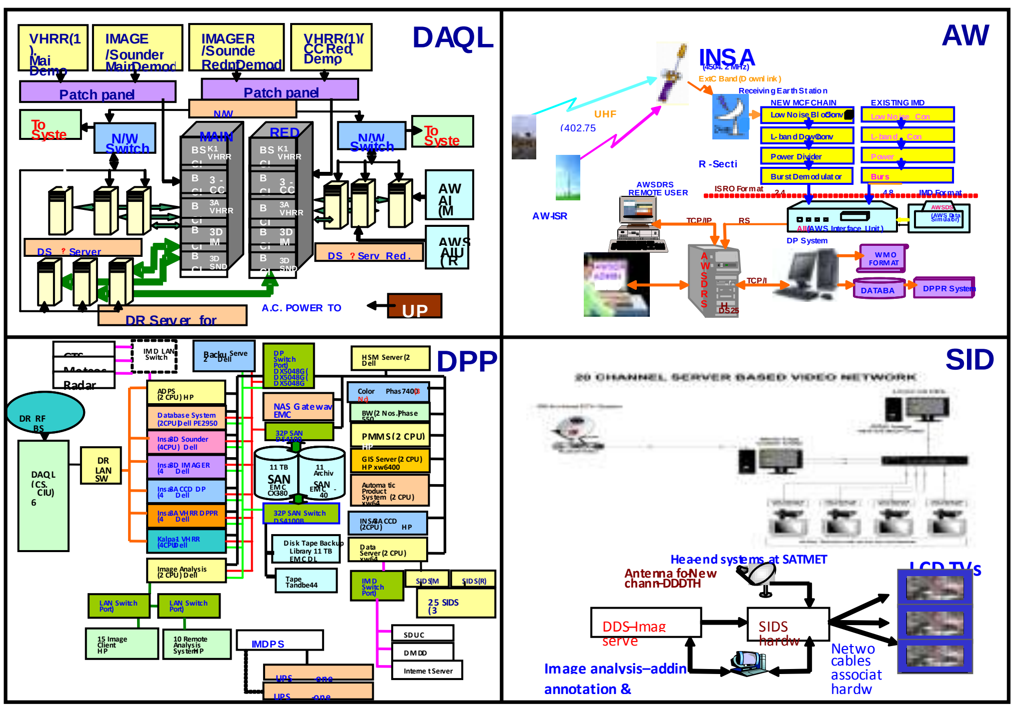
[2] Map Projections - A Working Manual (U.S. Geological Survey Professional Paper 1395) by John P. Snyder

[3] INSAT 3A CCD Data Products generation using an Automated Temporal Image registration SAC/SIPG /RESIPA/DPSD/ TN-22 Dec 2006.

[4] INSAT Geophysical Parameter Retrieval System – Algorithm Theoretical Definition (ATBD), Doc.No. SAC/IMDPS/TN-05/Version-1



Schduler **Sector Gen GUI**



IMDPS System Diagram

PLANETARY DATA PROCESSING - OVERVIEW (Indian Context)

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Introduction: Planetary exploration by satellites started way back in 1957. Since then, globally there are many satellite missions or space probes flown to various planets, comets and asteroids of our solar system and a wealth of data has been collected, processed and analysed/being analysed towards planetary mapping and exploration. The final interpretation of the data will depend on the data processing approach after accounting for appropriate instrument calibration. Earth Observation satellite data processing is being carried out as a routine process for the past four decades in ISRO. This involves understanding of mission characterestics, payloads, ancillary information from satellite, simulations, modeling of imaging geometry, coordinate systems involved, user needs, concepts of signal & image processing and the mission objectives. With the launch of the first planetary mission to moon viz., Chandrayaan-1, first time the concept of planetary data processing is evolved at ISRO. In addition to the above listed items, planetary data processing further involves understanding of the planetary coordinate systems, data archival procedures & standards and approaches of data usage by the global users towards deriving science from the instrument data. The science needs put more emphasis on the calibration of the instruments towards deriving the accurate science results. The planetary data processing gained further importance in Indian context in view of the future planetary missions to be launched by ISRO viz., Mars, Chandrayaan-2 and Aditya.

Steps in Planetary Data Processing: Usually satellite data processing has modeling various processes involved in collecting data and then putting the data in terms of products directly usable by the scientific community globally. Hence, in this first the data products or processing levels are to be defined accordingly; and the processing pipelines are to be developed by the data producers with the help of instrument scientists and Principle Investigators (PI), so that they can then use these data sets for their experiments. The data also needs to be properly archived including some browsing facility towards a long term use. The data processing approach will be different for different kind of instruments. In many cases the data is to be referenced to the surface of the planet (for mapping applications). In some cases, it may be related to the atmospheric neutral particle studies, where referencing may not be important.

Data Products and Processing Levels: The Committee on Data Management, Archiving, and Computing (CODMAC) standards [8] are taken as reference for levels of processing for planetary data products generation. There are other standards viz., NASA and ISRO [8]. The ISRO standards for processing level definitions for Chandrayaan-1 are:

1. Level-0: Raw payload data along with the ancillary information, which includes ephemeris and attitude. This level of processing includes data qualification, (byte alignment, data decompression, band separated, if required) and time tagging. Also the data is given along with the calibration information [CODEMAC 2]
2. Level-1: Calibrated/ corrected and geometrically mapped. (For imaging sensor like TMC or HySI, the processing includes detector response normalization, framing, line/pixel loss correction and tagging the selenographic coordinate to each pixel in addition to band separation for HySI. Each pixel is given in radiances and the conversion parameters to count value is provided) [CODMAC 3]

3. Level-2: Calibration and resampling added over and above the level-1 processing [CODEMAC 4]
4. Level-3: Derived results [CODMAC 5]

Mapping between NASA, ISRO and CODMAC are given in [8].

Basic products: Usually the basic products for planetary data are Level-0 and Level-1, where radiometric and geometric corrections are either taken care (especially for optical payloads) or the total information related to calibration are provided. In the image atlas some of the images of Chandrayaan-1 are given after Level-1 processing [16]. For optical payloads, radiometric calibration is carried out using the prelaunch laboratory calibration coefiicients and these will be fine tuned with the actual data after launch. Most of the payloads need inflight data for post launch calibration on some known targets/signatures. For imaging payloads, to reference each pixel to the surface of the planet one need to construct a precise imaging model. A typical Level-1 data processing pipeline for Chandrayaan-1 TMC/HySI is given in **Figure-1.**

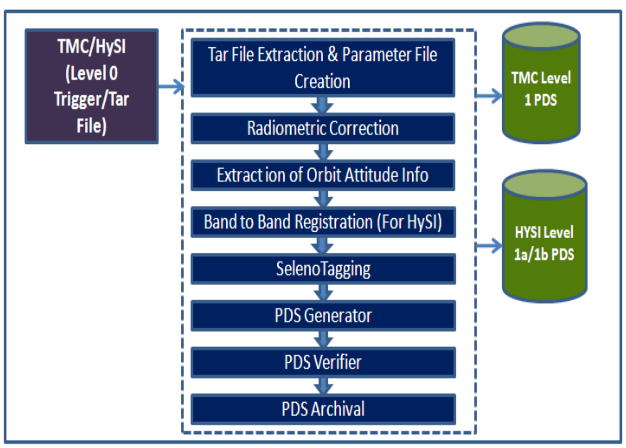

Figure-1: Level-1 Data Processing pipeline for Chandrayaan-1

Depending on the processing requirements of instrument data similar pipelines exist for other payloads also.

Geometric Models: There are two types of modeling approaches used for planetary data processing viz. (i) Rigorous Sensor Model (or physical model called RSM) and (ii) Rational Polynomial Model (RPM). Either of the models is used to reconstruct a very precise relationship between 2D images to 3D planetary surface using orbit and attitude data available as SPICE kernels [2]. The core of the modeling is the establishment of the precise viewing direction or look vector in the presence of distortions arising from camera tilt, spacecraft motion & orientation, planet rotation & curvature in addition to surface relief through series of coordinate transformations specially chosen for Chandrayaan-1 with proper definition and conventions [17]. A reference planetary coordinate system is required for establishing the precise mapping between image and the object on the planetary surface.

Planetary coordinate System: Planetary coordinate systems are defined relative to their mean axis of rotation and various definitions of longitude depending on the body. The longitude systems of most of those bodies with observable rigid surfaces have been defined by references to a surface feature such as a crater. Approximate expressions for these rotational elements with respect to the J2000 inertial coordinate system have been derived. The International Celestial Reference Frame (ICRF) is the reference coordinate frame of epoch2000 which is January 1.5 (JD 2451545.0). The north pole is that pole of rotation that lies on the north side of the invariable plane of the solar system. The direction of the north pole is specified by the value of its right ascension α_0 and declination δ_0 where as the location of the prime meridian is specified by the angle W that is measured along the planet's equator in an easterly direction with respect to the planet's north pole from the node Q (located at righrt ascension 90°+ α_0) of the planet's equator on the standard equator to the point where the prime meridian crosses the planet's equator (see **Figure-2**)

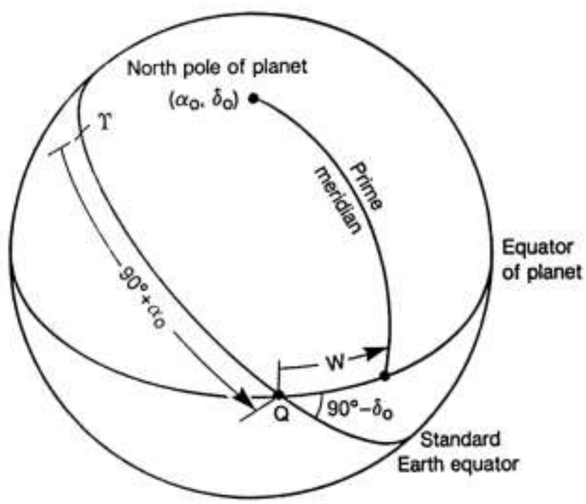

Figure -2: Reference system used to define orientation of the planet [19]

Reference Coordinate System for Moon:

- Mean Earth / Polar Axis Coordinate System (International Aatronomical Unit (IAU) guidelines)
- Longitude should run from 0° to 360°
- Latitude should run from +90° t0 -90°
- Radius of this reference sphere for the Moon is 1737.4 km (spherical datum)

Higher Level Products: Higher level products are the derived products generated from basic products. For Chandrayaan-1 TMC DEM, orthoimages and Lunar ATLAS [9, 10, 11, 12, 13, 17, 20] are the some of the higher level products. Similarly science output from the instrument data derived from Level-1/2 data sets for other instruments are also considered as higher level products. The references used to generate higher level products for TMC and HySI of Chandrayaan-1 are Clementine UVVIS mosaic [4] for planimetry and LOLA DEM [3] for elevation. A sample DEM of a part of moon crater Mare Orientale with color coding is shown in **Figure-3** and Chandrayaan-1 topo orthoimage map is shown in **Figure-4**. Some of the higher level products and science findings of other payloads of chandrayaan-1 viz., C1XS, LLRI, M3, SARA, are given in various references [5, 22, 15, 14].

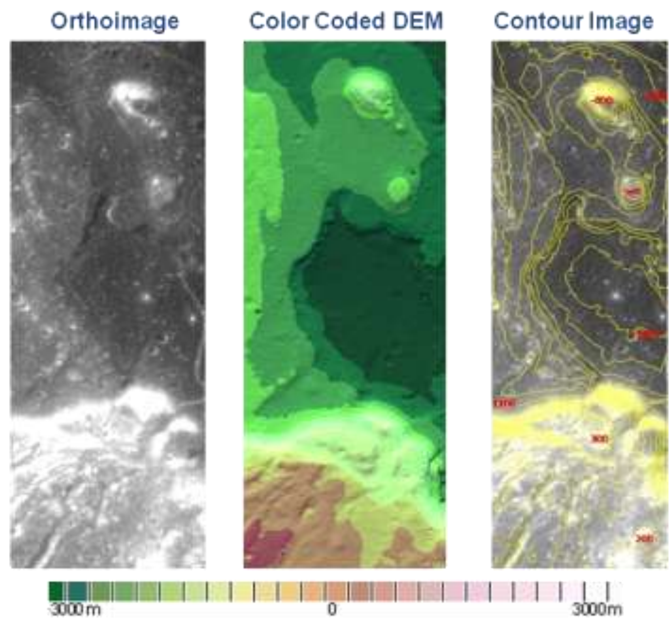

Figure-3: Topography of part of Mare Orientale (Moon crater); Strip width/length: 20 km/60 km

Data Archival Standards: In order to make planetary science data useful to those not directly involved in its creation, supporting information must be made available with the data to allow effective use and interpretation. The exchange of data is increasingly important in planetary science; thus there is a need for establishment and enforcement of standards regarding the quality and completeness of data. Electronic communication has become more sophisticated, and the use of new media (such as CD-ROMs and DVD) for data storage and transfer requires additional formatting standards to ensure long-term readability and usability. To these ends, the Planetary Data System (PDS) has developed a data set nomenclature consistent across discipline boundaries, as well as standards for labeling data files developed by NASA.

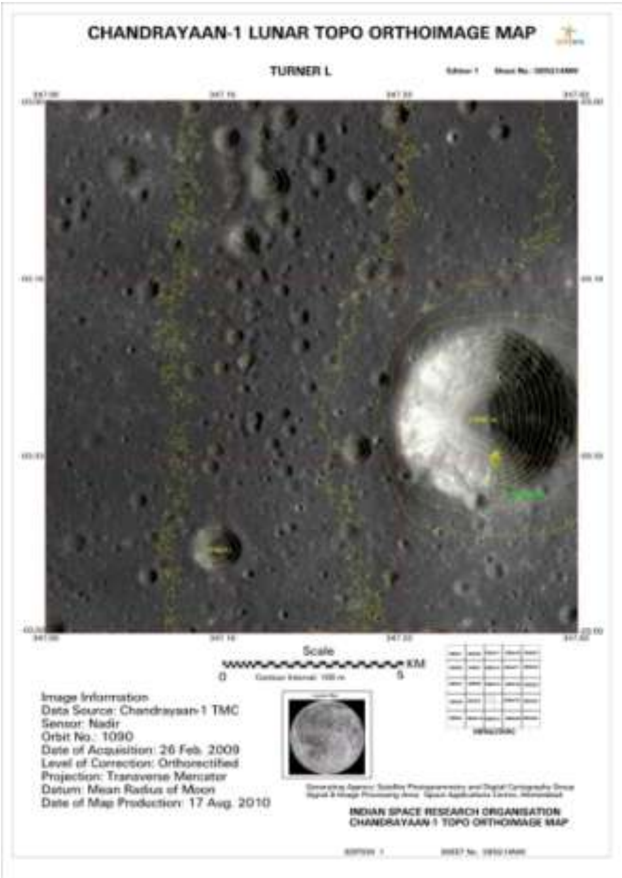

Figure-4: Chandrayaan-1 topo orthoimage map

PDS is a Data representation format that would allow long term storage, which was developed in order to guarantee its usability long after the mission. All PDS-produced products are peer-reviewed, well-documented, and easily accessible via. a system of online catalogues that are organized by planetary disciplines. PDS standards are useful for describing and storing data that are designed to enable future scientists who are unfamiliar with the original experiments to analyze the data. These standards (PDS Standards Reference and Planetary Science Data Dictionary) address the data structure, description contents, media design, and a set of terms [1].

SPICE [2]: Space science data is of two kinds viz., (i) Instruments data and (ii) ancillary or engineering data. The ancillary data from planetary missions is represented in the form of SPICE which deals with the observation geometry, time and events. SPICE is an ancillary information system that provides scientists and engineers the capability to include space geometry and event data into mission design, science observation planning, and science data analysis software. The principle components of the SPICE system are SPICE Toolkit software and SPICE data files—often called "kernels." For Chandrayaan-1 and the future ISRO science missions, PDS is the standard followed for data products and archival [6, 8, 18]

Available Tools

ISIS [1, 21] is a software environment for the cartographic and scientific analysis of planetary image data, developed and maintained by the U.S. Geological Survey. It forms the backbone for some ground data systems that process raw spacecraft data into products suitable for archiving in the NASA PDS. For example, the processing of the Lunar Reconnaissance Orbiter LROC and Mars Reconnaissance Orbiter HiRISE images relies on ISIS.

SAC DP software: Chandrayaan-1 DP team from SAC developed software for Level-1 products generation for TMC and HySI. A pipeline is built at ISSDC which can take Level-0 files and generate Level-1. The same pipeline can be used with minor modifications for future missions. Similar pipelines exit for other instruments of Chandrayaan-1 to generate Level-0 and Level-1 products.

LDEM/LMS: Teams from SAC and ADRIN developed two separate software packages with different capabilities to generate Lunar DEM and orthoimages from the Chandrayaan-1 full pass stereo data. With minor modifications, these packages can be tuned to generate DEMs from future stereo missions.

Mapping software: Lunar mapping software is developed at SAC through COTS customization, which is being used for generation of Lunar Atlas. This can be used for future missions with minimal modifications.

Other COTS packages: Some of the available COTS packages can be used for planetary data processing tasks in a roundabout way or with some interface building. However they don't work directly on the planetary data.

Future Explorations: By the beginning of the twenty-first century, reconnaissance had been completed for the inner solar system and for the giant planets of the outer solar system. Orbital surveys, rover exploration and flybys have been accomplished at the Moon (Lunar Orbiters, Clementine, Lunar Prospector, Smart-1, Selene, Chang'e1, Chandrayaan-1, LRO, Chang'e-2), Venus (Magellan, Venera-9/10/12/13/14/15/16, Pioneer venus-1/2, Venus express, IKAROS), Mars (Mars-5/6/7, Viking-1/2, Mariner 9, Viking, Mars Global Surveyor, Mars Odyssey, Mars express, Mars Reconnaissance Orbiter), Mars rovers (Mars pathfinder, Spirit, Phoenix, Curiosity), Jupiter (Voyager-1/2, Galileo, Juno), Saturn (Pioneer-11, Cassini), Mercury (Messenger, Mariner-10), Pluto (New Horizons), Neptune (Voyager-2), and Sun (soho, Genesis). Some asteroids have been photographed by passing spacecraft, and the NEAR Shoemaker spacecraft engaged in a rendezvous with the asteroid Eros. Samples have been returned from the Moon and asteroids (Hayabusa mission from Japan). Meteorites collected on Earth are samples from (unknown) asteroids, from the Moon, and from Mars. Human exploration has lasted briefly and only on the Moon.

The National Aeronautics and Space Administration (NASA) has future plans for more orbital surveys of Mars as well as landings and sample return missions. Human exploration of Mars is being discussed, as is further human exploration of the Moon. European and Japanese spacecrafts will visit the Moon. Some private companies have plans to land on the Moon through profit-seeking ventures. ESA is planning an orbital survey of Mercury. Planetary exploration is becoming an international activity. Equally exciting is the prospect of planetary missions sponsored by institutions other than the traditional government agencies. There is an exciting future for the planetary exploration and the related data processing for finding new avenues.

Indian Context: Mars Orbiter Mission (MOM) is the immediate planetary mission towards MARS exploration, which will carry five instruments viz., Mars Color Camera (MCC) to map various morphological features on Mars with varying resolution and scales using the unique elliptical orbit, Methane Sensor for Mars (MSM) to measure total column of methane in the Martian atmosphere, Thermal Infrared Imaging Spectrometer (TIS) to map surface composition & mineralogy of mars, Mars Exospheric Neutral Composition Analyser (MENCA) to study the composition and density of the Martian neutral atmosphere and Lyman Alpha Photometer (LAP) to investigate the loss process of water in Martian atmosphere, towards fulfilling the mission objectives. The next planetary mission will be Chandrayaan-2 which consists of an orbiter having five instruments viz, (i) Imaging IR Spectrometer (IIRS) for mineral mapping, (ii) TMC-2 for topographic mapping, (iii) MiniSAR to detect water ice in the permanently shadowed regions on the Lunar poles, upto a depth of a few meters, (iv) Large Area Soft X-ray spectrometer (CLASS) & Solar X-ray Monitor (XAM) for mapping the major elements present on the lunar surface and (v)Neutral Mass Spectrometer (ChACE2) to carry out a detailed study of the lunar exosphere towards moon exploration; a rover for some specific experiments and a Lander for technology experiment and demonstration. Mission to Sun for coronagraph studies is another planetary mission in near future. New challenges are ahead for these instruments with respect to the data processing. PDS is followed for instrument data archive for all the current and future science missions.

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References:

1. http://isis.astrogeology.usgs.gov/Isis2/isis-bin//naif_spice.cgi?isis_moc_kernels.html
2. http://www.naif.jpl.nasa.gov/naif/
3. http://imbrium.mit.edu/Data/LOLA_GDR
http://ode.rsl.wustl.edu/moon/indexDatasets.aspx

4. //webgis.wr.usgs.gov/download/ClementineUVVIS/Mosaic//webgis.wr.usgs.gov/download/Clementine UVVIS ULCN 2005.warp
5. http://www.isro.org/chandrayaan/htmls/ImageMoon_C1XS.htm
6. Archive & Data Management Activities for ISRO Science Archives, Thakkar Navita et al., 39th COSPAR Scientific Assembly, July 14-22, 2012, Mysore, India
7. Build your own Topographic Model: A Photogrammetry Guest Facility for Planetary Researchers, R.L. Kirk et al. (2009), LPS XL.
8. Chandrayaan-1 Archive Plan, Jagjeet Singh Nain et al., CH1-SAC-PL-001, Issue. 1, Rev. b, 10 Feb 2008
9. Chandrayaan-1 Lunar Science Atlas, Prakash Chauhan et al., Space Applications Centre, Ahmedabad, India, ISBN: 978-93-82760-01-6, February 2013.
10. Data Processing and Product generation for Chandrayaan-1 TMC and HySI Payloads, B Gopala Krishna, SAC Courier, Vol. 23, No.1, House Journal of Space Applications Centre, January 2009, pp. 9-12
11. DEM Generation for Lunar Surface using Chandrayaan-1 TMC Triplet Data, V. Sivakumar, Binay Kumar et al., Journal of Indian Soc Remote Sensing, Published on line on 05 Jan 2012.
12. Digital Elevation Models of The Lunar Surface from Chandrayaan-1 Terrain Mapping Camera (TMC) Imagery – Initial Results, B. Gopala Krishna et al. (2009), LPS XL, Abstract # 1694
13. Exploring the moon in three dimensions, P K Srivastava et al., Coordinates, Volume V, Issue 4, April 2009, pp. 6-10.
14. Extremely high reflection of solar wind protons as neutral hydrogen atoms from regolith in space, Wiser M. et al., Planetary and Space Science 57 (2009) 2132-2134
15. Identification of a new Spinel-rich lunar rock type by the Moon Mineralogy Mapper (M3), Pieters C. M. et al. (2010), LPS XL1 , Abstract # 1854
16. Images of Moon from Chandrayaan-1, B Gopala Krishna et al., Space Applications Centre, Ahmedabad, India, ISBN: 978-81-909978-3-6, 2011.
17. Photogrammetric Stereo Models and Lunar Atlas for Chandrayaan-1, Sanjay Singh et al., Signatures, 2013, this volume.
18. Planetary Data Archiving Activities in Indian Space Research Organisation (ISRO), B Gopala Krishna and P K Srivastava, 38th COSPAR Scientific Assembly, July 18-25, 2010, Bremen, Germany.
19. “Planetary Mapping”, Ronald Greeley and Raymond M. Batson (editors), Cambridge University Press, 1990
20. Rational Polynomial Modeling for Cartosat-1 Data, Sanjay K Singh et al., ISPRS Beijing Congress Proceedings, Jul 3-11, 2008, Vol. XXXVII, Part B1, TC-I, pp 885-888.
21. Support and Future Vision for the Integrated Software for Imagers and Spectrometers (ISIS), Keszthelyi, L., et. al. (2013), LPS XLIV, Abstract # 2546.
22. Water and hydroxyl on the moon as seen by the Moon Mineralogy Mapper (M3), Clark R et al. (2010), LPS XL1, Abstract # 2302

HIGH RESOLUTION DATA PROCESSING: ADVANCES AND CHALLENGES

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Introduction: The ever increasing number of high and very high resolution optical data obtained from space borne satellite sensors has revolutionised the field of Cartography, Photogrammetry and Mapping and continued allowing scientific community to get accurate and reliable information details of the earth surface. Since the launch of IKONOS and Quickbird satellites slightly more than a decade ago, the number of commercial high-resolution (HR) satellites has steadily increased over recent years and high-resolution images acquired in panchromatic and multispectral bands have been widely used for extracting geospatial information for photogrammetric and remote sensing applications. In Indian scenario, a new era has begun with the launch of the Technology Experimental Satellite (TES) in the year 2001, followed by Cartosat series of satellites carrying high-resolution mono/stereo sensors. The available image data from the current operational satellites have a ground resolution varying from a few metres to half a metre with rich information content. Processing of HR images poses a major challenge in terms of development of algorithms, suitable photogrammetric techniques and corresponding software. In order to take the full potential of these images, advanced algorithms, automation methods have to be considered and applied in the processing systems. A suitable sensor orientation models describing the relationship between image space and object space are essential for the extraction of metric information from images. The achievable quality of the final results are governed by imaging geometry, sensor performance, system calibration, among others, as they play a major role in transforming raw data into corrected product with acceptable quality. In the case of stereo sensors, full exploitation of high resolution stereo images for dense DEM generation is one of the major tasks.

In the past decade, considerable amount of research has been carried out in photogrammetric processing of high resolution Indian satellite images, especially in the area of sensor modelling, image orientation and analysis, automatic digital terrain model extraction and 3D mapping techniques. Data Processing (DP) team at SAC studied and investigated various methods, conducted exercises in modelling and simulation, developed a full suite of new algorithms leading to realisation of operational software packages built in-house for generating high resolution data products as well as producing good quality DEMs from high resolution stereo images. DP software has been operationally used and maintained at Indian as well as various other International Ground Stations (IGS) for processing data beamed from HR Cartosat sensors. GlobalDEM generation using HR Cartosat-1 stereo sensors is one of the greatest challenges and efforts are on towards achieving this. Exercises in simulation and modelling are underway in understanding TDI concepts towards upcoming next generation advanced Carto series of satellites. A glimpse on some of the experiences, accomplishments in processing high resolution data from Cartosat-1/2 missions and challenges ahead for processing HR data for earth & planetary missions are discussed here.

Evolution of Indian high resolution missions: Thanks to the growing requirements of resource applications and emerging advanced technologies, HR missions have become reality in India in the past one decade. The first HR Indian satellite TES (Technology Experimental Satellite) operating in Step-and-Stare mode with one meter resolution, launched in October 2001, paved the way for demonstrating the capability of going for high resolution missions in India. Not only this mission has enabled understanding various key issues and challenges related to processing of high resolution sensor data in terms of radiometry and geometry but necessitated the model improvements for processing step-and-stare imaging mode and other newer operational modes of data acquisition. Subsequently, with the launch of Cartosat-1 in May 2005, along track stereo data with 2.5 m spatial resolution (panchromatic) and 0.62 B/H ratios has become available to the user community. It has opened many new areas of applications such as large scale cartographic mapping, terrain modelling and visualization [11]. The primary goal and advantage of Cartosat-1 mission is generation of Digital Elevation Model (DEM) of a given geographic region of interest (e. g. country) for extracting drainage patterns, contour line generation, orthoimage production and 3D terrain visualization on a global basis. The stereo imagery pair from Cartosat-1 has been used to derive secondary ground control points (i.e. Triangulated Control Points) towards generating high accuracy satellite data products. Cartosat-1 has completed 8 years in orbit and continues to provide stereo data. Launched in January 2007, Cartosat-2 with step-and-stare technology having 0.8m spatial resolution has further boosted the geo-spatial applications. Cartosat-2A (in 2008) / 2B (in 2010) missions were subsequent in the series but meant for various applications. All these missions have provided wealth of HR data over the globe and data processing team has made great strides in studying, understanding, handling, processing, analyzing and delivering good quality HR data products.

New elements, techniques and challenges in HR Cartosat data processing: As is known, high resolution data processing demands handling of large volume of data, delivery of products in quick time while preserving the good quality both in terms of radiometry and geometry as per user's expectations. In order to make the data processed by commercially available software packages, consideration of products from contemporary missions, compatibility of product types & formats were essential. Accordingly, software processing strategies, product types were worked out and realised for Cartosat-1 and Cartosat-2.

Experiences with Cartosat-1: Cartosat-1 is the first operational remote sensing satellite capable of providing in-orbit stereo images with 2.5m nadir resolution and 27km swath. The two payloads viz. PAN-Fore and PAN-Aft are designed with state-of-the-art technologies in order to provide images of high quality products. They are mounted in along track direction with a tilt of +26 deg (Fore) and –5 deg (Aft) to provide along track stereo with 2.5m resolutions each approximately. Two major software packages were operationalised at NRSC, Hyderabad viz. Data Processing Generation System (DPGS)[8] and Stereo Strip Triangulation System (SSTS) for processing stereo data of Cartosat-1. Some of the accomplishments made, challenges faced, new data processing techniques/elements introduced and realized first time for processing of high-resolution stereo data from Cartosat-1 are highlighted below.

Accomplishments in Data Processing approach

Some of major accomplishments in processing HR Cartosat-1 stereo data are given below.

- A rigorous sensor model using photogrammetric approach for data products generation is realised first time. The crux of the modelling is the establishment of the precise viewing direction or look vector in the presence of distortions arising from camera tilt, spacecraft motion & orientation, earth rotation & curvature in addition to surface relief through series of coordinate transformations. This dynamic processing approach maps 2D image points to corresponding 3D object space points very precisely;
- Software design & development based on object-oriented approach was realized for Data Products Generation System (DPGS) first for Cartosat-1 rather than using functional or procedure based one (started for first Cartosat-1 but realized for TES and adopted for Cartosat-1) using C,C++ languages for core processing and Java for front-end components;
- Handling of Quaternion model instead of conventional attitude angles in DP software;
- Introduced Rational Polynomial Coefficients (RPC)

Model first time in data processing – led to realisation of stereo orthokit products (RAD & GEO levels) enabling users to process higher level products generation;

- Certification of COTS software packages for Integration with Cartosat-1 data products (for enabling processing of orthokit products, a tie up with vendors of COTS software packages thro' MOU reached between ANTRIX and commercial vendors);
- Handling of raw data after compression/decompression in DP chain and handling compression by pass mode data thro' DP software chain for validation of onboard/ground processing systems;
- Capability to process wide-mono data acquisition (for large swath realisation)
- Area of Interest (AOI) product generation realised first time for Cartosat-1;
- Reverse stereo data handling (to cover gap areas left uncovered by normal stereo in the north India) and strengthened DEM accuracy[10];
- Carried out periodic in-flight calibration[1,3] thro' test bed data acquisition and use of precise GCPs to characterise the system through estimation of platform biases, payload alignment angles and other camera specific parameters and improve the system performance, leading to realisation of high accurate data products;
- Characterisation of image quality, radiometric Look-Up Table (LUT) enhancement, noise removal and introduction of MTF correction for restoration of image (**Figure 1.0);**

Figure 1.0 (a) Cartosat-1 AFT (Original)

Figure 1.0 (b) Cartosat-1 AFT

- Cartosat-1 Scientific Assessment Programme (C-SAP) – ISPRS-ISRO joint programme conducted investigations and assessed mapping potential of Cartosat-1 by global users, first of its kind for any Indian Remote Sensing(IRS) missions;
- Realisation of generating merged product or multi-satellite/multi-sensor fused data product using HR Cartosat-1 data and Resourcesat-1/2 data sets;
- Customised software solutions through indigenously developed SAPHIRC-C (scene based DEM generation) and GEMS (GCP library data base management system) software for external/internal users, as applicable;

Stereo Data Processing : The major achievement and challenge was to develop & demonstrate a technology to extract DEM from Cartosat-1's high resolution stereo data based on geometric modelling of long stereo strips using a few Ground Control Points (GCPs) over a strip of 500km length through indigenously developed software called SSTS (Stereo Strip Triangulation System)[7,12] for which dual camera space resection software is the core. Stereo GCPs as observations were adjusted in rigorous photogrammetric *imaging geometry* model in order to update spacecraft attitude parameters for achieving geometric accuracies of < 25m in planimetry. Besides this, updated orientation parameters, DEM and TCPs over a strip are the outputs.

In fact, DEM generation was planned in three phases and the first two have been successfully realized through SSTS software (for operational ortho generation) and CartoDEM software (for generation of national level dense digital elevation model with 1/3 arc sec grid spacing along with an orthoimage reference). In third phase, generation of DEM over globe is planned for which new modelling techniques; improvements in algorithms, different processing strategies and software design are in advanced level of development. DEM generation flow using Cartosat-1 stereo data is given in **Figure 2.0.** A typical DEM and corresponding orthoimage generated from Cartosat-1 data is shown in **Figure 3.0.** SSTS Post adjustment model results for the period of 2005-2011 is shown (orbit wise) in **Figure 4.0**.

Cartosat-1 mission offered a lot of scope and challenges in processing of full pass stereo data, estimation of platform biases for accuracy improvement, resolving issues related to stagger, image matching, RPC based processing etc. and generation of national DEM and hence, resulting in understanding of various complex system parameters. Other R&D efforts and additional exercises carried out were towards strengthening DEM generation using normal and reverse stereo data, improving system accuracy using various photogrammetric models viz. coplanarity model, line based approach [9], Kalman Filter with the help of a few controls or no control, SSR (Solid State Recorder) data processing & bundle adjustment technique for processing multi-orbits for GlobalDEM purpose.

As part of R&D, exercises on model augmentation towards GlobalDEM realization, full pass modeling[2] was taken up for Cartosat-1 pass (up to 2000km instead of normal 500km strip) using only two control points, resulted in significant improvement of model error within 3 pixels.

Experiences with Cartosat-2,2A & 2B HR data processing

As mentioned earlier, Cartosat–2 series of HR systems are in operational use since 2007. As the resolution was 3 times finer than Cartosat-1, additional challenges were encountered in terms of image quality enhancement, geometric accuracy improvement, handling various operational imaging modes in making the DP system fully functional and operational.

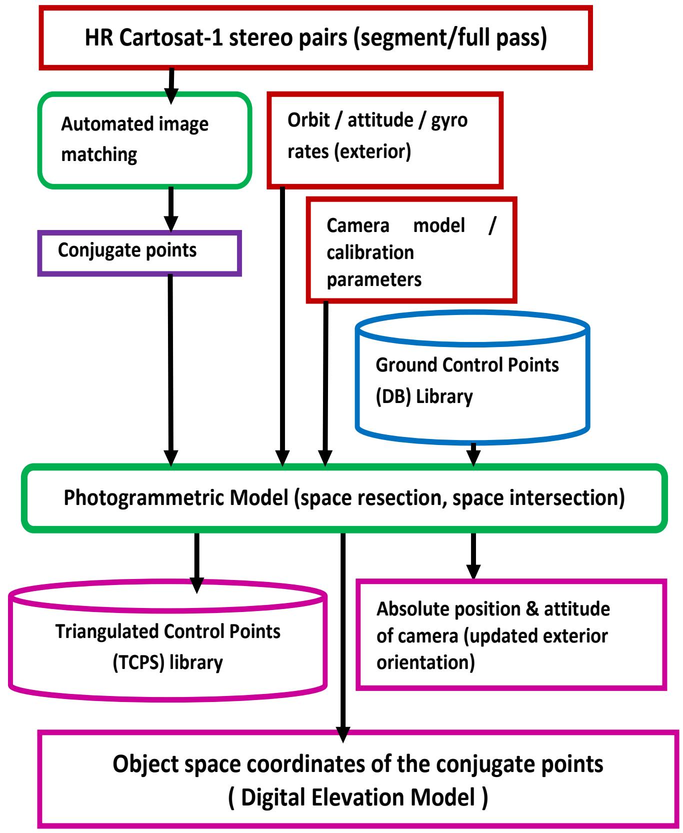

Figure 2.0: DEM generation process for Cartosat-1

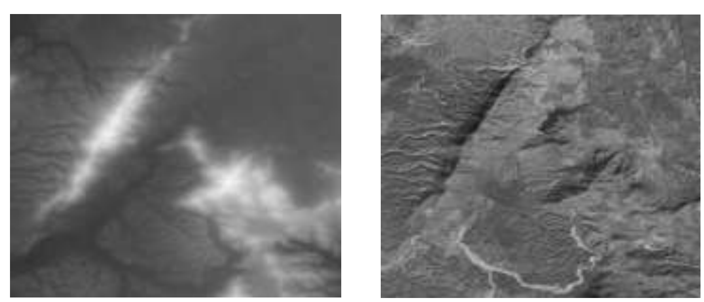

Figure 3.0 A typical Carto DEM & corresponding Orthoimage

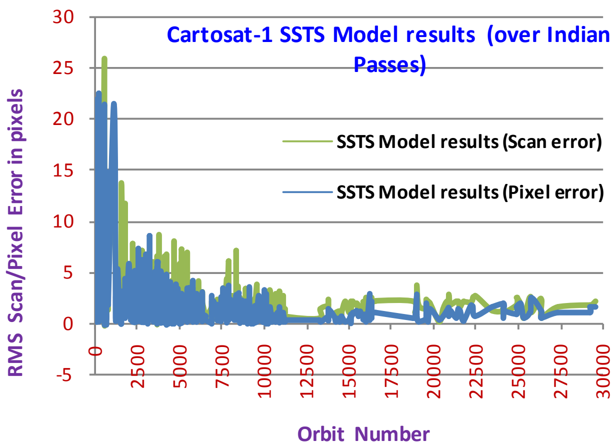

Figure 4.0 Cartosat-1 SSTS Model Results

High-resolution data better than 1m geometric resolution with 10 bits per pixel quantization over a scene size of approximately 10 km coming from various imaging modes like spot, PaintBrush and Multi-view were processed by DPGS to deliver various levels of data products like system corrected, orthokit, ortho etc. Various activities related to studying, understanding & testing the data for improving both geometric and radiometric qualities were attempted[4]. These include fine-tuning of radiometric LUT, improving system level data products accuracy and image quality. Apart from the above, a number of R&D activities were taken up to process data obtained from Variable Integration Time (VIT) mode, stellar observations, higher Ground Sampling Distance (GSD), large yaw case etc.

Cartosat-2 collects data from one of its two similar CCDs viz. Main or redundant. One of the important observations made during initial days on both CCD1 and CCD2 images was that every feature was found to have lack of sharpness or some kind of blur associated with. This blur was attributed to the effect of extended point spread function (PSF). Stellar and control earth observations reveal that the PSF is extended or spread over multiples of pixel in both scan line and pixel directions. Significant amount of efforts have gone in from DP side for improving the image quality in respect of study and characterization of PSFs with the help of stellar data. Using stellar derived PSFs, MTF correction, Noise correction, reduction of artifacts were introduced in DP chain for the first time for Cartosat-2 to improve the spatial resolution and hence image quality. Concept proving exercises for high-resolution data sets acquired in Paint-Brush mode over two cities have been tested for mosaicking of city geocoded products. Automatic DEM extraction of Cartosat-2 multi-View data with RPCs and without use of GCPs was also realised on R&D basis.

One of the important elements that happened during initial phase is the realization of meeting data products accuracy at system level, better than 100m (CE90) using GCPs/TCPs through nominal imaging (2.5m) without step-stare and stellar calibration mode. Additional logic was provided in C2 data processing chain for handling of 0.4m data acquisition to make the image sharper and is operational at NRSC now. A typical data of C2 collected in 0.4m gsd mode is shown in **Figure 5.0** (left image is original raw data i.e 0.4m x 0.8m and the right one is radiometrically corrected, sum of two consecutive lines considered and PSF corrected i.e 0.8m x 0.8m).

The experience gained through C2 data processing helped largely for making DP operations chain smooth for Cartosat-2A/2B initial phase operations[5,6] for giving feedback to mission as well as for qualifying the system. R&D efforts undertaken in resolving stagger issues through image data for Cartosat-2B has helped in detecting the presence of micro-vibration effect in the platform, related to spacecraft stability which is critical for image quality. Apart from the above, a number of new elements like full strip data processing and handling of manoeuvre data (during step-and-stare mode operation, from one spot to another , data is collected but not generally used as platform undergoes severe manoeuvring) to see the image quality. The later called for extra understanding of the scenario and processing mechanism (see **Figure 6.0**). Rigorous study and exercises are on at DP end in making C2 ortho product chain operational, which uses CartoDEM tiles and Ortho as reference image for a scene, as there is no GCP available for each 10km scene. The challenge lies in making automatic image registration work for all kind of terrain and for variety of image collection modes.

Figure 5.0 Cartosat-2 Image acquired in 0.4m GSD
(a) RAW (0.4m x 0.8m) (b) Rad sum: PSF corrected 0.8m x 0.8m

Figure 6.0 Cartosat-2B: Manoeuvre data

Cartosat data processing will soon be operational through **I**ntegrated **M**ulti-mission **G**round segment for **E**arth **O**bservation **S**atellites (IMGEOS) chain at NRSC, Shadnagar, as part of other missions.

Cartosat-2C Data Products: New Elements and Challenges: Cartosat-2C is the next high resolution satellite to be launched in the Cartosat series having both panchromatic (<1m) and multispectral (<2m) imaging capabilities. Cartosat-2C contains state-of-the-art new technologies in-built to provide high quality data products from 500km altitude covering nearly 10km swath [13]. These new elements also pose new challenges to data processing software in terms of radiometric and geometric qualities, which are given below.

Time Delay Integration: A Time Delay and Integration (TDI) charge-coupled device (CCD) is planned first time in ISRO's mission for getting a better signal to noise ratio and hence better geometric fidelity. Though it improves the signal to noise ratio, it puts stringent requirements on platform stability. Since the two dimensional array needs to move precisely, the platform should be stable enough so that each pixel position is where it is supposed to be. Even slight deviation from this will result in blurring of the image. Correction of this data is a challenge to the data processing software. Simulations exercises are underway which will use various satellite-drift values and see its effect on the image and quantify its quality.

Data Compression/High data volumes: Designed to have high spatial and radiometric resolution, Cartosat-2C acquires a very high volume of data (PAN and MX) to be downloaded on ground with limited transmission time and bandwidth. Hence, an efficient compression viz. Discrete Wavelet Transform (DWT) is chosen to get high data quality at greater compression ratios, as per CCSDS (Consultative Committee for Space Data systems) standard, compared to earlier used Discrete Cosine Transform (DCT) based compression. DP team has conducted simulation studies to determine the compression ratio with acceptable losses, which verifies that DWT is indeed better than DCT.

Optical Butting: The payload's full swath is not realised by a single array but by combining smaller detector arrays in the horizontal direction, due to other technological constraints. Neighbouring arrays are placed in different planes and a mirror is used to reflect the light beam to fall on the detector in the other plane. This mechanism is called optical butting and it will introduce certain amount of loss or degradation in MTF in the data at the junction of the detector arrays, which has to be characterised and corrected by Data Processing software.

On board Non Uniformity Correction (NUC): A few studies indicate that there might be improvement in the compression of data if the data is corrected for detector non uniformity before subjecting it to compression. This requires NUC being done on-board. There will still be a requirement to correct the residual non-uniformity on ground and will be done by Data processing software.

Event Monitoring Camera: Event monitoring camera is being proposed which will image video data for a certain portion on the ground which can aid in monitoring system performance through deriving the satellite navigational parameters and using them in correction process in DP. Processing of this data will also be carried out by DP software.

Following types of data products are proposed for Cartosat-2C viz. Raw, Rad, Geo-referenced (with/without RPCs), Ortho rectified, Merged (PAN+MX), Bundled (PAN & MX) and Off The Shelf products. Realization of high image quality products in the presence of TDI, optical butting, compression and onboard LUT application with reasonably good platform stability is the big challenge. Also, a high geometric accuracy specification for data products is to be evolved and met, keeping in mind current GCP library specifications or best available references. Elements like near real-time processing, full pass data processing, increased throughput, meeting the product specifications, web based data dissemination and information products generation are some of the important and tough tasks to be tackled operationally, among others during Cartosat-2C time frame. Image matching across multi-sensors, effect of micro-vibration on image quality and non-availability of good references at sensor resolution or better are primary uphill tasks to be understood and issues/obstacles are to be surmounted.

Future Missions : Many high-resolution satellites in Cartosat series are planned to provide data for applications like town planning, cartography, digital elevation model etc. To start with, Cartosat-2C with <1m in Panchromatic and <2m in multispectral bands is planned in 2015, followed by Cartosat-2D having similar configuration, whereas very high resolution payloads are planned in Carto-3 series of satellites during 12th Five Year Plan. Carto-1 has completed 8 years of operational life and has provided excellent imagery. Further, high-resolution sensors on-board orbiter, lander and rover with specific purpose in Chandrayaan-2 will give more insight to explore the system.

Conclusions: The maturity, expertise and experiences gained over years in processing and operationalisation of data products generation software for different Cartosat-1 and Cartosat-2 series of satellites will go a long way in exploiting the full potential of HR data from Cartosat-2C sensors. Advances in technology, improved techniques/algorithms and procedures, requirement of quick turn-around time, system infrastructure, new trends and changing scenario will lead to major transition in terms of data processing during Cartosat-2C time. With the adoption of software process standards and continuous improvement in photogrammetric techniques, & image processing algorithms, DP is geared to take up challenges that involve simulations, modeling, development of advanced techniques, efficient software and its qualification for achieving state of the art data product specifications for future HR imaging systems for earth, lunar, planetary and astronomical missions. Adopting to ever evolving new requirements, realisation of data products prior to launch of satellites through modelling and simulation is always an interesting and a great challenge for all upcoming HR missions.

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References:

1) Srinivasan, T. P., Islam, B. Sanjay K. Singh, Gopala Krishna, B., Srivastava, P. K., In-flight Geometric Calibration - An experience with CARTOSAT-1 and CARTOSAT-2 Page(s) 83-88, ISPRS Archives – Volume XXXVII Part B1, 2008, (WG I/1 Standards, Calibration and Validation)
2) Amit Gupta, Jagjeet Singh Nain, Sanjay K Singh, T P Srinivasan, B Gopala Krishna, P K Srivastava , Long Strip Modelling for CARTOSAT-1 with Minimum Control, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B1. Beijing 2008'
3) Srinivasan T.P., Amit Gupta, Sanjay K. Singh, Gopala Krishna, B., Report on Cartosat-1 in-orbit geometric calibration exercises (IRS-P5/DP/SAC/RESIPA /SIPG /SPDD/TN-27/Oct.'05)
4) Cartosat-2 DP team, Cartosat-2 Data Products System - Report on Cartosat-2 Initial Phase Exercises and Data analysis (CARTOSAT-2/DP/SAC/SIPA/SPDCG/TN-09/September 2007)
5) Cartosat-2A DP team, Cartosat-2A Data Products System - Report on Cartosat-2A Initial Phase Exercises and Data analysis (CARTOSAT-2A/DP/SAC /SIPA/SPDCG/TN-04/July 2008)
6) Cartosat-2B DP Team, Compiled by T. P. Srinivasan, Cartosat-2B Data Products System - Report on Initial Phase Exercises and Data analysis (CARTOSAT-2B/ DP/SAC/ SIPA/ SPDCG/TN-28/December 2010)
7) Srinivasan T. P., Sanjay Singh, et al. 2006, Stereo Strip Triangulation for Cartosat-1, Technical Commission IV symposium on "Geospatial Databases for sustainable development", Goa, India.
8) Nandakumar R., Srinivasan T. P., Gopala Krishna B., Srivastava, P. K. 2005. Data Products for Cartosat-1, *ISG newsletter*, Vol. 11, No. 2&3, Special issue on Cartosat, June & September 2005, pp. 18-24, ISSN: 0972-642X
9) Srinivasan,T. P., Islam, B., Medha Alurkar, Gopala Krishna B., Stereo Sensor modeling for autonomous Navigation-In-flight Geometric Calibration (SAC/SIPA/SPDCG/TN-23/August 2010)
10) Amitabh, T P Srinivasan, B Gopala Krishna - A Comparative Study between Forward and Reverse Stereos of Cartosat-1 ,(SAC/SIPA/SPDCG/TN-22/September 2010)
11) Srivastava, P.K., Gopala Krishna, B., Srinivasan, T.P. et al. (2006), Cartosat-1 Data Products for Topographic Mapping, ISPRS Commission IV Symposium on Geospatial Databases for Sustainable Development, Goa, 27-30 September, 2006.
12) Srivastava', P. K., Srinivasan, T.P. et al. (2008), Advanced Studies In Strip Pair Processing Of Cartosat-1 Data, The Photogrammetric Record 23(123): 290–304 (September 2008)
13) Preliminary Design Review – Document on Cartosat-2C Payload, Volume 1of 2 & Volume 2 of /2, May 2012(SAC/SEDA/14/05/2012/02)

RISAT-1 DATA PRODUCTS

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Introduction: The Synthetic Aperture Radar is an active microwave imaging system with the capability to penetrate cloud cover and image during night. The SAR image represents the Radar reflectivity (backscatter) of the target as a function of position. It measures the back scattering coefficient σ_0 as a function of incidence angle, wavelength & polarization - in amplitude calibrated system & can measure the relative phase between different polarizations (SAR Polarimetry) & two receiving antennas (SAR Interferometry) - in a phase calibrated system. SAR achieves high resolution in the range by the pulse compression technique. Here the peak power is lowered and a long pulse is transmitted to keep the average power at a high level for better S/N. Signal processing of the received signal allows compression from low to high range resolution. The SAR achieves high azimuth resolution by synthesizing a longer antenna from the movement of a physically small antenna by the utilizing the forward sensor motion. The advantages of SAR are

(i) All weather imaging capability (penetrating through cloud cover)
(ii) Day and night imaging capability
(iii) Penetration through vegetation and soil is possible to some extent.

Radar imaging Satellite (RISAT)-1 is India's first space borne active imaging synthetic aperture radar satellite operating in C band. It was launched on 26th April 2012 from Shriharikota through PSLV launch vehicle For RISAT-1 a polar sun synchronous orbit at 536.38 kms altitude and inclination of 97.554 deg. with repetivity cycle of 377 orbits in 25 days with a descending node local time of 6:00 AM +/- 5 min is chosen . Main guiding parameter for choosing the orbit for RISAT-1 is achieving a global coverage in a systematic way for a given swath. Orbit parameters are planned to be variable as per mission operation requirements for various imaging modes. The satellite can image on both the side with respect to sub satellite track. Various modes available for imaging ground are described in table-1 and viewing geometry is described in figure-1.

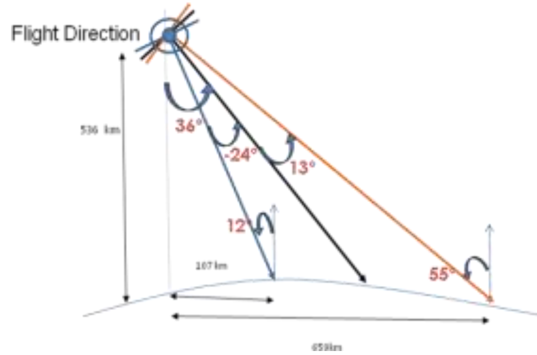


Figure 1: RISAT-1 Viewing Geometry

Table 1: RISAT-1 payload modes, polarization, swath and resolution

Payload modes	No. of beams	Polarisation	Swath (km)	Resolution (m)
Coarse Resolution (CRS)	12	Single, Dual, Circular	223	50
Medium Resolution (MRS)	6	Single, Dual, Circular	115	25
Fine Resolution (FRS-1)	1	Single, Dual, Circular	25	3
Fine Resolution (FRS-2)	1	Quad, Circular	25	9
High Resolution (HRS)	1	Single, Dual, Circular	10	1

Operational data processing: The data processing for RISAT-1 is carried out at NRSC, Shadnagar in an Integrated Multi mission Ground segment for Earth

Table 2: Data Processing Time at IMGEOS

MODE	SCENE ACQUISITION TIME	SCENE PROCESSING TIME (Raw data to L2 GeoTiff)
FRS-1 (30 km)	4.6s	15s
FRS-2 (30 Km)	4.6s	45s
MRS (115 Km)	17.5s	55s
CRS (230 Km)	32.8s	120s

Observation Satellites (IMGEOS) environment in almost near real time on 6 nodes with each one having 4 CPU and 8 core machines. There exists a provision to download data in real time mode or recording on board and playback later. The basic steps of SAR data processing can be summerised as

- Block Adaptive Quantisation decompression
- Correction for I&Q imbalance
- Doppler centroid Estimation
- Range Compression
- Range Cell Migration Correction
- Azimuth Compression
- Single Look Complex or Multi-look data generation
- Slant range to Ground range conversion
- Geocoding

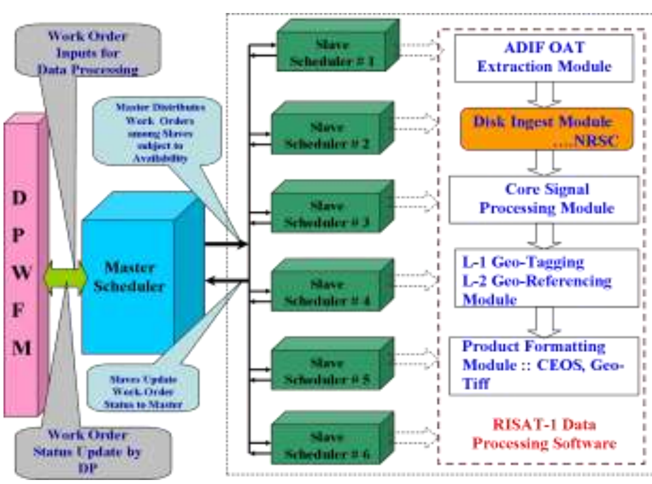


Figure 2: RISAT-1 data processing flow at IMGEOS

The basic data flow diagram is shown in Figure 2.

The request for data products generation is ingested through Data Products work flow managers. Master and Slave scheduler execute on separate hosts. Once a work-order arrives, the software automatically routes it to a free slave node and generates the outputs. The status of work-orders viz. running, suspended, aborted, scheduled, error or completed for a particular scheduler session can be known from the GUI.The processing time for various modes of data is shown in table 2:

The data products generation facility caters to following modes of RISAT-1 satellite.

- *Stripmap Mode(FRS)*

The antenna pointing angle is kept constant as the radar platform moves. The beam sweeps along the ground at an approximately uniform rate, and a strip of ground is imaged. The azimuth resolution is governed by the antenna length. It provides 2 m slant resolution image over 25 km swath in either single or dual polarisations

- *ScanSAR Mode(MRS,CRS)*

The antenna beam is switched in range many times during a synthetic aperture. A much wider swath is covered at the cost of azimuth resolution. There are two scansar modes, namely Medium Resolution (MRS) and coarse resolution(CRS). MRS provides 8 m slant resolution image over swath of 115 km in either single or dual polarisation. CRS provides 8 m slant resolution image over swath of 223 km in either single or dual polarisation.

- Alternate Polarization Mode

The transmitter polarization is switched a number of times in the synthetic aperture. Rest all conditions are same as in Stripmap mode. It provides 4 m slant resolution image over 25 km swath in quad polarisation.

- *Spotlight Mode(HRS)*

Best resolution can be achieved in this mode by steering the beam gradually backwards as the sensor passes the scene. Coverage in the along track direction is a fraction of the along track traversed distance. It generates 1 m resolution image for a spot of 10 km (Azimuth) and 10 km (ground range swath) for either single or dual polarisation.

The various levels of products defined for RISAT-1 are as follows:

- *Raw Signal Products (Level-0):*

This product contains raw or unprocessed radar echo data in complex in-phase and quadrature signal (I and Q) format. The only processing performed on the data is the stripping of the downlink frame format, BAQ decoded (optional) and re-assembly of the data into contiguous radar range lines. Each range line of data is represented by one Signal Data Record in the RAW CEOS product. Auxiliary data required for processing is also made available along with echo data.

- *Geo-Tagged Products (Level-1) :*

The image is geo-tagged using orbit and attitude data from the satellite. This allows latitude and longitude information to be calculated for each line in the image. The earth geometry is assumed to be the standard ellipsoid. Each image line contains auxiliary information which includes the latitude and longitude of the first, mid and last pixels of the line. The raw radar signal data is processed to provide SAR image data pixels. The image pixel data is represented by a series of CEOS processed data records, each record containing one complete line of pixels lying in the range dimension of the image. The product can be obtained as slant range data (16 bit I and 16 bit Q) or ground range data (16 bit) amplitude data. Additionally, an auxiliary file containing a dense grid of geo-locations is associated along with the data file.

- *Terrain corrected Geocoded Products (level-2) :*

This product contains terrain corrected and geocoded data. There exists provision for UTM (default) and Polyconic map projections. For systematic processing UTM projection is provided. The pixel spacing in the product will depend on mode, no. of looks and look angle. The options for product format are CEOS and GEOTIFF. In figure (3) the data products generated for various polarisation and mode have been shown.

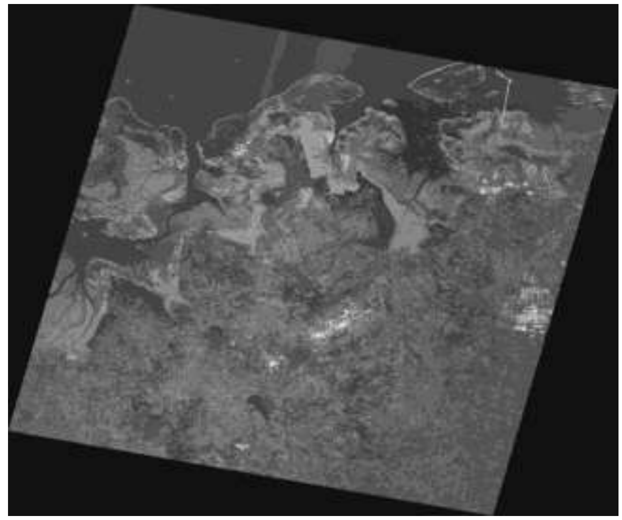


Figure 3(a): FRS-1 VV polarisation

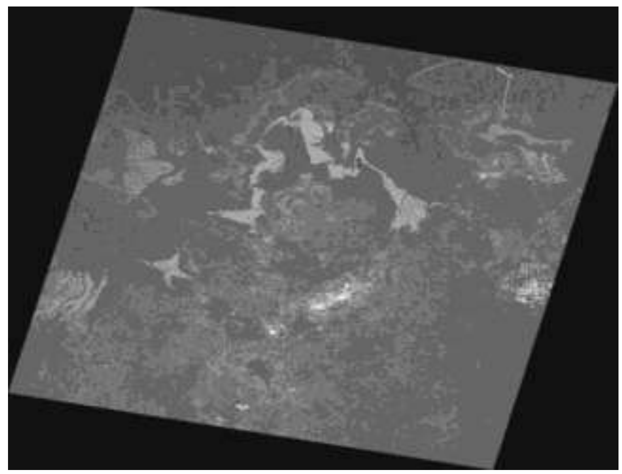


Figure 3(b): FRS-1 VH polarisation

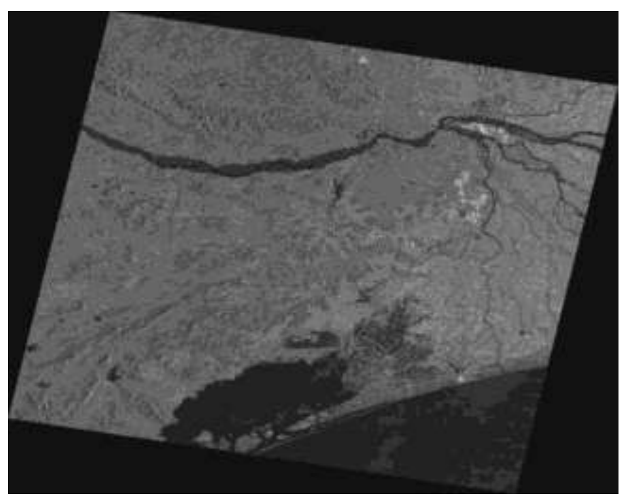


Figure 3(c): MRS HH polarisation

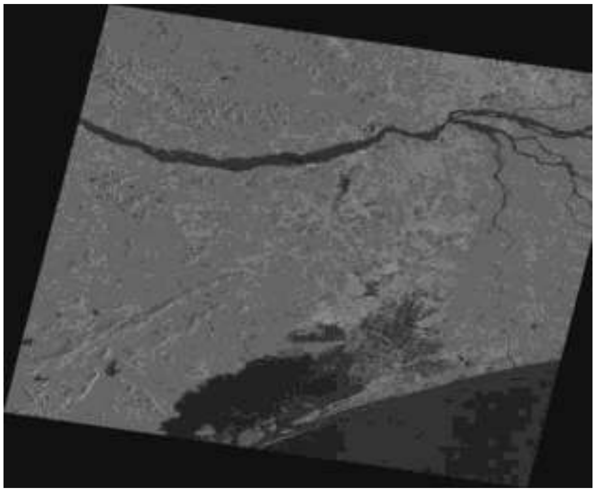
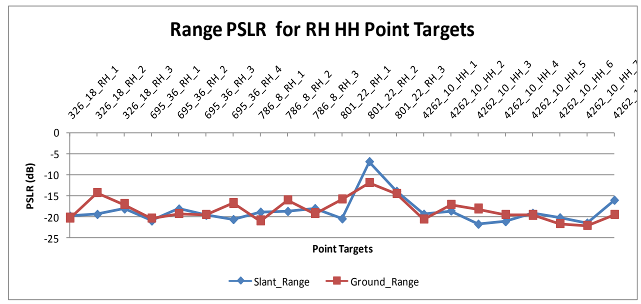


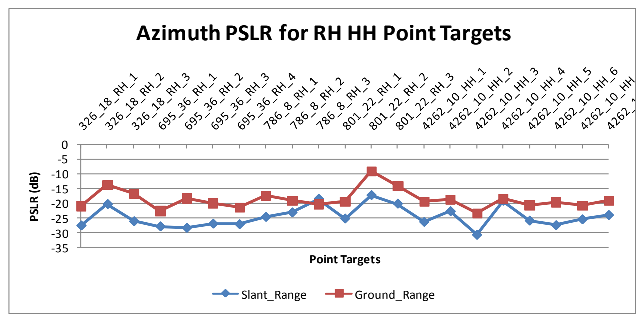
Figure 3(d): MRS HV polarisation

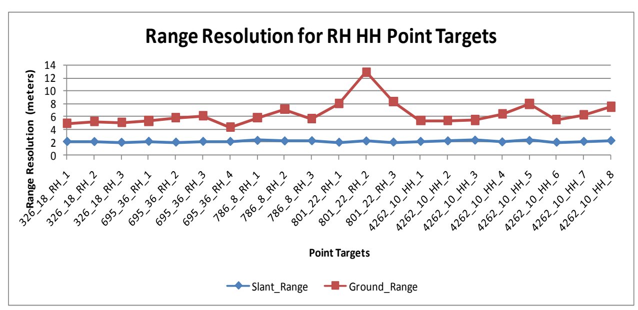
Figure 3(e): Hybrid Polarimetry data using CFRS-1 mode data

Figure 3(f): color composite using FRS-2 mode data

Validation of data Product: Attempts have been made to validate product specifications like ISLR, PSLR, Range and azimuth Resolutions etc. Also calibration constant has been derived for various modes of data and is evaluated using natural targets like Amazon and also compared with Radarsat-2 data. Figure 4 describes various scene related parameters evaluated using corner reflectors data. Table 3 displays comparison with Radarsat-2 data sets.







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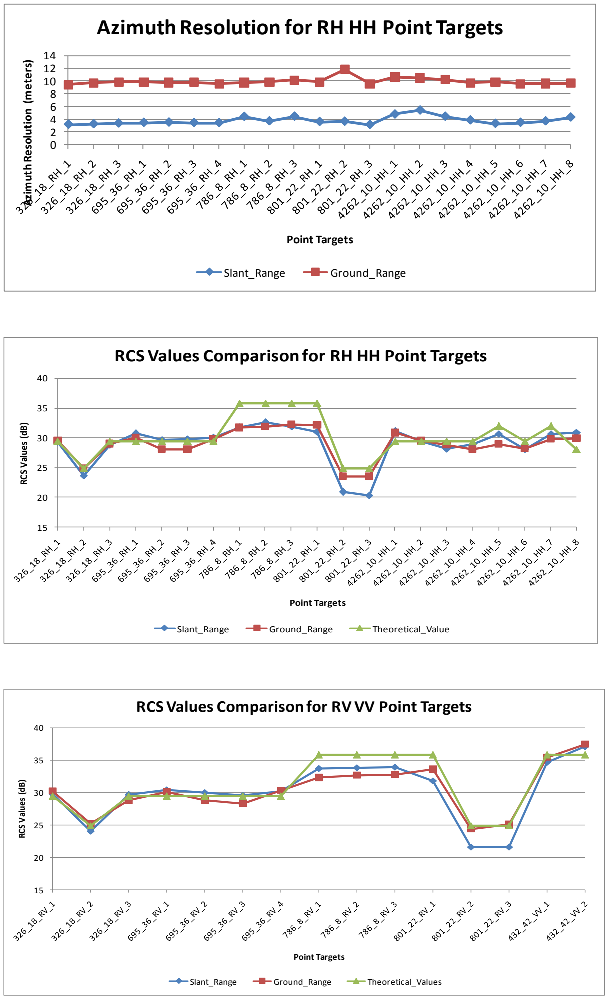

Figure 4: PSLR, Resolutions and RCS using Corner reflectors data

In figure 5 computation of sigma-0 and gamma-0 over various scenes in along track direction for VV and VH polarisation over amazon area is shown.

Table 3: Comparision with Radarsat-2 sigma-0

Data set No.	Polrzn.	Average Sigma0 (dB)		Sigma0 Histogram Peak (db)	
		RISAT-1	RADARSAT-2	RISAT-1	RADARSAT-2
Data-1	HH HV	-8.733 - 17.346	-8.284 -18.162	-6.7 -16.8	-6.3 -16.7
Data-2	HH HV	- 10.587 - 18.435	-10.629 -18.929	-8.8 -16.8	-9.3 -17.4
Data-3	HH HV	- 10.245 - 17.680	-9.865 -17.752	-9.8 -17.6	-9.4 -16.8

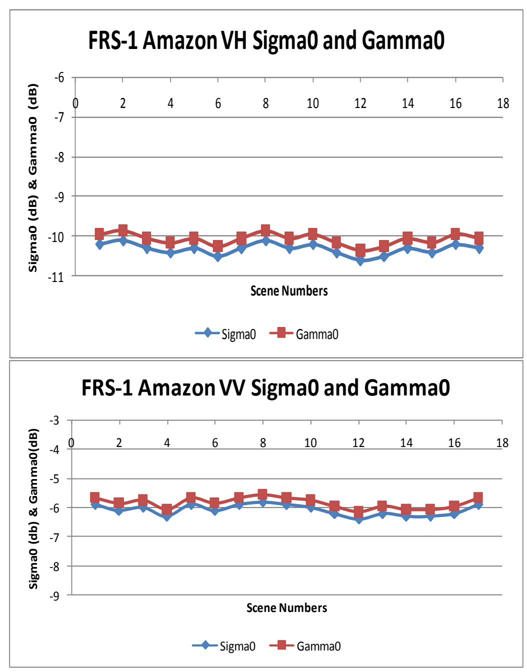

Figure 5: sigma-0 and gamma-0 over Amazon

Conclusion: RISAT-1 data products generation has been successfully operationalised at NRSC for FRS-1, FRS-2 , MRS and CRS mode of data. Data products generation is carried out in a near real time in IMGEOS environment. Data products are calibrated using natural targets and limited comparision has been made with Radarsat-2 data sets. Also various scene related parameters have been evaluated using corner reflectors and they are found to be within specifications.

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*Sh*ARP+ Data Products

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Abstract : Synthetic Aperture Radar (SAR) is essential for imaging in poor weather and lighting conditions that prohibit electro-optical data collection. SAR uses range, azimuth, and frequency and phase measurements of radar reflectance. It is complementary to optical imaging.

A robust and powerful SAR processing system known as Synthetic Aperture Radar Processor plus (*Sh*ARP+) is developed at ADRIN to process data from existing sensors e.g. ERS-1/2, RADARSAT-1, PALSAR, RISAT-2 and RISAT-1. It handles multiple data format, option of working on a region of interest (ROI), having full control in focusing parameters, special applications like moving target indication, to name a few. ADRIN SAR processor is built with a generic "one-fits-all" approach and is sensor independent. It is a multi-mode digital SAR processor capable of handling different modes of SAR acquisitions e.g. STRIPSAR, ScanSAR and SPOTLIGHT. This processor provides phase preserving single-look complex (SLC) images in slant range suitable for interferometric and polarimetric applications. It also provides value addition like geocoding and orthoimage generation [1, 2, 3]. It incorporates multiple processing algorithms such as Range Doppler Algorithm (RDA) and Chirp Scale Algorithm (CSA) for STRIPSAR mode; Range Migration Algorithm (RMA), Polar format Algorithm (PFA) and Extended CSA for spotlight and SPECAN for ScanSAR mode. The data flow diagram of *Sh*ARP+ is shown in Figure-1 built around C++ and C#.

This paper brings out few special products generated in *Sh*ARP+ for advanced users pertaining to RISAT-1, ISRO's first SAR satellite operating in C band.

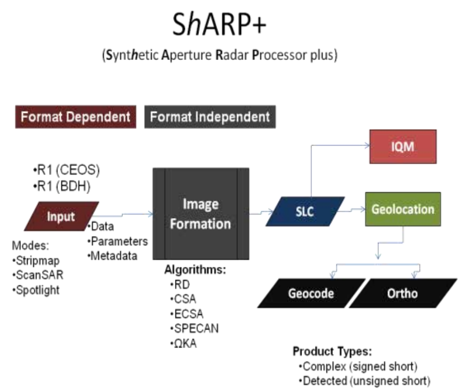

Figure-1: SAR data processing system at ADRIN

1.0 RISAT-1

Radar imaging satellite, RISAT-1 carries a SAR payload onboard operating in the C-band at 5.35 GHz [5] which has the capability to operate in multiple beams and multi-polarization mode. It has fine resolution stripmap (FRS-1) and FRS-2, medium resolution ScanSAR (MRS) and coarse resolution ScanSAR (CRS), high resolution SPOTLIGHT (HRS) and two experimental modes e.g. circular polarization and *sliding SPOT*. Imaging is done in various swaths ranging from 10 km to 223 km with spatial resolutions ranging from 1m to 50m.

Focusing Algorithms: SAR image formation can be achieved through various algorithms published in the literature [4, 5, 6,]. Range Doppler Algorithm (RDA) uses the large difference in time scale of range and azimuth data and approximately separates processing in these two directions using Range Cell Migration Correction (RCMC). The Chirp Scale Algorithm (CSA) provides accurate SAR processing without an interpolator. ScanSAR is a particular SAR mode that achieves very wide swath coverage scanning through several range sub-swaths by periodical switching of the antenna pointing based on burst mode of operation. ScanSAR data can take advantage of the algorithm known as SPECtral ANalysis (SPECAN) which is efficient and requires less memory than RDA, while producing the image quality required for these moderate-resolution applications. There are several algorithms for SPOTLIGHT processing. The type of algorithm is chosen according to the mode and the requirement of phase retention.

Value Added Products : ShARP+ is designed to make value added products for advanced users for special applications.

Standard Product: Geo-tagged SLC : The standard products are available in CEOS format and retain both phase and amplitude. This product is suitable for interferometric and polarimetric studies. Product is geo-tagged and not resampled to Earth reference. Figure-2 shows a geo-tagged SLC product from RISAT-1 cFRS-1 mode.

Figure-2: cFRS-1 mode images of Ahmadabad.

Geocoded ellipsoid corrected product: The standard Geocoded or Geocoded Ellipsoid Corrected (GEC) uses an Earth ellipsoid as local reference [7]. The height of the terrain is approximated by a global elevation model such as 3” SRTM DEM and the scene is geolocated using satellite orbit vectors and other parameters extracted from the image itself. The product is available either in CEOS, Geotiff, ADRIN formats.

Precision Products : The precise or Geocoded Terrain Corrected (GTC) uses the actual terrain heights from DEM. The product is available either in GeoTiff, ADRIN Image Processing Software (AIPS) and CEOS format. Figure-3 shows an RISAT-1 ortho-image over Ahmadabad draped over SRTM DEM.

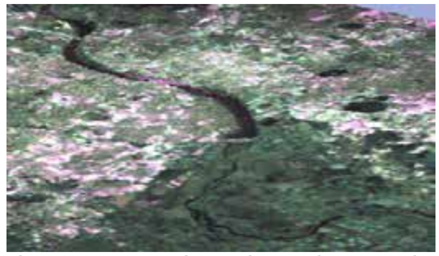

Figure-3: Polarimetric ortho product draped on SRTM DEM.

Special Products : Polarimetric: Each pulse can be transmitted polarized, either vertically (V) or horizontally (H) and the backscatter signal could be either of the two polarizations. The received signal can be single, dual or quad polarized. RISAT-1 has the capability of all the polarization combinations including a Circular polarization. These products are useful to distinguish odd and even bounces on polarimetric combined images suitable for detecting manmade objects like buildings. Figure-4 illustrates an area in San Fransisco, where one can distinguish different type buildings.

Figure-4: Polarimetric combination showing clear distinct between different bounces.

SAR Sharpened: SAR-Sharpening merges high resolution radar and lower resolution multispectral imagery to create a single high resolution colour image. It is similar to the method of PAN-sharpening. PAN-Sharpening merges high resolution panchromatic and lower resolution multispectral imagery to create a single high resolution colour image. “SAR-Sharpening”, on the other hand, uses a radar image instead of a panchromatic one. This gives an intuitive feeling to a user as illustrated in Figure- 5.

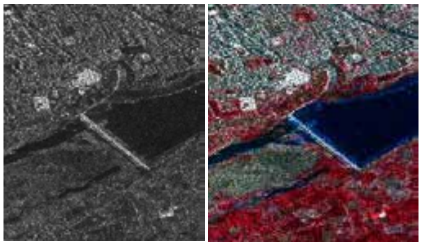

Figure-5: SAR sharpening: left: SAR image, right: SAR fused with IRS-P6 L4 image

Radiometrically Enhanced: Speckle noise is a common phenomenon in any coherent imaging system like SAR imagery. The source of noise is a characteristic of random interference between the coherent returns from many scatterers present in a resolution cell. A radiometrically enhanced technique reduces speckle with minimum or no loss of information like geometric features. Adaptive filters improve the image based on statistics extracted from the local area of each pixel. Various algorithms are built to reduce speckle noise in SAR images.

Radiometrically Calibrated : All SAR products are processed in radar brightness (β^0) representing radar brightness in slant range. Radiometric corrections compensate the effects of local pixel scattering area and incidence angle on the backscatter e.g. radiometrically calibrated product (σ^0) by applying sin(θ_i) factor to β^0 and radiometrically normalized product (γ^0) which represents constant reflectivity over a wide range of incidence angles for rough surfaces and is a product for antenna calibration purposes [8].

Geometrically Enhanced ; Products can be generated in S*h*ARP+ with better image characteristics like spatial resolution and pixel spacing whenever possible.

Mosaicked*:* In order to cover a geographical area larger than a standard scene, adjacent geocoded or orthorectified images are combined into one image in a seamless way.

Moving Train - an Application: Standard SAR processing methods are based on the assumption of a static scene. If the targets are moving, their positions in the SAR image are translated in azimuth direction and defocusing may occur. The Doppler frequency shift (f_d) of a stationary reflector on a SAR image operating in wavelength (λ) is given by

$$f_d = 2V\,sn(\theta)/\lambda$$

Where V is the velocity of the SAR platform and θ is the look angle to the resolution cell.

If the moving train as shown in Figure-6 has a velocity component v_R in the range direction, its Doppler shift is changed with that from a stationary reflector

$$\delta f_d = 2\,v_R/\lambda$$

The SAR processing algorithm transforms the frequency error into angular error ($\delta\theta$) given by

$$\delta\theta = -(v_R/V)(1/\cos(\theta))$$

Giving the target displacement (d) in azimuth direction given by

$$d = R.\ \delta\theta$$

where, R is the range to the train.

In this example the target displacement is 384m on 3m ground sampled FRS-1 RISAT-1 image. This displacement correspond to a speed of 54 km/hr in NE direction.

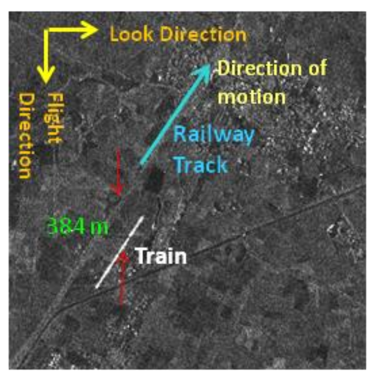

Figure-6: Speed and direction estimation of a moving train on RISAT-1 image

Conclusions: ADRIN has built a *generic* SAR processor handling muti-sensor SAR raw data in all the modes and has the capability of generating standard, precise products in standard formats for any user. It also generates special products for advanced users.

References

- RISAT SAR Payload: DDR Document, SAC/RISAT/DDR/01/2009.
- Image Quality Evaluation - RISAT -2 IPO, SDA&A/ADRIN/TN/June2009.
- SAR Image Formation Processor– DDR, ADRIN/SDA&A/SPD/DDR/Aug2011.
- I. Cumming, F.Wong, digital processing of Synthetic Aperture radar data, Artech House, Boston London, 2005.
-

G.Carrara, R.S. Goodman, and R.M. Majewski, Spotlight Synthetic Aperture Radar, Norwood, MA: Artech House, 1995.

- G. Franceschetti, R. Lanari, Synthetic Aperture Radar Processing, CRC Press, Boca Raton, F.L.,1999.
- J.C. Curlander and R.N. McDonough, Synthetic Aperture Radar Systems and signal processing, New York, Wiley, 1991.
- TerraSAR-X Value Added Product Specifications, Doc No. TSSX-ITD-SPE-0009, Issue 1, Mar2013

DATA PROCESSING CONCEPTS & CHALLENGES FOR MEGHA-TROPIQUES MISSION

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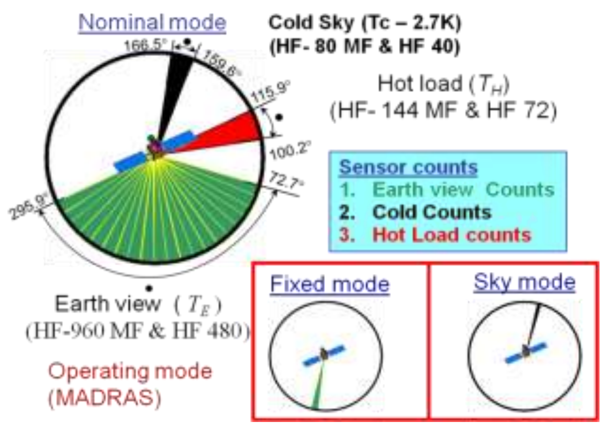
Introduction: The Megha-Tropiques mission was launched on 12th October 2011 from Shriharikota through PSLV launch vehicle by carrying three radiometers namely Microwave Analysis and Detection of Rain and Atmospheric Systems (MADRAS), A microwave instrument for the retrieval of water vapour vertical profiles (SAPHIR) and an optical radiometer devoted to the measurement of outgoing radiative fluxes at the top of the atmosphere (ScaRaB). The satellite orbit is intended for global data coverage with repetivity of 7 days over tropical region for simultaneous and frequent measurement of Brightness temperature and radiance over the path of acquisition. The estimation of Rainfall, water vapor, liquid water, ice, humidity profile, surface winds and radiative flux using above parameters leads to understand the energy and water cycle in tropical convective systems.

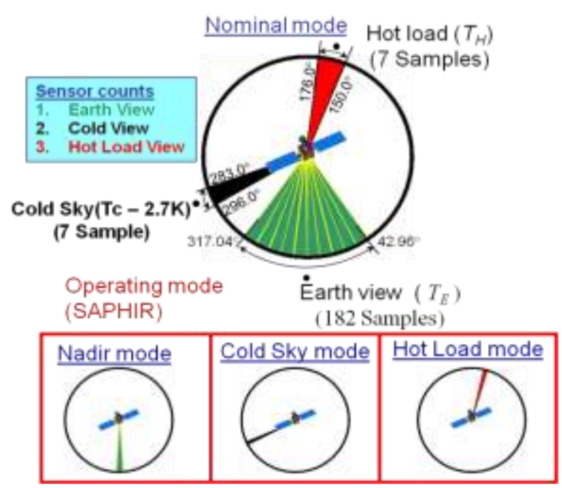
The onboard acquired data is received & processed at ISSDC for dissemination of data to global community with in 180minutes from the time of acquisition.

MT Sensors, Science Parameters & Data products: MADRAS measures the Electro-Magnetic Radiation emanating from all objects within its field-of-view at the microwave frequencies (LF: 18.7GHz (V&H), 23.8GHz (V), 36.5GHz (V&H), MF: 89.0GHz (V&H) and HF: 157.0GHz (V&H)) using conical scanning mechanism at approximately constant incidence angle of 53.3°. The instrument acquires respectively 480 & 960 observations over the swath of 1700km from the altitude of 867km with sampling time of respectively 2ms for LF & MF and 1ms for HF. The MADRAS operating modes are shown in figure: 1a.

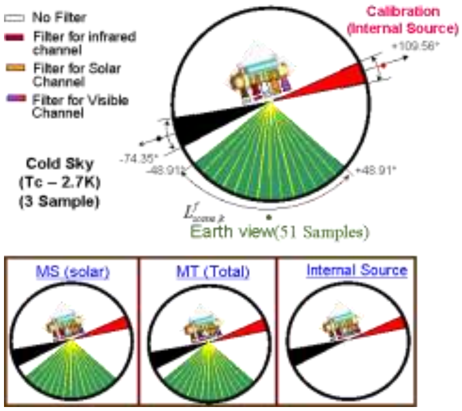
The on-board payload SAPHIR is multi channel passive microwave humidity sounder with its field-of-view through across track scanning mechanism with incidence angle at off nadir ±42.5° around the microwave frequencies 183.31GHz in six annular channels with offsets of ±0.2GHz, ±1.1GHz, ±2.8GHz, ±4.2GHz, ±6.8GHz and ±11.0GHz. The instrument acquires 182 observations over the swath of 1705km from the altitude of 867km with sampling time of 4.576ms. The SAPHIR operating modes are shown in figure: 1b.



(a): MADRAS



(b) : SAPHIR



(c) : SCARAB

Figure: 1 Operating modes

The on-board payload SCARAB is a passive optical radiometer for measuring the outgoing radiative flux at the top of the atmosphere by scanning through its field-of-view (±48.91°) with a across track scanning mechanism for the Visible (0.5to0.7µm), Solar (0.2to 4µm), Total (0.2 to 200µm) and IR (10.5 to 12.5µm) channels. The Long wave (4 to 200µm) is synthesized using solar & total channel. The instrument acquires 51 observations over the swath of 2242km from the altitude of 867km with sampling time of 62.5ms. The SCARAB operating modes are shown in figure: 1c.

The onboard data is dumped at ISTRAC & CNES Ground Stations during their visibility. Data is transferred at ISSDC and payload-wise separated. The processing is done at ISSDC to generate Level-0 products. The Science data products are generated from Level-0 data products by performing radiometric & geometric processing. The Level-1 & Level-2 type products are subsequently generated. Dump-wise Level-1A, Level-1A2, Level-1A3 & Level-1B products are generated at ISSDC and Level-2 products at MOSDAC in near real time for operational users. Orbit-wise products are generated for long term users. The definition of various levels of products are as follow:

Level-0: It is a product comprising of sensor's earth view and calibration related measurements for all channels of three payloads along with the Orbit & attitude information for the satellite.

Level-1A: It is the brightness temperature (MADRAS & SAPHIR) & radiance (SCARAB) geo-tagged product for all channels in scan mode (acquired geometry).

Level-1A2: It is the brightness temperature (MADRAS & SAPHIR) product covering the scan swath with non overlapping MADRAS 89Ghz pixels for MADRAS and non overlapping SAPHIR pixels for SAPHIR sensor products respectively for all channels.

Level-1A3: It is the brightness temperature (MADRAS & SAPHIR) & radiance (SCARAB) product in non overlapping MADRAS 89Ghz pixels grid.

Level-1B: It is the brightness temperature (MADRAS & SAPHIR) & radiance (SCARAB) product in grid Mode with grid interval of 5 km for HF, 10 km for LF and MF of MADRAS sensor, 10 km for SAPHIR and 40 km for SCARAB.

Level-2A: The geophysical products for MADRAS are *Rain fall, water vapour, Cloud liquid water content & Ocean surface wind speed*. The geophysical products for SAPHIR are *Humidity level in six layers.* The geophysical products for SCARAB are *Radiation flux at the top of atmosphere, Short wave flux, Long Wave Flux and Cloud flag.* The Geo-physical products are geo-tagged in scan mode.

Level-2B: The above Geo-physical parameters are generated in grid mode from Level- 2A products.

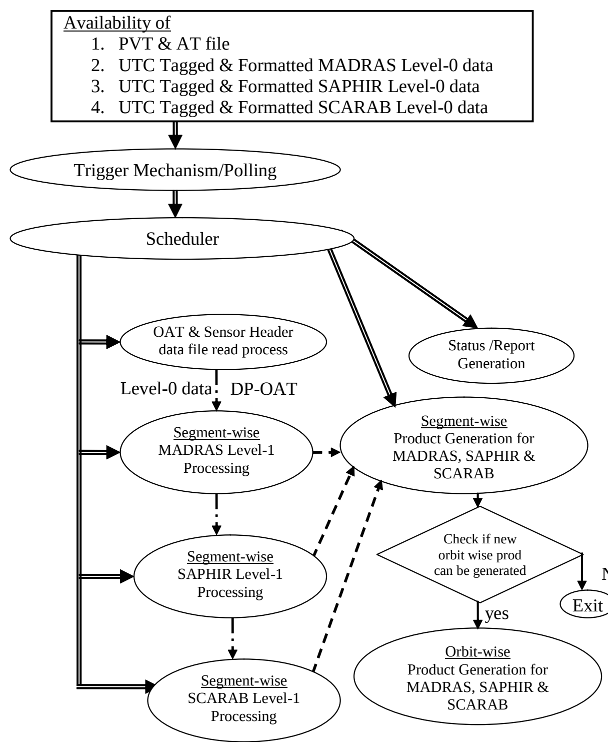
Challenges for development of Data product Generation system: MT Level-1 DP was installed at ISSDC, Bangalore. The requirement of MT Level-1 DP system was to incorporate auto Trigger mechanism with single scheduler to handle the three payload data processing, capabilities to handle the processing history, processing information extraction capabilities, orbit-wise processing, acquisition data anomaly detection & correction namely time jump, madras count anomaly, invalid quaternion in oat file, and quality of data. The turnaround time requirement for the processing was 180 minutes from the time of first data acquisition in an orbit. This translated to the requirement completing Level-1 data processing within

25minutes for an orbit dump of 102minutes duration.

These requirements had added enormous complexity in scheduling and Level-1 core segment. The various processes related to processing & scheduling were decomposed in to 1786 components. Software corresponding to these processes were customized to perform the jobs like process chain activation, process scheduling, database management, Level-0 data validation, radiometric parameter estimation, geometric parameter estimation, swath grid generation, grid mode parameter estimation & format generation. Over and above these software elements, there was a requirement for development of a Quick Look Display system(QLD) in initial phase of operations to check the quality of the data as and when it was received at ground station to quickly detect any anomaly in the data.

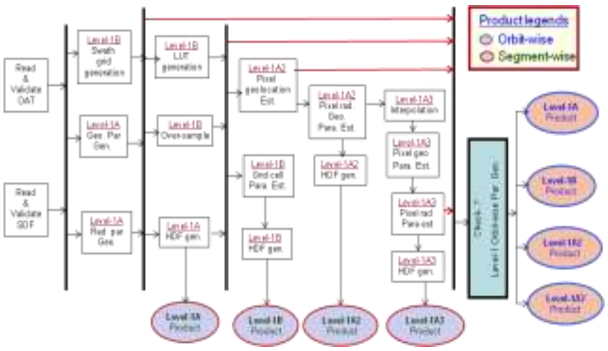
Level-1 Data product Generation system: MT Level-1 data processing has been broadly divided into two parts, namely MT Level-1 Data processing scheduler and Level-1 core data processor. The Level- 1 data processing is based on jointly agreed ISRO-CNES product definition & algorithm requirements. SAC DP team has developed data products software, configured processing systems (figure-3c) and Operationalized software at ISSDC. The system is designed to cater generation of 11 types of products as described in section 1.1. The generated products are jointly validated by ISRO & CNES teams for every update of operational software at ISSDC.

MT-DP Level-1 scheduling process is designed in such a way that it can initiate processing segment-wise, orbit-wise and emergency products by acting on information provided by trigger mechanism(figure: 2a). It either gets activated on receipt of completion status from Level-0 processor by a trigger daemon or by availability of OAT & SDF files confirmed by polling. Emergency mode processing can be initiated by prioritizing. The scheduler invokes Level-1 processing for a given segment for three payloads in three multi-CPU machines. The input for the Level-1 processing is OAT files and respective sensor acquired data along with time tagged information in specified format. Level-1 processes are initiated on multiple cores to optimize computational time (figure-2b). The scheduler initiates Level-1 software for orbit-wise product generation when all processed segments corresponding to the given orbit are available (figure-2a). The scheduler activates tasks e.g. database updation, disk space management and report generation, etc. The process control flow from input to output in accordance with the definition of activation of different processes and definition of synchronisation bars. The processes between the two synchronisation bars are physically independent processes. After completion of execution of all these processes between two bars, the process control is transferred to the next bar and so on till process control has not reached to end of processing schedule.

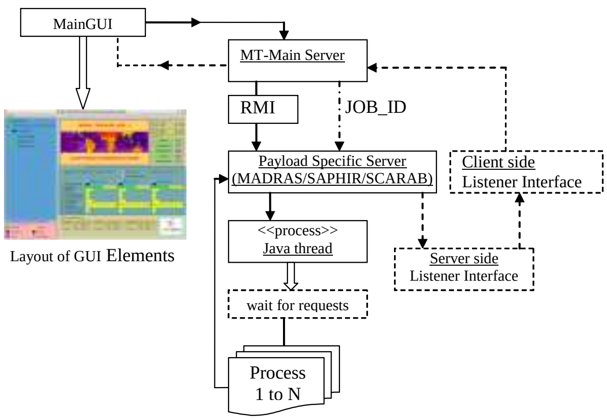


(a) MT Level-1 DP Activation

(Figure Continued on next page)



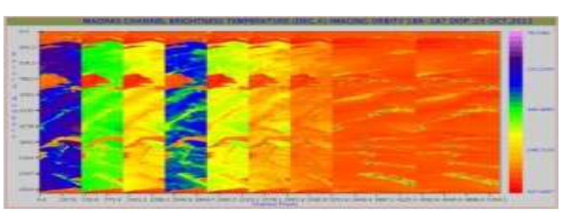
(b) MT Level-1 DP Processing Chain



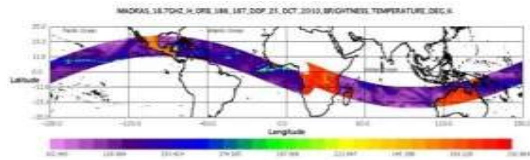
(c) Communication between main GUI thread and distributor thread

Fig. 2: MT DP Level-1 Product Generation System

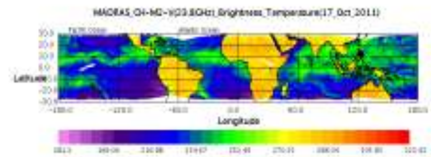
The interaction between scheduler and Level-1 processor for a given payload is presented Figure 2c. The Distributor process handles Level-1 processing for different payloads. Any event caused by an operator intervention/input is also routed similarly. Client/Server Remote Method Invocation (RMI) establishes a two-way communication protocol. The MT-Level-1 products are depicted pictorially in fig.3.



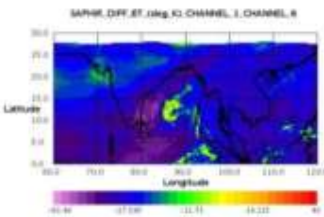
(a) MADRAS Count Data for Channels



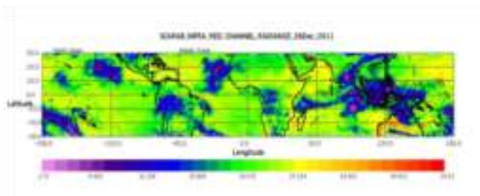
(b) MADRAS data corresponding to one dump



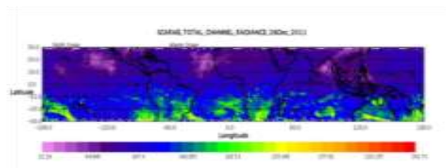
(c) MADRAS Data for a day(9 dumps)



(d) SAPHIR data(Channel:1-6)



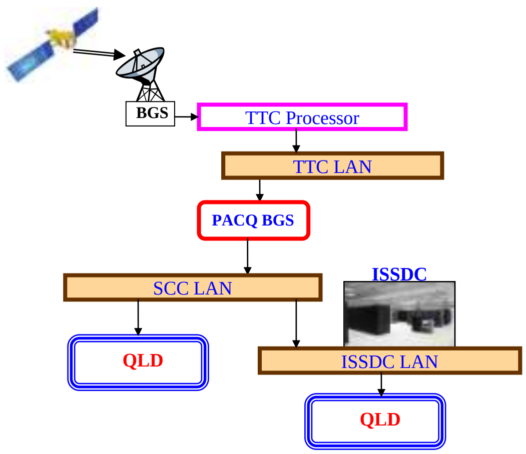
(e) SCARAB IR channel



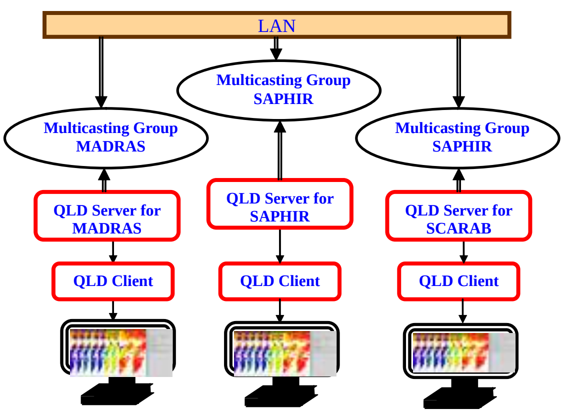
(f) SCARAB Total channel

Fig. 3 MT data products

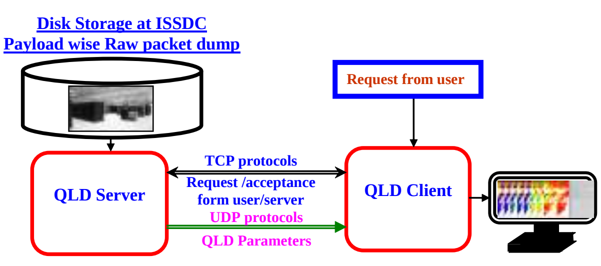
Quick Look display system: This utility is designed to provide first look on the quality of data as and when it is received at ground station and data packets are flooded in the network. The QLD software is designed and implemented for MT payloads based on client/server architecture to receive the packets at the rate as they arrive, decode the packets and display the science observations. It is operated in two modes namely operational mode & offline mode. In the operational mode, data packets are received from payload data acquisition (PACQ) system by the QLD server and sends to the QLD client for display as well as storage. The QLD server for each payload receives and decodes the packets, extracts science data and scan-wise sends to the QLD client for display. In offline mode utility is developed to review the stored data. The QLD interface in operational & offline mode is shown in Figure 4. The view of display for a dump orbit is shown in Figure 5.



(a) Interface for Operational Mode

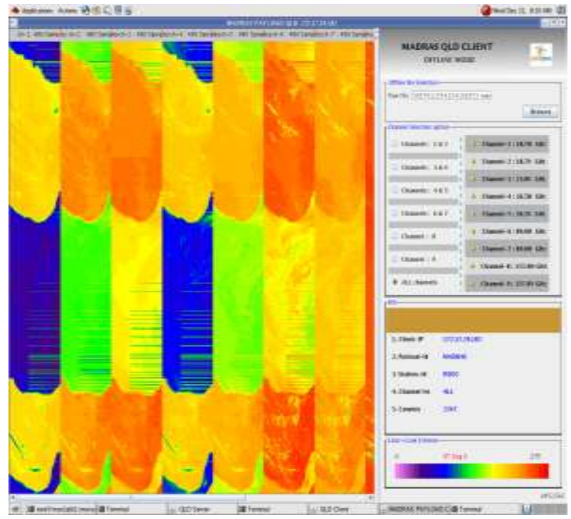


(b) software chain for Operational Mode



(c) Interface for offline mode

Figure: 4 Quick Look Display system



MADRAS Anomaly

Figure: 5 Quick Look Display

Orbit-wise product generation: The orbit-wise product is generated by patching contiguous dump-wise segments (Figure: 6).

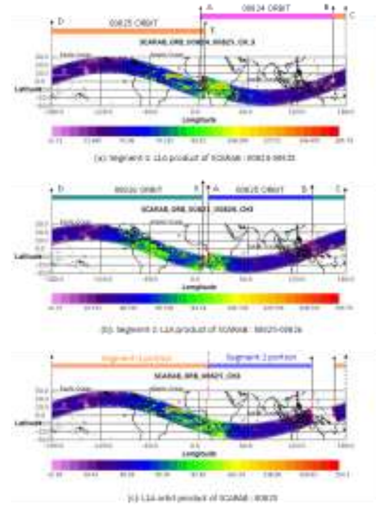


Fig. 6 :Orbit-wise product eneration

Level-2 Data product Generation system: The level-2 Data Processing scheduler gets activated after receiving the trigger. This trigger signifies the availability of the level-1 products in the input area of the level-2 data processing chain. The input for the level-2 processing is level-1A product for all the three payloads. The scheduler processes the level-2 processing for a given segment or orbit for the three payload MADRAS, SAPHIR & ScaRaB in multi-threaded environment to optimize the computational time. The scheduler also updates the database after the completion of the level-2 processing for each segment or orbit. The scheduler also has the feature of disk space management, report generation and Electronic notification system.

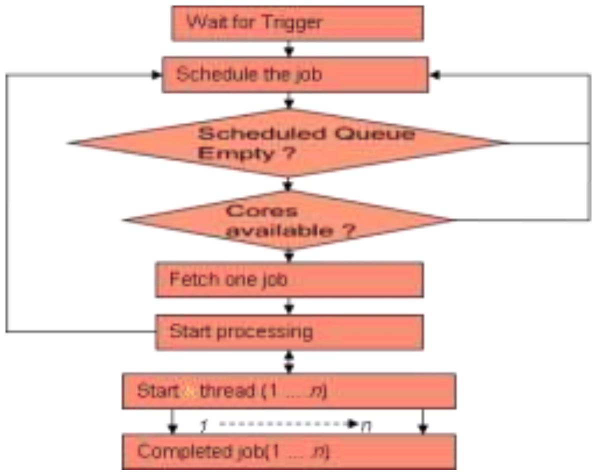


Fig 7: Level-2 Data Processing

Turnaround time: After on board data acquisition, the Level-0 is processed to generate Level-1 & Level-2 products to disseminate the data to science user like ICARE, CNES, France ,NCMRWF, Indian & global agencies for assimilation. The Level-1 processing is carried out on three 4 CPU 6 core machines and it takes around 15 minutes time at ISSDC whereas Level-2 processing is carried out on one 4 CPU 6 core machines at MOSDAC and it takes 10 minutes time. The turnaround time required for data downloaded at ISTRAC and CNES ground stations are provided in the table below.

Table 1: Data turnaround times

Parameters	ISTRAC	CNES
Data Acquisition time	110min	
Data transfer time to ISSDC	3min	22min
Level-0 processing time	8min	
Level-1 processing time	20min	
Data transfer time to MOSDAC	5min	
Level-2 processing time	10min	
Total turn around time	156min	173min

Conclusion: The Operationalization of MT Level-1 data processing at ISSDC and Level-2 at MOSDAC have been materialized and the designed and developed DP software takes care of complexities of the processing and operational requirements. The brightness temperature and radiance products generated for the three payloads have been analysed for radiometric and geometric characteristics and product formats. Sensitivities derived from Brightness Temperature and Radiance fields have met the specifications. The geo-location accuracy requirement of 5Km is met.

Acknowledgment: The Megha Tropiques Data Products team is thankful to Shri AS Kiran kumar, Director, SAC for periodically reviewing Megha Tropiques Data Products related activities. We are thankful to Shri Santanu Chowdhury, Deputy Director, SIPA for technical guidance and review. We are thankful to Dr. R Ramakrishnan, GD DPSG for encouragement and support. We are thankful to Ms. N Karouche, Mr. C Goldstein and other CNES Team members for discussions on Level-1 product definitions, algorithms, and software and product validation.

References:

- Volume-4: Megha-Tropiques Level-1 Data Products System for MADRAS, SAPHIR & SCARAB Payloads (Preliminary Design Review Document), Dinesh Kumar Jain, Bakul G Vaghela & Santanu Chowdhury, ISRO-MT-SAC-DP-40-2007, dated 25-04-2010.
- Volume-2: Megha-Tropiques Level-1 Data Products System for MADRAS, SAPHIR & SCARAB Payloads (Critical Design Review Document), Dinesh Kumar Jain, Bakul G Vaghela, MPT Chamy & Santanu Chowdhury ISRO-MT-SAC-DP-40-2007, dated 25-04-2010.
- *Megha Tropiuqes Level-1 Products Definition*, ISRO & CNES DP Teams, TRO-0-ST-1610-CNES, Ed2 Ver 3 dated 27-09-2011
- "MEGHA-TROPIQUES Data Processing System" by Dinesh Kumar Jain, Meenakshi Sarkar, Bakul G Vaghela & MPT Chamy, Signatures, Newsletter of the ISRS–AC, Vol. 24, No.3, July-Dec. 2012
- "Quick Look Display Software for Megha-Tropiques MADRAS SAPHIR & SCARAB Payloads" by Bakul Vaghela, Dinesh Kumar Jain, Devang Mankad & Santanu Chowdhury, SAC/SIPA/AIPG/TN-14/September, 2009.

OCEANSAT-2 SCATTEROMETER DATA PROCESSING, PERFORMANCE EVALUATION & UPDATION PLAN

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Introduction: The oceans of the Earth play very important role in regulating the earth environment. An accurate understanding of current conditions over the ocean is required to predict future weather patterns. Satellite remote sensing has the potential to provide measurements of local weather conditions with high repeat cycle and spatial resolution. Oceansat-2 launched in September 2009 with ocean colour monitor and scatterometer payload was aimed for understanding global weather patterns. Of primary importance in the remotely sensed data is the determination of accurate wind fields over the oceans' surface to support global weather forecasting, air/sea interaction studies and climate change programs. When wind blows across the ocean, it causes the generation of very small surface waves, called capillary waves. These waves are on the top of the much larger ocean waves. Scatterometers can be used to measure the amount of backscatter of the ocean surface. Multiple spatially and temporally collocated measurements of radar cross-section, obtained from different viewing geometries, can be used to estimate wind velocity if the dependence between backscatter cross-section and environmental conditions are known for the particular radar and geometric parameters of the instrument. Calculation of the wind velocity from scatterometer measurements involves (i) acquisition of accurate, colocated measurements of the backscatter cross-section of the ocean from several different viewing geometries, (ii) knowledge of the model function which is relationship between the backscatter cross-section, environmental conditions (mainly wind velocity) and radar parameters; and (iii) determination, using an objective algorithm, of wind velocities consistent with both the set of backscatter measurements and the model function ("wind retrieval").

Oceansat-2 Scatterometer data processing: Figure (1) displays viewing geometry of Oceansat-2 scatteormeter payload. The entire process of data products generation from pencil beam scatterometer raw data can be divided in to following major tasks:

(1) Doppler Compensation
(2) (Echo +noise) energy and noise energy detection and noise subtraction
(3) Internal calibration
(4)Correction for antenna gain and computation of σ_0 at
slice level
(5) Computation of σ_0 on a grid basis
(6) Wind vector estimation

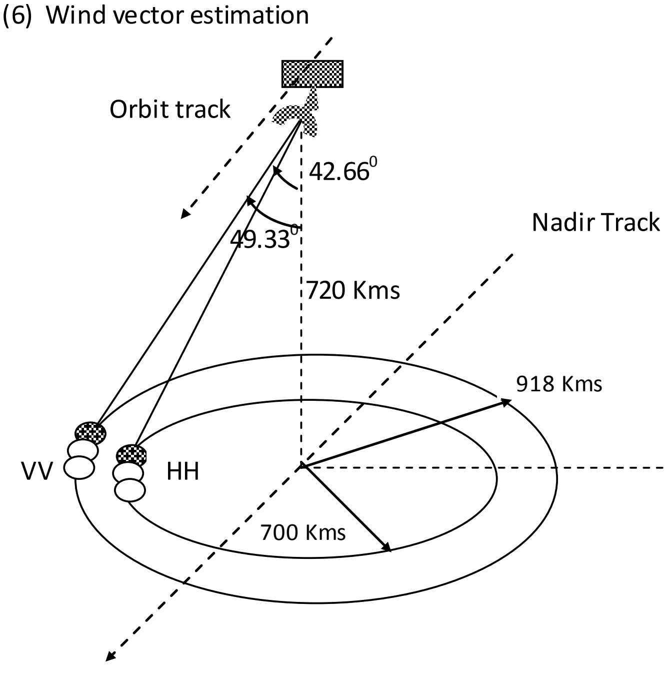

Figure 1: Oceansat-II Scatterometer Viewing Geometry

Originally the data downloading was planned at Shadnagar only and products generation and dissemination was planned at 12 hours interval in a day at 6 PM and 6 AM. However with the interest of international users like NASA, NOAA, EUMETSAT and KNMI the scenario for data processing and dissemination was changed. It was planned to download every orbit at Svalbard and transfer the data from Svalbard to Shadnagar through 45 Mbps link and disseminate data within 180 minutes of acquisition which includes 100 minutes of orbit duration. The achieved turnaround time is 155 minutes. Figure 2 display the data flow diagram for Oceansat-2 scatterometer.

Scatteormeter data products: The inner beam with HH polarisation has a footprint size of 26 X 46 km and outer beam with VV polarisation has a footprint size of 30 X 69 km. In nominal configuration with slice bandwidth of 9.54 KHz, inner beam will have 7 slices and outer beam will have 12 slices.

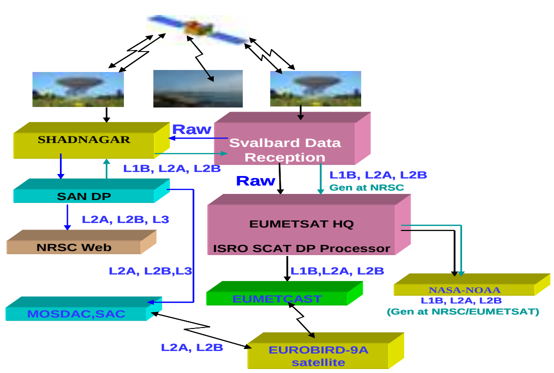

Figure 2: Oceansat-II Scatterometer data flow

The various levels of data products consists of Level-1B (sigma-0 product in scan mode), level-2A(sigma-0 product in swath mode), Level-2B (wind product in swath mode) and Level-3S and 3W (global sigma-0 and wind product for a day).

Modelling of noise measurements: Post launch, it was found that there is a 30° interpretation error in decoding the angle decoder value by the onboard processor. This resulted in the Doppler component due to scanning geometry not getting fully compensated for all scan angles. The uncompensated component causes the footprint centre to drift over a wide range of positions instead of remaining stationary around the centre of the signal+noise sample set. The footprint centre can be allowed to migrate in such a way that all the slices for the HH and VV beams lie within the 32 sample set. In order to ensure the above requirement and also to see the normal functioning of other payloads onboard, the spacecraft was given a -20° yaw bias for data acquisition in the operational phase. Due to residual Doppler not being compensated onboard, for some scans of VV beam, we observe that either the left noise or the right noise gets distorted or saturated for a certain range of scan angles. This happens for a larger number of scans for VV beam and few scans in the HH beam. Figure (3a) describes left and right noise characteristics for a scan for outer beam and figure (3b) display the blended noise for a scan.

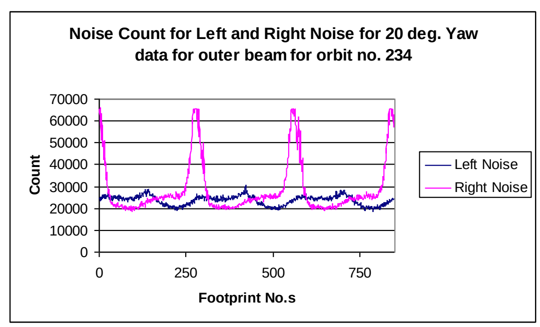

Figure 3a: left and right noise for a scan

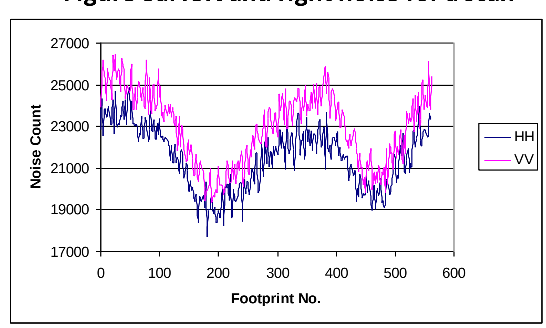

Figure 3b: left and right noise blended for a scan

Back scattered count, C_S is defined as difference of S+N sample and noise sample.

$$C_S = C_{S+N} - C_N$$

The value of signal+noise in general remains higher than noise. But in cases like calm sea, it can be even lower than noise. Hence, back scattered count can have both the polarities. The occurrence of negative back scattered count increases with decreasing sigma-0 parameter. A slice with a noise equivalent sigma0 value is represented by a unique percent of negative sigma0 Vs SNR characteristics. This characteristic should be invariant over all footprint positions. The Oceansat-2 Scatterometer platform was reoriented so that the OCM payload could image moon while the Scatterometer can scan free space. The signal and noise component during this event is analyzed. A bias to equalize percentage of negative back scattered counts (or sigma-0) over a scan was derived as a function of footprint position. Figure (4) describes bias for footprint position for adjusting % of negative sigma-0. Also this is monitored with deep space observations at regular interval as shown in figure (5a and 5b) with S+ N and N counts.

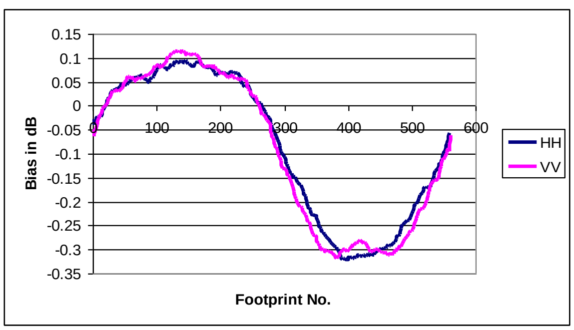

Figure 4: Bias for adjusting % of negative

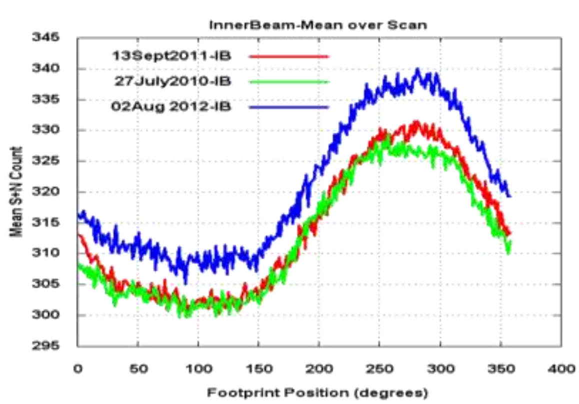

Figure 5a: S+N count for HH beam for deep space

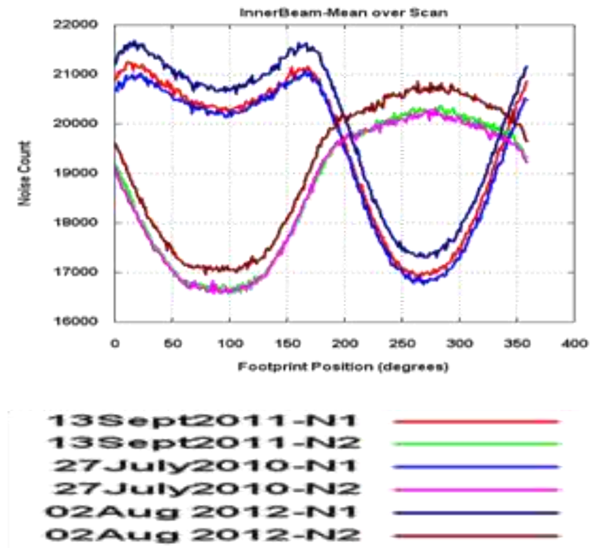

Figure 5b: N1 and N2 count for HH beam for deep space

Consistency of Sigma-0: Consistency of sigma-0 has been checked at regular interval with respect to wind and also with natural targets. Fig. 6(a) describes sigma-0 and relative wind direction characteristics and fig. 6(b) describes comparison of O2SCAT sigma-0 and NSCAT-2 model sigma-0 with respect to wind speed for different seasons.

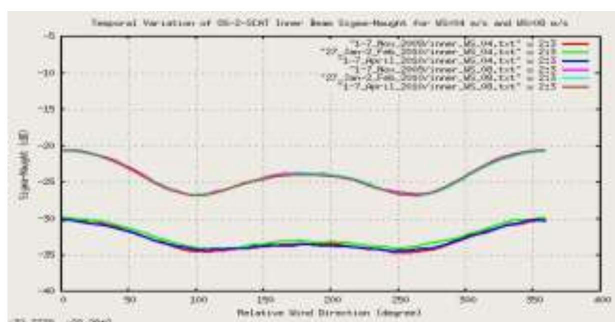

Figure 6(a): Sigma-0 and relative wind direction

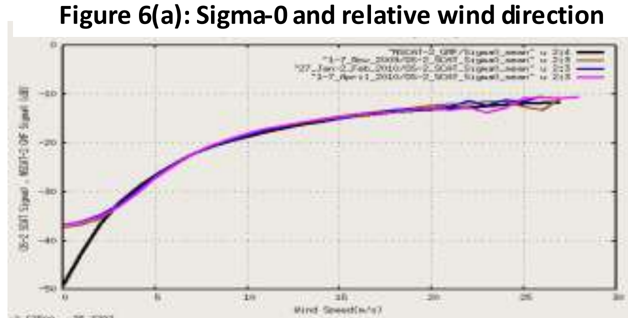

Figure 6(b): O2SCAT and NSCAT-2 model Sigma-0 and wind speed

Figure 7(a) and (b) show amazon area mean and standard deviation of sigma-0 for VV polarisation over 3 years. The region with green colour indicate no data.

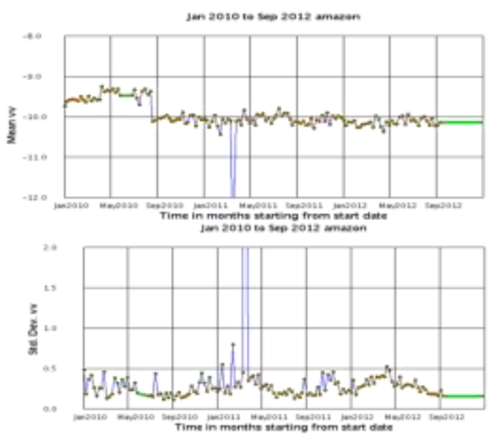

Figure 7 (a) & (b): Amazon area VV polarisation mean sigma-0 and standard deviation of sigma-0

(Level-2B) are provided on a 50 km grid. The Level-2A sigma-0 product is a composite sigma-0 generated from slice sigma-0. The geometric accuracy has been evaluated at slice level, footprint level and Level-2A sigma-0 products using land-sea flag and sigma-0 values. The product accuracy is better than 25 km.

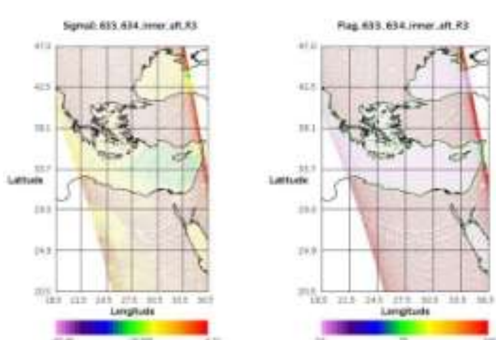

Figure 8a: footprint level sigma-0 and land-sea flag

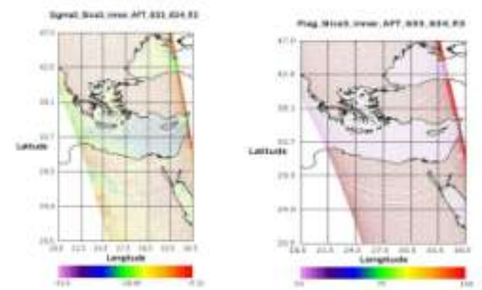

Figure 8b: Slice level sigma-0 and land-sea flag

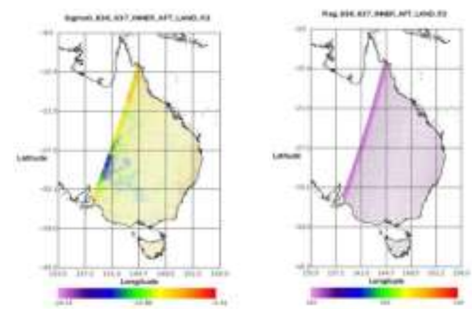

Figure 8b: Level-2A: sigma-0 Land area and land-sea flag

Software Updation: The Oceansat-2 Scatterometer data products are operationally generated in an automated way from data downloading to products dissemination for the past three and half years successfully through software version 1.3. The products are being used by various national and international agencies including NASA, NOAA, EUMETSAT, KNMI etc. A limited comparison has been done with Quik-scat re-pointed data at one scan angle and look angle similar to that of Oceansat-2 Scatterometer. The data quality has been found to be satisfactory for operational use by various user agencies. There is plan to generate climate quality products and also 25 km grid interval products. Sample data sets with 25 km has been already generated (Figure 9) and provided to users and feedback has been obtained. Over the time it has been observed that there is minor increase in noise as well as signal + noise level. Due to this the brightness temperature computation needs to be corrected as only noise data is used for that. However, sigma-0 computation is not affected due to this. The next version of software upgrade (version 1.4) is planned in near future to take care of change in brightness temperature due to change in noise level.

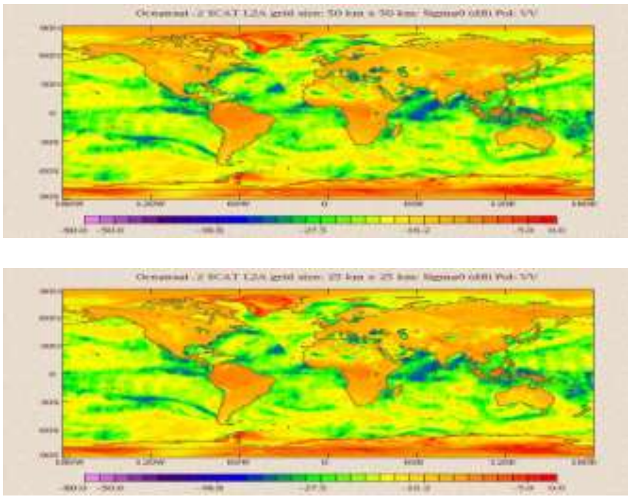

Figure 9: Level-2A: sigma-0 50 km and 25 km grid

Acknowledgements: The authors would like to thank Shri Santanu Chowdhury, Deputy Director, SIPA, for technically reviewing the activity during development and operationalization of O2SCAT data products software. Thanks are also due to Dr. R. Ramakrishnan, Group Director, DPSG and SIPA for encouragement and support at project level. Last but not the least, we thank support from members of AIPD and other colleagues involved in O2SCAT data processing related activities.

ROSA DATA PROCESSING

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Introduction: The ROSA (Radio occultation sounding of the atmosphère) receiver is a GPS receiver supplied by Thales Alenia Space, Italy for SPACE-borne applications, specifically designed for limb sounding of the atmosphère by radio occultation to obtain profiles of temp., pressure, humidity and electron density etc. [1,2]. There have been many missions earlier carrying on-board GPS receivers providing radio occultation data for atmospheric remote sensing, viz., GPS-MET, CHAMP, SAC-C, GRACE, COSMIC, TerraSAR-X, EQUARS, METOP etc.. Oceansat-2 (O2) ROSA (Radio Occultation Sounding of the Atmosphere) payload (launched on 23 September 2009) carried a GPS Receiver mounted in velocity direction to detect rising occultations whereas Megha-Tropiques (MT) ROSA (launched on 12th October 2011) carried two receivers mounted in velocity as well as anti-velocity directions to detect both rising and setting occultations. The instrument provides real time raw and navigation data (position, velocity and time) as a typical GPS space receiver. ROSA payload operates in L-band frequencies of L1 (1575.42 MHz); C/A code signal and P code signal and L2 (1227.60 MHz); P code signal [3].

Principle of RO Technique: Earlier this technique was used for measuring the physical properties of the planetary atmosphere by detecting changes in a radio signal as it passes through the planet's atmosphere i.e., as it is occulted by the atmosphere. The radio signals traverse a long atmospheric limb path as a moving receiver or transmitter sets or rises behind the horizon. When electromagnetic radiation passes through the atmosphere it gets refracted. When the radio wave is refracted and its travel time is delayed due to variations in refractivity, the angle with which it bends can be calculated using the Doppler shift of the signal, with known geometry of the transmitter and receiver.

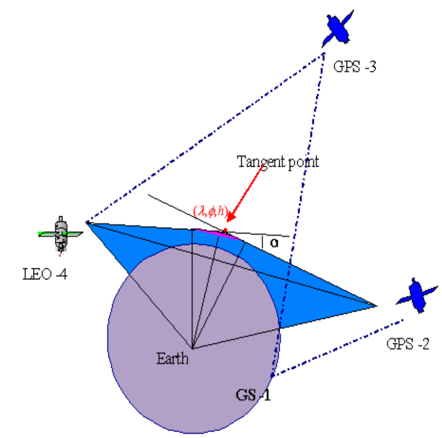

Figure 1 : Occultation geometry

The amount of bending can be related to the refractive index by using Abel transform. The refractivity derived from refractive index, depends on the electron density in the ionosphere, and on the pressure, temperature, and humidity in the atmosphere. Information on the refractivity structure of the atmosphere, and hence the pressure, temperature, humidity and electron density of the atmosphere, can then be retrieved from accurate measurements of the amplitude and phase delay of the radio waves. The technique is illustrated in illustrated in Figure 1.

Rosa data products: The GPS observables are recorded as a function of time for L1 and L2 frequencies. The observables are separated as per occultation events [4]. The distribution of occultation events for both MT-ROSA and O2-ROSA on world map is depicted in Figure 2 with events of MT-ROSA shown in 'Green' color and O2-ROSA shown in 'Red' color.

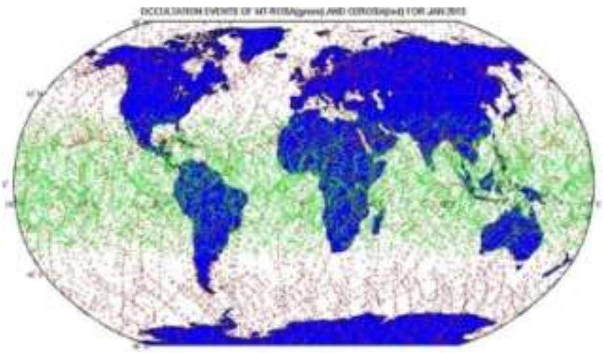

Figure 2

GPS ephemeris and clock bias is obtained from GPS website. Excess phase which is simply the excess phase introduced by the refractivity medium [5] is computed from GPS observables (Pseudo range, carrier phase and SNR) and ephemeris. If the occultation event is of "setting" type, the excess phase values are positive and increase with time. If the occultation event is of rising type, the excess phase values are negative and decrease with time. Occultation geometry is reconstructed and occultation point is estimated and parameters are transferred from earth centered reference frame to local centre of curvature of trajectory. Bending angle profile is estimated using Bouguer's rule and snell's law. Refractivity profile is retrieved from bending angle profile using Abel transform [6]. The refractivity profile is further used to generate temp., pressure and humidity profiles.

ROSA Data processing software has been developed in-house and Level 1 software has been successfully installed at ISSDC for MT satellite and NRSC for O2 satellite. MT-ROSA raw data of each orbit is downloaded at ISSDC, Byalalu for generating data products. O2-ROSA raw data is downloaded dump-wise at NRSC, Shadnagar for generating data products. Figure 1 shows the occultation geometry and Figure 3 shows the overview of ROSA DPGS (Data Products Generating System). The Level-1 products are disseminated to MOSDAC, Ahmedabad for generating Level-2 products. The turn- around time (TAT) is about 3 hours for near real time products and 12 to 18 days for final products. This TAT depends on the availability of GPS ephemeris data via Internet. The following data products [7] are generated:

- <u>Level-1A</u>: These are RINEX (Receiver INdependent EXchange) formatted data files generated from Level-0 raw data using an executable provided by payload designer.
- <u>Level-1B</u>: It is the profile of the behaviour of the excess phase with respect to time.
- <u>Level-1C</u>: It gives the profile of the behaviour of the bending angle, refractivity and impact parameter with respect to height of all occulting events.
- <u>Level-1D</u>: It is same as that of Level-1C with an additional latitude/longitude profiles.

Data products are generated in three Steps:

1. Ultra Rapid product, which is generated on the day of occultation event.
2. Rapid product, which is processed after two days for the same dataset.
3. Final product, which is processed after twelve/eighteen days of occultation.

Typically the range of bending angle is from 0.1 μrad to 40 mrad whereas the range of refractivity is from 0.1 to 360 and the range of height is 0 to 60 km.

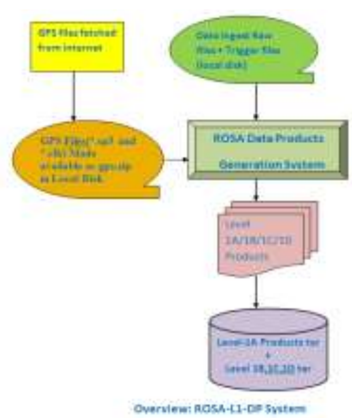

Figure 3

Inter-sensor comparison with cosmic: For inter-sensor comparison study, analysis was carried out between ROSA data product and COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate) data product. For this purpose data product for month of January 2013 of O2-ROSA and MT-ROSA was generated and data product for same period for COSMIC was fetched from UCAR (University corporation for atmospheric research) COSMIC data analysis and archival center (CDAAC) website, http://www.cosmic.ucar.edu/ . The statistical details for the data processing of O2-ROSA and MT-ROSA are there in Table 1.

Table 1: Statistical analysis (Data used: January 2013)

Sensor	Orbits	Events	Event type	Products	(%)
MT-ROSA	388	15100	Rising(7469) Setting(7631)	11895	79
O2-ROSA	100	6960	Rising events only	5066	73

Methodology: To carry out the inter-sensor comparison, co-located and co-temporal events of MT-ROSA and O2-ROSA with COSMIC are selected. Comparison is carried out in terms of relative refractivity bias (between MT-ROSA/O2-ROSA and COSMIC) and RMSD (root mean square deviation) of relative refractivity bias. The relative refractivity bias or the fractional refractivity difference can be defined as [8],

$$\Delta N(\%) = \frac{(N_{ROSA} - N_{COSMIC})}{N_{COSMIC}} \times 100$$

Comparison between MT-ROSA and COSMIC: Co-located and co-temporal events (lat/Lon(±1°), time(±1hr)) of MT-ROSA and COSMIC for the month Jan 2013 are analyzed. Variation of number of co-located events with altitude has been shown in Figure 4. It can be inferred from Figure 5 that the relative refractivity bias varies between ±10% from 0 to 60 km, to be more specific the relative bias is more below 10 km and above 50 km. A similar trend can be observed in RMSD in Figure 6 .

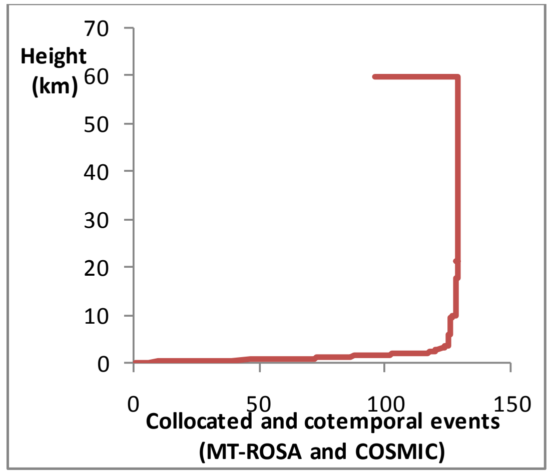

Figure 4

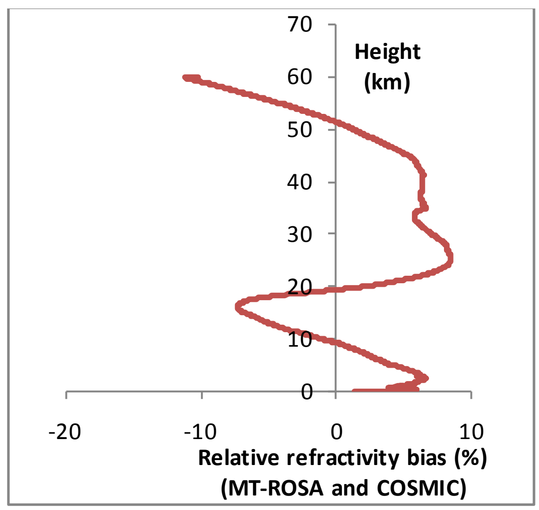

Figure 5

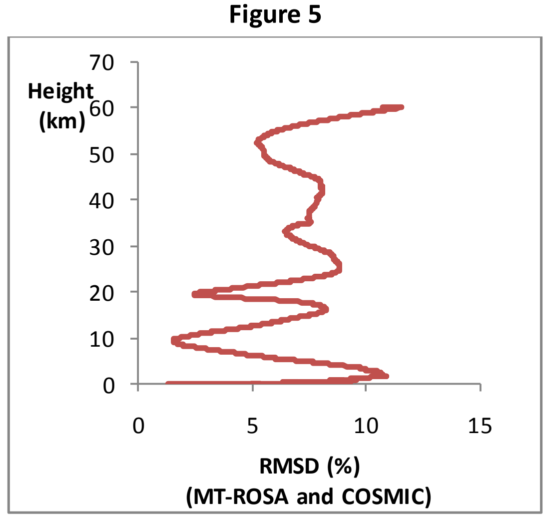

Figure 6

Comparison between O2-ROSA and COSMIC: Co-located and co-temporal events (lat/Lon (±3°), time(±3hr)) of O2-ROSA and COSMIC for the month Jan 2013 are analyzed. The window has been kept more in this case because in O2-ROSA we have only rising events. Variation of number of co-located events with altitude has been shown in Figure 7. Since we have global coverage in O2-ROSA we can categorize the events in low latitude (0 to ±30°), mid latitude (between -30°/30° and -60°/60°) and high latitude (between -60°/60° and -90°/90°) windows to have a better comparison. Just as in case of MT-ROSA the overall relative refractivity bias (Figure 8) follows the similar pattern. Again we can see the overall trend of RMSD from Figure 9, it can be seen that RMSD increases below 10 km and above 40 km. However, in particular it can be observed from Figure 10 that the RMSD value is more for lower latitude and lower height and similarly for higher latitude and higher height.

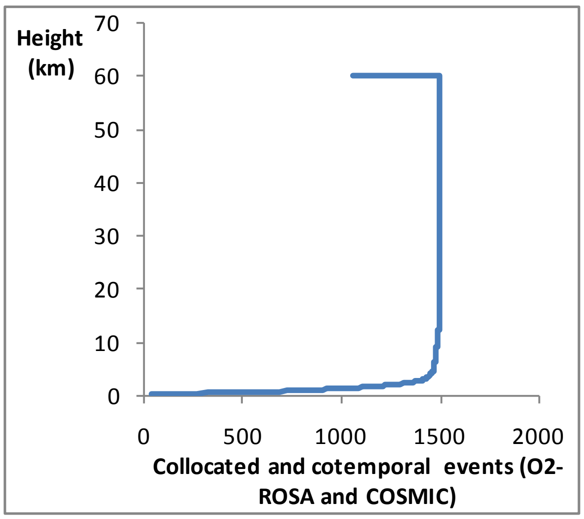

Figure 7

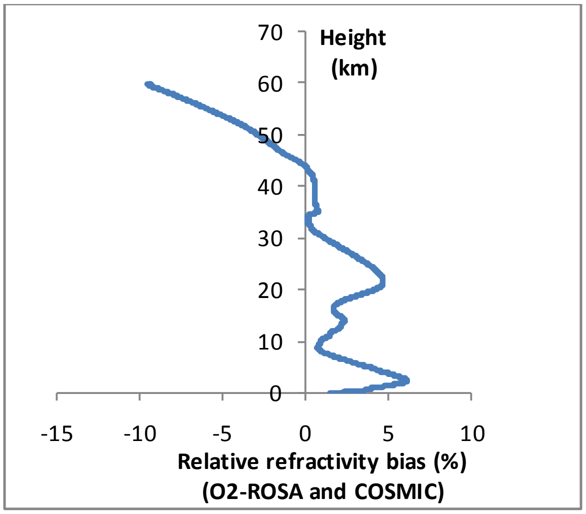

Figure 8

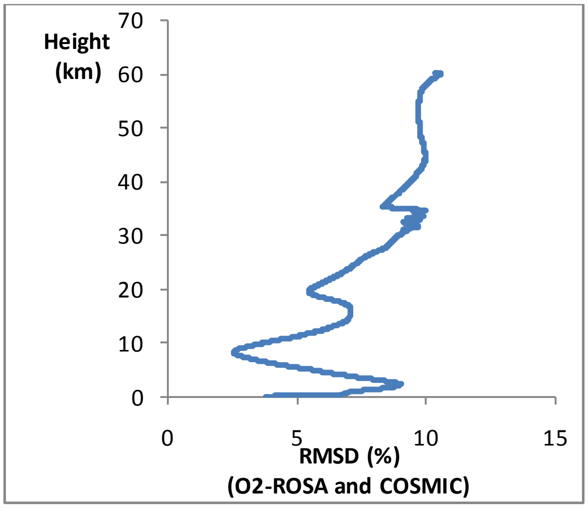

Figure 9

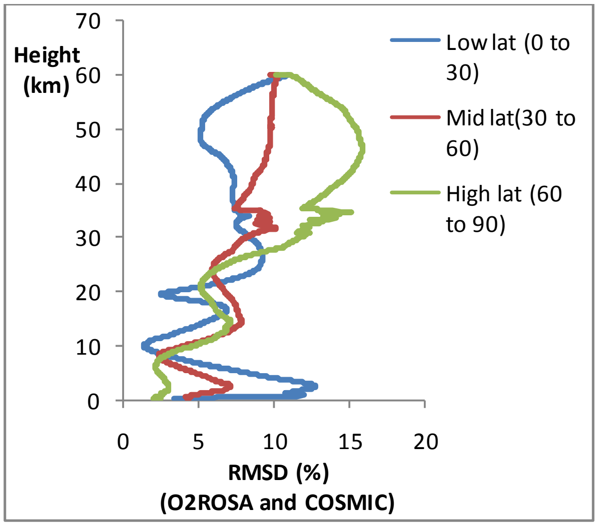

Figure 10

Conclusion: MT-ROSA and O2-ROSA show the overall relative refractivity bias within ±10% (approx.). The overall RMSD (of relative refractivity bias) varies up to maximum of 10-12 %. The relative refractivity bias and the corresponding RMSD increases below 10 km i.e. in lower troposphere, this can be attributed to the complicated structure of humidity causing multipath effect, super refraction and receiver tracking errors [9]. Similarly, the relative refractivity bias and the corresponding RMSD increases above 35-40 km i.e. in upper stratosphere and Mesosphere. In general, the comparison of ROSA co-located and co-temporal occultation events with those of COSMIC show good agreement between 10 to 40 km. The problem in the lower troposphere can be solved by radio holographic methods like FSI (Full spectrum inversion), [10] canonical transform [11] and Back-propagation [12]. These methods allow for efficient computation of bending angle profiles within region of multipath ray propagation. Errors introduced by closed loop receiver tracking are reduced by OL (open loop) tracking [13].

Acknowledgements: The authors are thankful to Shri A S Kiran Kumar, Director SAC for providing guidelines to carry out this activity. We gratefully acknowledge the encouragement and technical guidance provided by Shri Santanu Chowdhury, DD-SIPA. Thanks are also due to Dr. R. Ramakrishnan, GD-DPSG for constant encouragement & supporting the activity. We are thankful to all the colleagues in AIPD for their support. Contribution and support of Dr A Subba Rao during his tenure at AIPD is thankfully acknowledged.

References:

1. Kursinski, E. R., G. A. Hajj, J. T. Schofield, R. Linfield and K. R. Hardy, "Observing Earth's atmosphere with radio occultation measurements using the Global Positioning System", J. Geophys. Res., 102(D19), 23,429-23,465, 1997.
2. "RO study team report", Department of Space, India, January 2009.
3. Subba Rao A, Kshatriya J, Gajaria A and Parasher P, ROSA Overview, Signatures, Newsletter of the ISRS-AC, Vol. 24, No. 3, July-Dec. 2012.
4. Jain D. K, Chowdhury S, "Extraction of instrument parameters of Oceansat-2 ROSA payload for occultation event", SAC/SIPA/AIPG/TN-18/Nov 2009. "ROSA payload for occultation event", SAC/SIPA/AIPG/TN-18/Nov 2009.
5. Melbourne William G., Radio occultations Using Earth Satellites: A Wave Theory Treatment, pp. 5
6. Kursinski, E. R., G. A. Hajj, S. S. Leroy, Herman B, The GPS Radio occultation technique, TAO, Vol. 11, No. 1, 53-114, March 2000.
7. Megha-Tropiques Level-1 RO Data Products System (Critical Design Review Document)", ISRO-MT-SAC-DP-43-2011, 21 July 2011.
8. Kuo, Y.-H., W. S. Schreiner, J. Wang, D. L. Rossiter, and Y. Zhang (2005), Comparison of GPS radio occultation soundings with radiosondes, Geophys. Res. Lett., 32, L05817, doi:10.1029/2004GL021443.
9. Kuo, Y.-H., S.V. Sokolovskiy, C. Rocken, W. S. Schreiner, D. Hunt and R.A. Anthes , Inversion and error estimation of GPS radio occultation data, Journal of the Metrological Society of Japan, Vol. 82, No. 1B, pp.507-531, 2004.
10. Jensen AS, Lohmann MS, Benzon H-H, Nielsen AS (2003) Full spectrum inversion of radio occultation signals. Radio Sci 38(3), 1040, doi:10.1029/2002RS002763.
11. M. E. Gorbunov, "Canonical Transform Method for Processing Radio Occultation Data in the Lower Troposphere," Radio Science, vol. 37, no. 5, 1076, doi:10.1029/2000RS002592, 2002.
12. Gorbunov M E, Sokolovskiy S V, Bengtson L. Advanced algorithms of inversion of GPS/MET satellite data and their application to reconstruction of temperature and humidity. Tech Rep.211, Max Plank Inst. For Meteorol., Hamburg, Germany, 1996.
13. Sokolovskiy, S., Tracking tropospheric radio occultation signals from low Earth orbit, Radio Sci., 36(3), 483–498, 2001.

DATA PROCESSING TECHNIQES FOR ASTROSAT PAYLOADS

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Introduction: Astrosat is India's first dedicated astronomy satellite, which is designed for the study of cosmic sources simultaneously over a wide range of the electromagnetic spectrum; from optical bands to high energy X-rays. This unique simultaneous multi-wavelength capability will allow Astrosat to make very important contributions in many areas of Astronomy. Simultaneous multi-wavelength observations will be made in the range of high energy X-ray to Visible with the help of four instruments viz. Cadmium Zinc Telluride Imager (CZTI, 10-150Kev), Large Area X-ray Proportional Counter (LAXPC, 3-100 KeV), Soft X-ray Telescope (SXT, 0.3-8 KeV) and Ultraviolet Imaging Telescope (UVIT, 120-550nm), as shown in **Figure-1**.

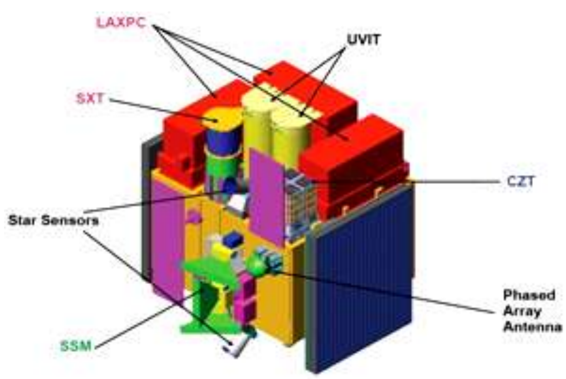

Figure-1: Astrosat satellite

Apart from these instruments, Sky Scanning Monitor (SSM, 2-10 KeV) will scan the sky 24 hrs to give feedback to other instruments for any interesting phenomenon happening in space [1, 2]. Details of instruments are given in **Table-1**.

Science Objectives : Astrosat is an observatory class mission, driven by proposals from user community. Most astronomical objects in the universe emit radiation comprising the complete electromagnetic spectrum from long wavelength radio waves to very short wavelength gamma rays. For a detailed understanding of the physical processes that give rise to wavelength dependent, time variable phenomenon, it is essential to carry out simultaneous multi-wavelength observations, which suits to Astrosat utmost by having such variety of instruments onboard.

Table-1: Instrument description

Name	FOV	Angular Resolution	Description
UVIT	29 arc min	1.8 arc sec	Two Telescopes, three detectors – Far Ultraviolet (FUV), Near Ultraviolet (NUV) and Visible (VIS).
CZTI	17x 17 deg (6x6 deg with CAM	8 arc min	Hard X-ray with Coded Aperture Mask (CAM), high spectral resolution, coarse imaging capability
LAXPC	1x1 deg	~5 arc min	Three instruments, non-imaging, record variation of intensity, high timing resolution
SXT	40 arc min	3-4 arc min	Focusing X-ray telescope with CCD camera, photon counting for position, time and energy
SSM	13x90 deg	5-10 arc min	Three instruments, all sky monitoring

Astrosat has been designed by keeping following scientific objectives [1, 2] in mind: a) determination of black hole masses; linkage between Micro-quasars and Quasars (if any), b) Details of nature of transient behaviour, Quasi Periodic Oscillations (QPO) and its evolution, period evolution, c) continued contribution to existing data on correlation between spectral states and intensity in many sources d) a better understanding of Active Galactic Nuclei (AGN) geometry and activity; additional clues on central source and e) Improved UV morphology, star formation and its evolution, galaxy luminosity function etc.

Data Products : To meet the above science objectives of Astrosat, it is therefore important that the data collected through these multiple instruments be together made available to the user in a timely manner and should be easily usable by astronomers. Space Applications Centre (SAC) is responsible for developing software for Quick Look Display (QLD), Science Data Processing Pipeline and Archive, Browse and Dissemination. QLD will be available at Indian Space Science Data Centre (ISSDC) and Mission Operation Complex (MOX), Bangalore. However a typical science data processing will happen at identified Payload Operation Centres (POC) for various instruments viz. Tata Institute of Fundamental Research (TIFR), Mumbai; Raman Research Institute (RRI), Bangalore; Inter University Centre for Astronomy and Astrophysics (IUCAA), Pune; and Indian Institute of Astrophysics (IIA), Bangalore. After the lock in period, data will be available to general users through ISSDC from archives. Browse and dissemination services will be available via internet hosted at ISSDC. A chain of science data processing software will also be made available at ISSDC for downloading through net by the user.

Three types of products have been defined for Astrosat [1] which are

Level-0: Raw data, segregated by instrument, along with auxiliary information. This is instrument/mission specific and will not be available for public use. Level-0 processing will happen at ISSDC.

Level-1: Reorganized raw data, written in FITS format along with related AUX for astronomical science use. Data will be released on web for science use, first to the Principal Investigator (PI) of the corresponding observing proposal and, after a specified initial lock in period, to anyone interested in the data. However, lock-in period does not apply to SSM data, as it will be available immediately after processing. This level of processing is planned at ISSDC.

Level-2: Contains standard science products (Light Curves, Spectrum, Images as applicable to the instruments) derived from Level-1. Where, light curves and spectrum explain about the source intensity variation with respect to time and energy respectively. Level-2 data would also be in FITS format and will be made available for science use, with the same lock-in criteria and release mechanism as for the Level-1 data. Similar to Level-1, the lock in criterion does not apply to SSM data. This level of processing is planned at POC. Apart from Level-2 data processing pipeline, QLD and Archive, Browse and Dissemination are also being developed by SAC.

With respect to the earth observation satellite data processing, data products for astronomical observations have certain new elements as it is planned first time in India. Some of them which were studied, researched and implemented during the development are X-ray imaging and data processing, Flexible Image Transport System (FITS), astrometry, X-ray spectroscopy, handling catalogs for X-ray and optical observations, calibration schemes/policies, software distribution through internet and product verifications.

Quick Look Display : QLD software is a real-time payload data concurrent displayer for UVIT, CZTI, LAXPC and SXT payloads. It has been developed in JAVA on LINUX platform. QLD software helps in quick assessment of payload performance for taking necessary corrective actions if required. QLD software works in client-server architecture and has two components namely QLD server and QLD client. QLD server does the real-time reception of payload packets in multicasting mode and processes each packet for every payload. Subsequently processed output of each payload data is transmitted to QLD clients of respective payloads. QLD clients of each payload have the algorithm built-in to generate light curve, spectrum and images and display it in required details. Each of image frames is enhanced for better display and has the additional option of changing brightness/contrast. Apart from processing of payload data, QLD server also extracts required telemetry information from space packets for data interpretation. QLD software is capable of receiving, processing and displaying immediately. **Figure-2** gives snap shots of server, client GUI and displays of LAXPC and SXT [3].

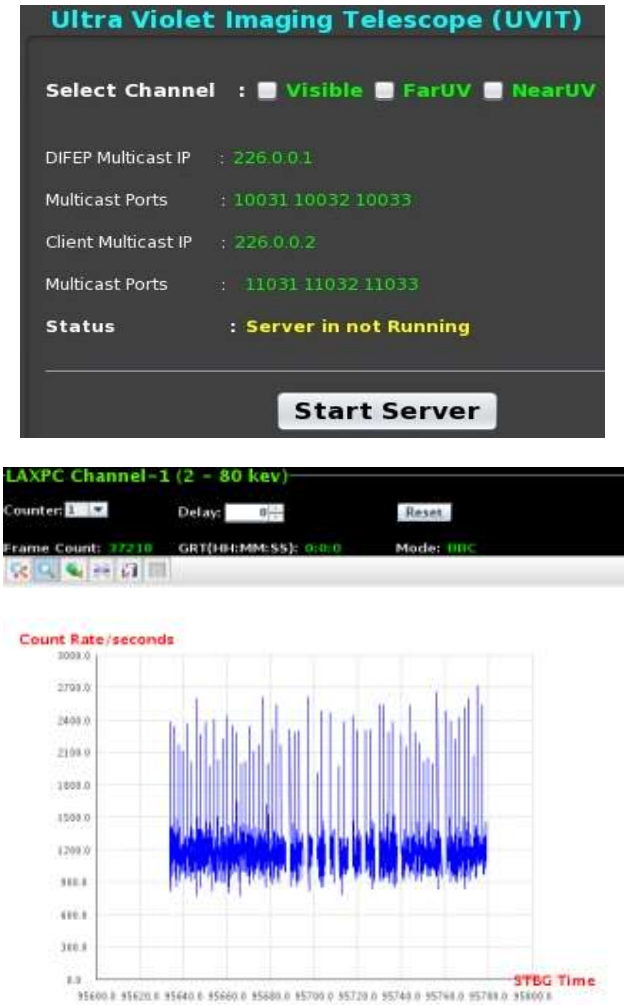

Figure-2: Astrosat QLD server/client with display of LAXPC

Continuous benchmarking and optimization of the software helped in achieving the real-time processing performance.

Level-2 Software: Level-2 s/w will be disseminated (executables as well as source) along with the Level-1 data to aid the user for getting Level-2 data (science output) at their end. Therefore open source libraries; common to all existing astronomical missions, has been used to develop Level-2 software. For FITS, read and write standard CFITSIO is used. However for parameter input and output at various stages of pipeline Parameter Interface Library (PIL) is used. For logging purpose, LOG4CPP and GoogleLOG are used in Level-2 software. Linux (RHEL 6) platform as Operating System and C++ language has been chosen to develop the software. However, windows compatible software will be produced later in due course of project. All the outputs of Level-2 pipeline can be visualised by FITS Viewer (FV). Some simulated outputs based on laboratory data are presented here for four instruments viz. CZTI, LAXPC, SXT and UVIT [4].

CZTI Level-2 Software Pipeline: CZTI is a hard X-ray instrument operated using a CAM imaging technique. It has 64 CZT detectors each with 16 x16 pixels which are divided into 4 quadrants. This instrument can be operated in normal mode, shadow mode, South Atlantic Anomaly (SAA) mode, fixed packet or reduced packet command mode. The four quadrants can be operated in different modes at a given time. CZTI will target hard X-ray sources such as Gamma Ray Bursts (GRBs), Quasars, Pulsars, Accreting Black Holes etc.

The level-2 software of CZTI provide the users with tools to process the data received from the instrument and generate products viz. Light Curve, Spectrum and Sky Images. The software provides the flexibility to play with different options/parameter values for generating products which is required for their data analysis. The Level-2 software basically contains modules for data decoding, energy mapping, bad pixel detection and filtering, event cleaning, average aspect generation, shadow generation, light curve generation, Sky Image reconstruction and celestial coordinates tagging (RA, DEC). **Figure-3** gives sky image and spectrum of three simulated sources.

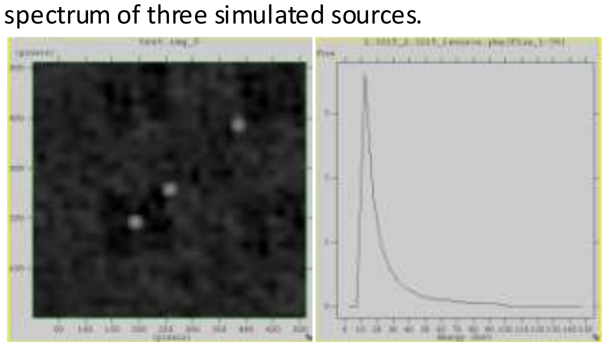

Figure-3: Sky image and spectra from CZTI s/w for simulated source

LAXPC Level-2 Software Pipeline : LAXPC has three modes of operations viz. Broad Band Counting (BBC) mode, Event Analysis mode (EA) and Fast Counter mode (FC). There are three co-aligned identical LAXPC instruments mounted on Astrosat which makes light collecting area wider for maximum photon collection. Each of the three detectors will operate in any of the three modes simultaneously. The Level-2 data pipeline software will run for each detector separately. The functionalities of Level-2 software pipeline includes data screening based on customised criterion on time and counters, universal coordinated time (UTC) conversion, barycentre correction, generation of light curve and spectra on valid combinations of counters. Also, the functionalities like merging two observations spliced for single or multiple sources are available in the software. **Figure-4** represents light curve and spectra of a laboratory source from EA mode.

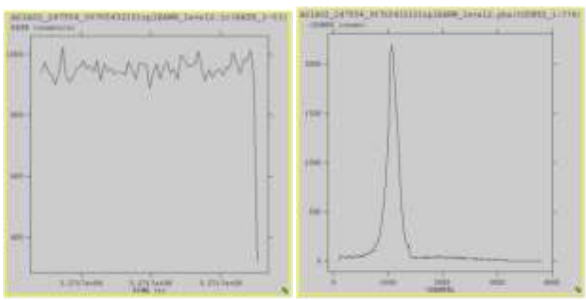

Figure-4: Light curve and spectra from LAXPC s/w for a lab source

SXT Level-2 Software Pipeline : SXT samples the brightest and the richest part of X-ray spectrum of cosmic X-ray sources i.e. 0.3 – 8 KeV. SXT design is based on grazing incidence optics. It has an X-ray sensitive CCD chip and an optical blocking filter in its focal plane. Its CCD array (600X600) will be operating in five modes viz. Photon Counting Mode (PC), Fast Windowed Photon Counting Mode (FW), Bias Map Mode (BM), Calibration Mode (CM) and House Keeping Mode (HK). The major steps involved in the Level-2 processing pipeline are event recognition using the centroid calculation, pulse height analyzer (PHA) generation, screening the event data on the basis of good and bad time, UTC conversion, conversion of raw coordinates to the sky coordinates using the attitude information and projecting in the World Coordinate System (WCS), bias correction, flagging the pixels for the bad, hot, flickering and calibration sources, grading of the events on the basis of pre computed grade library, calculating the pulse invariant (PI), data filtering on the basis of grade, energy, PI, region and time, Image generation with the sky co-ordinates and rotation as per the RA, Dec, light curve and spectrum generation with binning and filtering. **Figure-5** presents the spectra of a laboratory source taken during calibration and sky image using the simulated orbit and attitude.

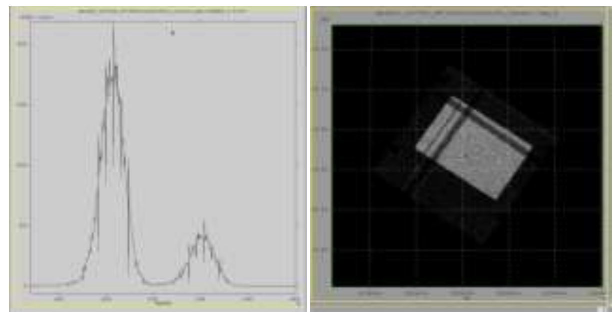

Figure-5: Spectra and image from SXT s/w for a lab source

UVIT Level-2 Software Pipeline: Out of two telescopes of UVIT, one covers FUV region while other one cover both NUV and VIS regions through a beam splitter. The detector of these telescopes normally operates in Photon Counting (PC) mode, however there is another mode where the detectors are operated with low gain called Integration mode (IM). In IM individual photons are not detected. The IM mode images from VIS channel are used to derive aspect of the UVIT instrument.

UVIT Level-2 software developed at SAC will be utilized by the user to generate the corrected and integrated sky image for a given exposure durations. The Level-2 software pipeline consists of the modules to do instrument data decoding, correction for various effects like cosmic ray, flat-field, centroid, centroid bias, and temperature on quantum efficiency, pixel padding and subdivision, star detection, aspect series calculation, registration, full-frame astrometry and finally converting into calibrated photometric magnitude and generating the normalized frame. Aspect series calculation is a separate chain which will generate aspect series by using VIS data in IM mode or NUV data in PC mode. The generated aspect series will be used in the Level-2 chain for frame shifting and rotation. **Figure-6** shows output of IM and PC mode lab data.

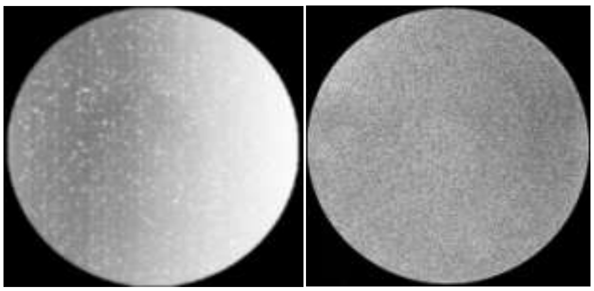

Figure-6: IM and PC mode corrected frame from lab source

Archive, Browse and Dissemination: The data archival and dissemination software is planned to be run at ISSDC. Archival software will archive Level-1 data for CZTI, SXT, UVIT and LAXPC and Level-2 data for all the 5 instruments including SSM. Level-1 and 2 Data dissemination for CZTI, LAXPC, SXT and UVIT will be carried out by Dissemination software through WEB. Dissemination of SSM Level-2 will be done through an exclusive website for SSM [5].

The archival software automates the Level-1 archival process. This software takes the Level-1 and 2 archived files from the Level-1 and POC respectively and checks for the version and extracts the data and archives along with a metadata in xml format which will be later used by browse software for the dissemination. Archival provides a web based interface for the user/ administrator where one can monitor the data archived and generate reports at ISSDC.

Browse is a web based application which takes the input from astro_metadata which deals with the metadata of the archived data in the archived layer. User can search through the internet browser for his object/source or RA/DEC, instrument_id or date of observation or proposal Information and can view for the datasets on the web site and request ISSDC for dataset as per their user privileges. **Figures 7, 8** and **9** show archival, browse interface on net and dissemination process respectively.

The dissemination system has interface with browse and will access the work-order created by the user consisting observation_id, Instrument_id and date of acquisition. These entries will be searched in archive database for user data retrieval and corresponding data product will be given to the user.

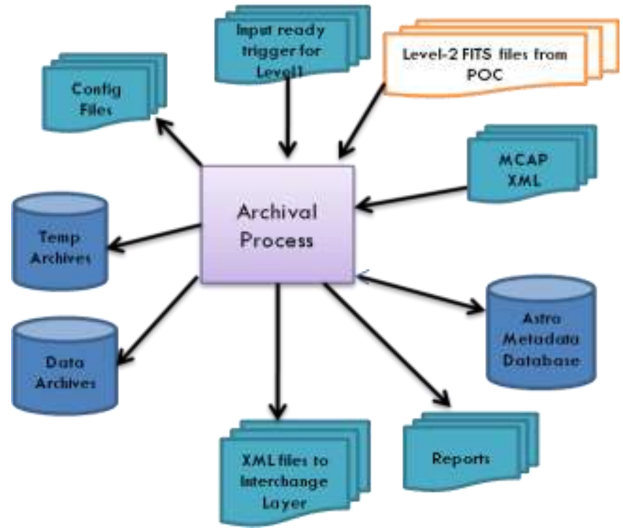

Figure-7: Astrosat data archival process

Figure-8: Astrosat browse interface on internet

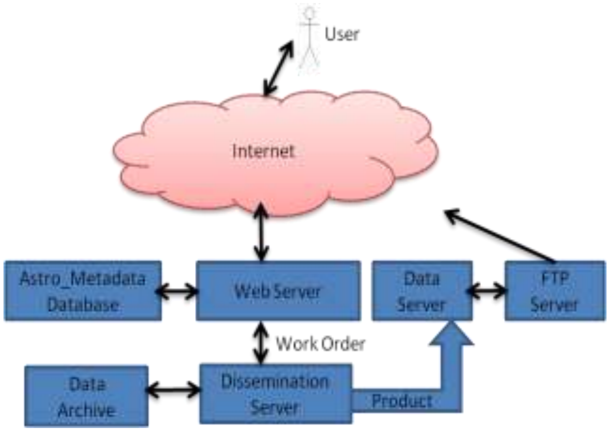

Figure-9: Astrosat data dissemination process

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Authors also wish to show gratitude towards other Astrosat team members from HRDPD who helped in realising the development.

References:

[1] Astrosat Data Pipeline Requirements Specifications, Version 2.5, May 2009.

[2] Concept of operations (CONOPS), Ground Segment CDR: Volume 1, 2013.

[3] Astrosat Quick Look Display Software, CDR Document, Astrosat-GS-QLD-CDR-07-2012

[4] Astrosat Level-2 Software, CDR Document, Astrosat-GS-L2-CDR-09-2012.

[5] Astros at Archival, Browse and Dissemination Software, CDR Document, Astrosat-GS-Archive& Dissemination-CDR-10-2012.

PHOTOGRAMMETRIC STEREO MODELS & LUNAR ATLAS FOR CHANDRAYAAN-1

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Introduction: Chandrayaan-1, India's first mission to moon was launched on 22nd October, 2008. Terrain Mapping Camera (TMC) onboard Chandrayaan-1 provided along track stereo images (triplets) acquired by its Fore, Aft and Nadir sensors with tilt angles of +26, 0 and -25 degrees respectively. The main objective of this payload is topographic mapping of the lunar surface **[1]**. The TMC datasets were received at Indian Space Science Data Center (ISSDC), which are made available at SAC Payload Operations Centre (POC), Ahmedabad for generating higher level products viz. DEM (Digital Elevation Model) and Orthoimage leading to preparation of LUNAR Atlas. To meet the above requirements, efforts were undertaken on sensor modeling using satellite photogrammetry concepts resulting in development of a technique/methodology and corresponding software known as LDEM (Lunar DEM) software. It is a unique s/w indigenously developed at SAC for generating DEM and Orthoimages from TMC data towards preparation of Lunar Atlas. This article discusses about the photogrammetric models developed for generation of DEM and Orthoimages from Chandrayaan-1 TMC stereo data. It also describes the procedure adopted at SAC for evaluation of these products. Details on Lunar Atlas generated using the DEMs and Orthoimage is also discussed in this article.

Photogrammetric Models: There are two types of modeling approaches adopted for DEM generation viz. (i) Rigorous Sensor Model (physical model called RSM) and (ii) Rational Polynomial Model (RPM) **[2]**. Either of the models is used to reconstruct a very precise relationship between 2D images to 3D lunar surface using orbit and attitude data available as SPICE kernels. The core of the modeling is the establishment of the precise viewing direction or look vector in the presence of distortions arising from camera tilt, spacecraft motion & orientation, planet rotation & curvature in addition to surface relief through series of coordinate transformations specially chosen for Chandrayaan-1 with proper definition and conventions. The rigorous sensor model is the physical model which is based on the collinearity condition which states that the perspective centre, image point and the corresponding object space point all lie in a same line. Mathematically it can be stated as

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = s * M * \begin{pmatrix} XA - XS \\ YA - YS \\ ZA - ZS \end{pmatrix} \quad \text{.........................} (1)$$

where, (x, y, z) are image or focal plane coordinates of an image point, s is a scale factor, M is the transformation (rotation) matrix between object and image space. Here, (XA, YA, ZA) are selenocentric coordinates of a ground point, (XS, YS, ZS) are selenocentric coordinates of the perspective center. Transformation matrix **M** consists of four rotation matrices:

M =**RL** * **RA** * **RO** * $\mathbf{R_{Lib}}$, where $\mathbf{R_{Lib}}$ is the rotation matrix for transformation from selenographic coordinate system to selenocentric coordinate system. These two coordinate systems are oriented by the Euler angles Ω′, i_s and Λ relative to each other as shown in **Figure 1**. Therefore, $\mathbf{R_{Lib}}$ can be further decomposed into three matrices. $\mathbf{R_{Lib}} = R(\Lambda)\, R(i_s)\, R(\Omega')$, where determination of Euler angles Ω′, i_s and Λ involves Moon's mean orbit, because of the relationship between Moon's mean position and the orientation of lunar selenographic coordinates.

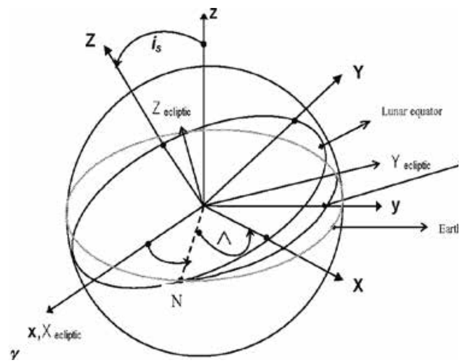

Fig.1 Selenocentric , Selenographic Coordinate Systems

RL is look angle rotation matrix transformation from spacecraft body coordinate system to sensor image coordinate system; **RL** can be further decomposed as:

RL = **Rpo** * **Rmp** , where '**Rmp**' transforms coordinates from Master Reference Cube (MRC) to Payload Cube (PLC) and '**Rpo**' transforms coordinates from Payload cube to optical axis.

RA is attitude rotation matrix transformation from orbital coordinate system to spacecraft body coordinate system & it is given as a product of three rotations Rpitch, Rroll and Ryaw.

Therefore, **RA** = Ryaw * Rroll * Rpitch

RA matrix is filled by using orbit to body quaternion in True of Date (TOD) reference system and **RO** is orbit rotation matrix transformation from selenocentric coordinate system to orbital coordinate system **[4]**.

In RPM approach, the complex physical model geometry is embedded in the form of ratio of cubic polynomials. This technique tries to model the imaging geometry which is based on satellite orientation parameters viz., orbit, attitude, camera geometry etc. through Rational Polynomial Coefficient (RPC). Since the RPC model is expressed simply as a ratio of two cubic polynomials, it is generic enough to be easily interfaced with most COTS photogrammetric packages. Furthermore, it contains enough degrees of freedom to maintain full accuracy of the physical senor model.

DEM Generation Approach: Following are the steps involved in generation of Lunar DEM using TMC data of Chandrayaan-1.

a. Level-1 product generation: Level-1 Data Products Generation System (DPGS) software takes the Level-0 data consisting of raw images and ancillary data in the form of SPICE kernels as the input. During level-1 product generation, the relevant ancillary information is extracted from the SPICE kernels, radiometric correction is performed and selenotagging is done.
b. Overlap computation: Common area between FORE, Nadir and AFT images is computed and the corresponding image is extracted.

c. RPC generation **[2]**: This is an optional process which generates the RPCs corresponding to overlapping region of all camera images. RPCs are generated for the entire height range of the lunar surface. Multiple height layers are created within the height range and grid points are derived for each height range for RPC generation.

d. Lunar Control Point (LCP) Identification: All the three overlapping radiometrically corrected images corresponding to the FORE, NADIR and AFT camera is displayed along with the Clementine image of the same region and some well-defined common features are identified. The latitude and longitude values are obtained from the Clementine image and the corresponding heights are obtained from the Lunar Orbiter Laser Altimeter (LOLA) DEM. During LCP identification, the distribution of the LCPs is ensured for better modeling. Normally 25 to 50 LCPs are identified for each orbit depending on the length of the pass/strip.

e. Space Resection **[5]**: The identified LCPs are used in space resection model to derive the refinement parameters.

From equation (1), derived collinearity equations are

$E1 = (xM1 + fM2)[\overline{X_A} - \overline{X_S}]$

$E2 = (yM1 + fM3)[\overline{X_A} - \overline{X_S}]$ ----------------------------**(2)**

Rotation matrix M is function of orbit as well as attitude. The attitude refinement model is assumed to be

$roll = original\ roll + \alpha_0 + \alpha_1 * time + \alpha_2 * time^2 + \ ....$

$pitch = original\ pitch + \beta_0 + \beta_1 * time + \beta_2 * time^2 + \ ....$

$yaw = original\ yaw + \gamma_0 + \gamma_1 * time + \gamma_2 * time^2 + \ ....$

where, $(\alpha_0, \alpha_1, ..., \beta_0, \beta_1, ..., \gamma_0, \gamma_1 ...)$ are the time varying error model coefficients for roll, pitch and yaw respectively. Equation (2) is linearized by Taylor's series expansion which will contain differentials of refinement parameters chosen for modeling. These parameters can then be computed by using least square. The parameters are computed iteratively and hence the corrections to the initial approximate values are updated.

In orbit based space resection, the orbital parameters inclination, longitude of ascending node and true anomaly are chosen for modeling. The state vector information is extracted from the SPICE kernels and then they are converted into orbital elements. These orbital parameters are refined using the LCPs **[3]**. In this, first the collinearity equations are linearized by Taylor series expansion with respect to orbital elements chosen for modeling. The orbital parameters chosen for modeling can be expressed as

$$inclination \ = original\ inclination + i_0 + i_1 * time + i_2 * time^2 + \ ....$$

$$longitude\ of\ ascending\ node = original\ longitude\ of\ ascending\ node + \Omega_0 + \Omega_1 * time + \Omega_2 * time^2 + \ ....$$

$$true\ anomaly \ = original\ true\ anomaly + F_0 + F_1 * time + F_2 * time^2 + \ ...$$

Where, $(i_0, i_1 ..., \Omega_0, \Omega_1, ..., F_0, F_1 ...)$ are the time varying error model coefficients for inclination, longitude of ascending node and true anomaly respectively.

The delta values for the orbital parameters are computed and adjusted iteratively to arrive at the best solution

In case of the RSM, the attitude parameters are refined to absorb the system level errors while in RPM, the adjustment parameters to the RPCs are computed for accounting for the errors. **Figure 2** shows the accuracies observed at the system level in across-track direction of various datasets and the corresponding improvements achieved after performing space resection. It can be easily observed from the plot that though the system level errors are as high as 25000 pixels, resection process is able to bring it down to within 5 to 50 pixels (1 pixel = ~ 5m) for all the orbits **(Figure 3)**.

f. Hierarchical Image matching (HIM): The HIM technique is used for generating dense conjugate points across the images of TMC i.e. the FORE, AFT and NADIR. The HIM process consists of Condensation, Interest Point identification, Local Mapping and Image Matching. Condensation generates the sub-sampled images from the full resolution sets, creating pyramid layers of the images with varying resolution. Interest Point Operator identifies the points, which are high in contrast, on the reference sub-sampled images for every layer. At the lower most level of the pyramid i.e. most coarser resolution, image matching is done directly by extracting a window area of 16x16 from the reference image around the interest points and correlation if performed on a search area window 32x32 of the other image around the probable location. The image matching results of the previous level are used to map the probable location of interest points in reference image to their probable counterpart in the other image by means of Local Mapping. Thereafter Image matching is done on the locally mapped points. Various filtering techniques are also required in order to reduce the number of false match points.

g. Space Intersection **[5]**: The conjugate points generated using the image matching is used in this process to generate 3D Lunar coordinates. The line connecting the perspective centers, object point and corresponding image point from individual camera are made to intersect in this process by space intersection models to derive the 3D ground coordinates. There are two types of space intersection models. One is based on the RSM and other is RPM based. Anyone of them can be chosen for DEM generation.

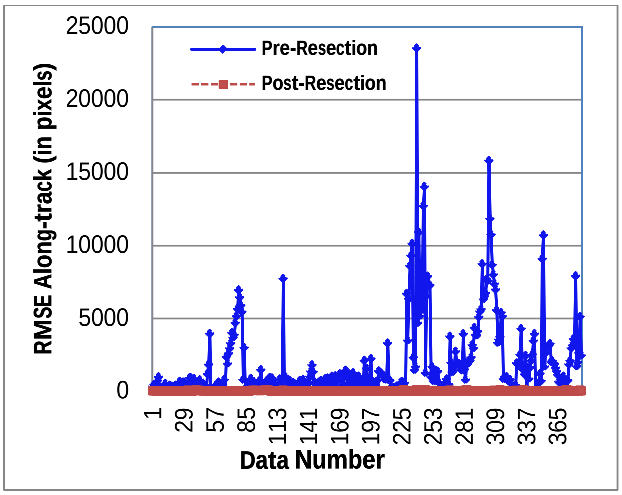

Figure 2: **Pre & Post Resection Errors**

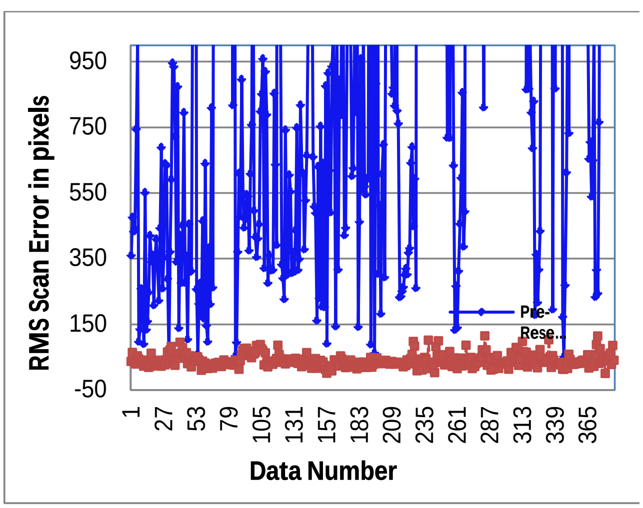

Figure 3: Pre & Post Resection Errors (zoomed)

h. DEM Interpolation: The irregular DEM generated in the above process is made regular at a pre-defined interval by using DEM Interpolation process. Currently regular DEM is generated at 25m posting.

i. Orthoimage Generation: Grid is generated by using the updated parameters obtained as an output of space resection process. Finally the image is resampled with respect to the grid to form an orthoimage. Currently NADIR image is used for orthoimage generation at 5m interval.

LDEM (Lunar DEM) Software: As mentioned earlier, LDEM is the state of the art software developed at SAC to generate DEMs and orthoimages from Chandrayaan-1 datasets. Following are some of the new and challenging features/elements involved in the development of the LDEM software Design

1. Development and implementation of Physical and RPC model based approaches towards Lunar DEM generation, which is first of its kind, since no planetary data processing software employed till date use RPCs for the processing.
2. An option for full-pass processing, where complexity of the modeling increases with respect to the length of the pass/segment of data.
3. Development of Lunar control point identification software which identifies the control points with respect to the reference image, which involves challenging task of matching multi resolution images.
4. Distributed processing of jobs on heterogeneous hardware platforms.
5. Software for 2.5D visualization of generated DEM and Ortho image.

Apart from LDEM software, the Browse generation software is also developed, which is the interface with the user. Using this , user can browse the DEMs and corresponding Orthoimage and place an order. This software caters to user interface with the planetary data towards data dissemination. Other Key features of the LDEM software includes

1. Possibility to define custom process workflow for every orbit.

2. Design and development of user friendly scheduler for LDEM s/w which interacts with individual processing modules.
3. It has the feature of scheduling, monitoring and management of jobs through web based interface.
4. Archival of the DEM and orthoimage data for dissemination
5. Data visualization and validation

DEM and Orthoimage Evaluation: DEMs and orthoimages generated are qualitatively and quantitatively evaluated. Under quality evaluation, DEM is checked for its visual quality like spikes within or outside craters, dark/normal patches, line and data losses, data/feature discontinuity (smoothness) etc. For each DEM, height range (minimum and maximum height variation) is compared with that of Lunar Orbiter Laser Altimeter (LOLA) DEM. Histograms of DEMs are compared with the references for the overall surface profile match. Quantitative analysis of TMC DEM and orthoimage is carried out with reference to Clementine data for planimetric accuracy and LOLA DEM for vertical accuracy by computing the differences in the respective coordinates. In DEM analysis, it is noted that height range of TMC DEM with respect to LOLA DEM mostly varies from 50m to 250m (**Table 1**). There are number of reasons due to which this error remains in the TMC DEM which includes the error in LCP identification, improper distribution of the LCPs or non-availability of LCPs in certain region. LCPs are identified on Clementine image which is at a coarser resolution of 100m. Also the TMC orbits may fall in the mosaic region of the Clementine and the mosaics are not having same accuracies.

Table 1: Errors in planimetry and height for some orbits

Sr No	Orbit No	RMSE (m)			Standard deviation (m)		
		Lat	Lon	Ht	Lat	Lon	Ht
1	385	5.4	30.3	41.07	24.6	3.9	34.3
2	437	76.5	51.7	107.3	75.2	57.6	100
3	499	11.5	17.8	202.7	14.1	21.6	206
4	2859	80.3	51.9	92.1	80.7	43.3	84.8

It is also observed that TMC DEM generated with data acquired at 100km altitude is having better accuracy than DEM generated with data acquired at 200km altitude. The reason for this may be due to large uncertainties in attitude variations, which could not be modeled. Currently NA (Nadir and Aft image) combination is used to generate DEMs but the models are in place to generate DEMs from other doublet combination as well the triplets. Comparison of the DEM generated for Orbit Number 385 using LDEM s/w with LOLA DEM is shown in the **Figure 4**. The range of the height values varies from -3000m to -800m and the difference between LOLA DEM and LDEM DEM is well within 125m.

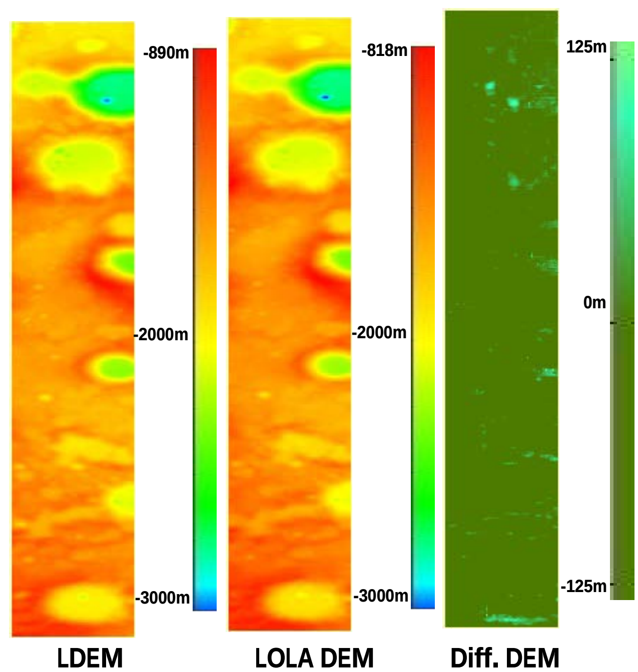

Figure 4: DEMs for orbit number 385

Chandrayaan-1 Lunar Map Catalogue: The high level data products defined for Chandrayaan-1 mission includes the Lunar Atlas and maps. The objectives of lunar atlas and map products are to prepare maps for the entire surface (~37.8 Million Sq. Km) of moon and its visualization. Atlas consists of Terrain Mapping Camera (TMC) and Hyper Spectral Imager (HySI) orthoimage and Image mosaics, DEM derived from TMC stereo data, contributory themes from other payloads and annotations. Lunar atlas is in softcopy while hardcopy is represented in map catalogue form.

The lunar topomap is composition of color coded DEMS with annotation. Lunar Ortho-image map contains PAN, FCC and NCC orthoimage with annotation while Lunar Topo-Ortho map contains contours overlaid on Orthoimage with annotation. Lunar thematic maps contain thematic layers provided by different POCs. This is realized by Lunar mapping software developed using the customization of the required COTS packages. The COTS packages are helpful even in generation of various layers of the Lunar Atlas, which are the outputs. **Figure 5** shows the sample Lunar map-sheet of 1^0 x 1^0 part of the Lunar Atlas.

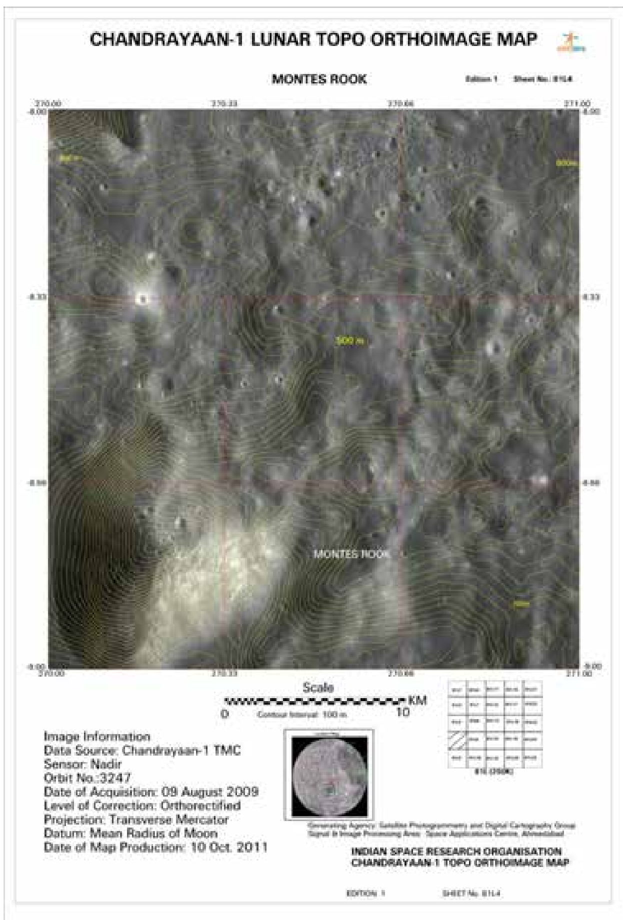

Figure 5: **Sample 1^0 x 1^0 Lunar map-sheet**

Conclusion: Planetary models, techniques, corresponding algorithms and software have been developed for the first time for Chandrayaaan-1 mission to cater to standard correction as well as for DEM generation. Both Physical model and RPC approach using photogrammetric techniques are adopted for DEM generation. It has been found that significant improvements in terms of planimteric and height accuracies are achieved for various TMC orbits. DEMs for around 690 orbits are generated with a 25m posting and orthoimage at 5m, which are utilized for Lunar Atlas generation at SAC and catering to the users of Chandrayaan-1 data. Also, 10m lunar DEM generation is currently going on which will be augmented by using GPGPU based approach and handling of triplet imageries. Some of the Lunar DEMs and Orthoimages generated at SAC-POC have already been used by Application Scientists for carrying out various studies of the lunar terrain. Efforts have been made to archive and disseminate all these datasets to the scientific community as well as general public via a web-based Chandrayaan-1 data Browse, released on 19^{th} April, 2013. This can be accessed from **http://www.issdc.gov.in**.

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References:

1. Digital Elevation Models of The Lunar Surface from Chandrayaan-1 Terrain Mapping Camera (TMC) Imagery – Initial Results, B. Gopala Krishna, Amitabh, Sanjay Singh, P. K. Srivastava and A. S. Kiran Kumar, Lunar and Planetary Science XXXX (2009).
2. DEM generation using Rational Polynomial Model – An experience with Cartosat-1 and Chandrayaan-1, Sanjay K. Singh, Medha Alurkar,

T. P. Srinivasan and B. Gopala Krishna, DP/SAC/SIPA/SPDCG/TN-14/November, 2009.

3. Photogrammetric Modeling & Data Processing: Chandrayaan-1 perspective (for Linear CCD Imaging Sensors), B Gopala Krishna, Sanjay Singh and T P Srinivasan, GEOMATICS, 2010.

Coordinate Systems for Lunar Mission, Krishna, A., Gopinath, N., 2001, FDD/MDG/CMA/ISAC.

4. Reconstruction of imaging geometry and 3D coordinate computation for Terrain Mapping Camera (TMC) of Chandrayaan-1, Sanjay K. Singh, Medha Alurkar, Goral Parekh, T. P. Srinivasan, B. Gopala Krishna.

MARS ORBITER MISSION (MOM) DATA PRODUCTS

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Introduction: The Indian Space Research Organization (ISRO) has started a new initiative to launch dedicated satellites for planetary exploration, astronomical observation and space sciences with the launch of Chandrayaan-1 which caught the attention of space agencies and public world over. The Mars orbiter Mission (MOM) is one of the approved missions of this new initiative. The basic objectives of the MOM, scheduled for launch in Oct, 2013, are to study the origin of methane found in Mars, dynamics and Deuterium-Hydrogen ratio of atmosphere of Mars, temperature and thermal inertia, mineralogy, surface features of Mars, neutral composition and distribution of the Martian exosphere in addition to synaptic observations of Mars and its moons. MOM is equipped with total five payloads to full fill mission objectives. The five instruments are

- Mars Color Camera (MCC)
- Methane Sensor for Mars (MSM)
- TIR imaging spectrometer (TIS)
- Mars Exospheric Neutral Composition Analyser (MENCA)
- Lyman Alpha Photometer (LAP)

Mars Orbiter Mission Overview: The mission will be achieved using indigenous Polar Satellite Launch Vehicle for its launch.

The Mars-Craft will be placed in an elliptical transfer orbit around Earth first and subsequently into a long cruise trajectory and finally a Mars transfer trajectory for Mars orbit insertion. The Mars-Craft will be placed in a ~371 km vs 80000 km elliptical Mars polar orbit. MOM will take 10 months to reach Mars after leaving Earth Bound Phase. The lifetime of the mission is planned to be six months around Mars.

Data collection will be possible in every phase of this mission starting from Earth Bound Phase through enroute Mars cruise Phase, Mars Orbit Insertion Phase and Mars Orbital Phase. The ground segment for MOM comprises four major elements, namely Deep Space Network (DSN), Spacecraft Control Center (SCC), Indian Space Science Data Center (ISSDC) and Payload Operations Centre (POC) shown in Fig-2. The ground segment is responsible for making the data available for the scientists along with auxiliary information, in addition to storage of payload, spacecraft data and product to users.

MOM Science Instruments from SAC: There are three science instruments built by SAC for the MOM shown in Fig-1. They are listed below in Table 1 along with their measurement objectives

a. CC b. TIS c. MSM

Fig-1: SAC instruments MCC, TIS and MSM

.

Table 1: SAC science instruments in Mars mission

Instrument	Science Theme
METHANE SENSOR FOR MARS (MSM) Measures radiance within extremely narrow absorption lines of CH_4.	Measurement of methane with high accuracy. CH_4 mapping is expected to answer many fundamental questions regarding the existence of life on Mars.
TIR IMAGING SPECTROMETER (TIS) using μ-bolometer array λ= 8- 14μm, Min. 32 selectable bands	Temperature and thermal inertia, surface composition and mineralogy, underground hydro thermal systems, atmospheric CO_2
MARS COLOR CAMERA (MCC) Medium-resolution RGB frame camera	Surface features, Martian dynamic processes (dust storms, changes in polar ice caps), morphology of area around methane-spots, Imaging of the Martian satellites, asteroids etc., Synoptic observation.

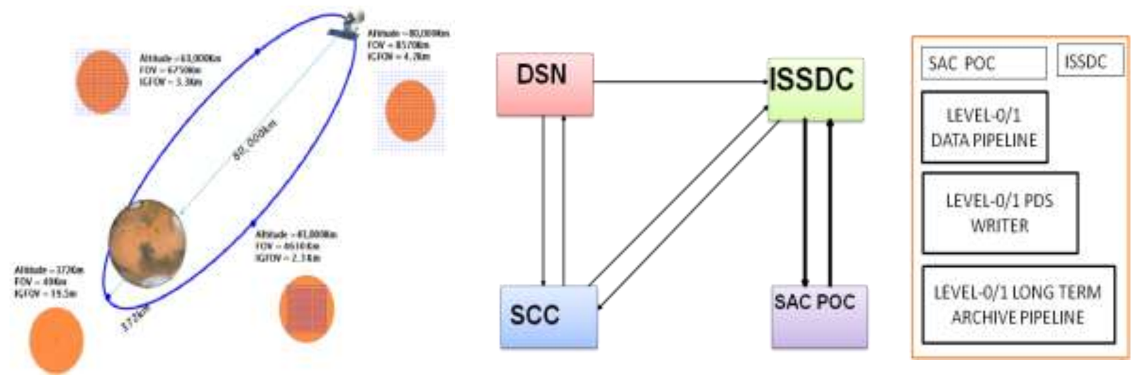

Fig-2: MOM Orbit and Ground segment Data Exchange and Processing Architecture

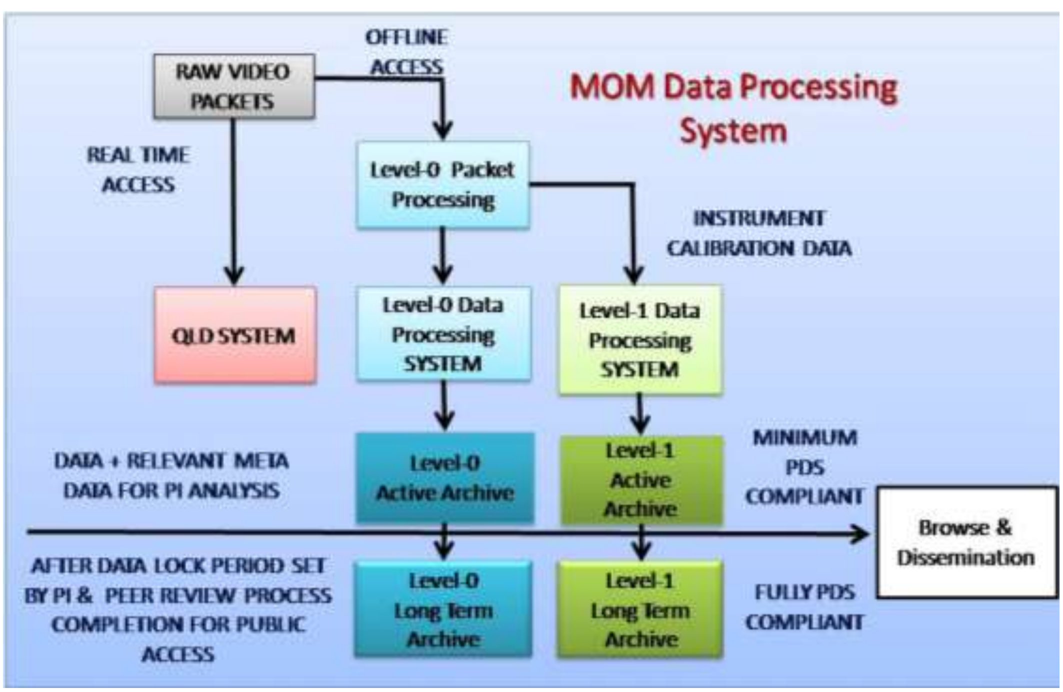

Fig-3: MOM Data Processing System Architecture and PDS Archive

Planetary Data System for Mars Mission: Planetary Data System (PDS) is the underlying data standard for planetary missions data archives practiced world over for preparing planetary or solar system data for Long Term Archive based on an information model that advocates meta data organization in a specific way that planetary scientists used to. MOM data archive will be prepared based on this data standard practice. The PDS archive planned will house not only primary instrument data, but also instrument calibration details, data, satellite position velocity information, and all other ancillary information either original or derived to be provided to the planetary scientists to take up their analysis tasks neatly arranged in a folder hierarchy.

Data Processing Details for MOM instrument Data sets: MOM data processing system (Fig-2) is an automation-intensive in-house developed software solution to streamline the work flow in a processing chain for MSM, TIS and MCC instrument data. DP system processes instrument (MCC, TIS MSM) data for edited and calibrated (as in Table-2), derives meta data about mission events, spacecraft operations, instrument operations, processing parameters, orbit and housekeeping details from ancillary data to generate PDS data. DP system also produces "active archive" for raw and calibrated data for instruments mentioned above, is minimum PDS compliant which will be accessed by instrument specific Principal Investigator (PI) community; this archive will reside at ISSDC as well as SAC POC.

The onboard data handling system handles all five payload data (MCC, MSM, and TIS LAP & MENCA) and auxiliary data. Level-0 system for MARS mission captures all pre processing requirements of payload data and auxiliary data. Level-0 will transfer decompressed, formatted, time tagged payload data with OAT and HK information to Level-1(DP) for next level processing. Further radiometric processing, AreoTagging and PDS conversion are handled by Data Processing system.

Table 2: MOM Data Processing Levels

Instrument	Product Level	Remarks
MCC,TIS,&MSM	Edited Raw (Level-0)	Corrected for telemetry errors and split or decommutated into a data set for a given instrument. Sometimes called Experimental Data Record. Data are also tagged with time and location of acquisition.
MCC,TIS,&MSM	Calibrated (Level-1)	Edited data that are still in units produced by instrument, but that have been corrected so that values are expressed in or are proportional to some physical unit such as radiance. No resampling, so edited data can be reconstructed.

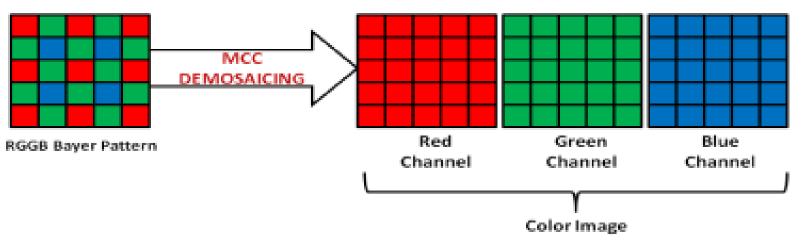

Fig-4: MCC Bayer Data and demosaicked RGB data

MOM Data description: MCC will provide raw images in a so called Bayer Pattern. Mars Color Camera is a moderate resolution color camera. Highly elliptical orbit of MARS-1 mission allows imaging of localized scenes at high spatial resolution as well as synoptic view of the full globe. The color camera uses a 2K×2K area array detector with RGB Bayer pattern. IGFOV of the sensor is 19.5 m where as frame size is about 40km × 40km from a platform altitude of 371km. The raw data volume is 40Mb/Frame from which color image has to be generated at ground using a demosaicing procedure represented in Fig-4.

TIS is a grating based spectrometer which makes use of an un-cooled micro-bolometer array as the detector. One of the main advantages of using the micro-bolometer is that it does not require cooling. The spectrometer will have a minimum of twelve bands in the spectral region 7- 14µm.

MSM is a differential radiometer operating in the short wave infrared (SWIR) region. It is based on the principle that if absorption spectra of atmospheric gas consist of evenly spaced line intensities, it is possible to measure radiation only at these spectral lines using an Fabory Perot Etalon (FPE) filter which transmits light at extremely narrow, well defined spectral bands evenly spaced in the frequency domain. Measured radiance at these spectral lines is very sensitive to variations in gas concentration since absorption coefficient at the line positions is very high compared to its mean value over a broad spectral band.

Quick Look Display (QLD) System: The QLD software depends on Payload data Acquisition system (PACQ) for input data. Instrument data is received by Deep Space Network (DSN) and transferred to PACQ (ISTRAC component) in sequential streams. The PACQ system de-multiplexes the stream and produces channel wise instrument data on separate channels. QLD receives these channel wise streams in parallel and process it concurrently. After the necessary processing of each channel wise data, it is sent to display terminal for visual interpretation of the instrument data. The core processing of the instrument data is done at ISSDC and results are displayed at IDSN.

MOM Data processing steps: MCC, MSM and TIS Data Pipelines will consist of three modules viz. Pre-processing, Radiometric Correction Module and Areo Tagging module. The function of level-0 software pipeline is to generate the level-0 output directly consumable to the PDS active archive generator. And, in Level-1 processing, radiometric correction will be applied additionally on the data for inconsistencies which will further tagged with mars coordinates in terms of lat/lon before converting to minimum complaint PDS archive. Calibration data presence is very crucial for achieving high radiometric quality of the data obtained from the instrument for deriving science results.

MOM Data Products Browse and Dissemination: Browse application gives the facility to view the acquired and processed data in a sub-sampled form along with its PDS metadata, using a web browser. Dissemination subsystem is mainly responsible for PDS data dissemination to PI and end users.

High level Data products: The POC's and PI's process the payload data retrieved from ISSDC and generate higher-level products. These products are subsequently sent back to ISSDC for archiving and dissemination. Higher level processing depends upon the type of instrument and its working principle.

Science plan for individual instruments can be found in instrument design documents and deliberations and minutes of committee meetings in the project, space segment and ground segment of Mars mission (Table-1).

Higher Levels Data Products from MCC: DP Team, has planned, apart from Level-1 corrections that process up to demosaicking of Bayer images to convert to RGB images, some more advanced corrections will be incorporated such as illumination estimated color processing. This may be possible with only periareion images.

The following are the high level products envisaged for MCC data.

1. Areoreferenced products (corrected for geometric distortions)
2. Image mosaics wherever possible
3. Image Enhancements for morphological studies
4. Super resolved output from overlapping images

These higher level products will be generated only at SAC POC and the final results will be transferred to ISSDC for public outreach purposes at a later date.

Fig-5: MCC evening outdoor image after demosaicking, white balancing, color balancing

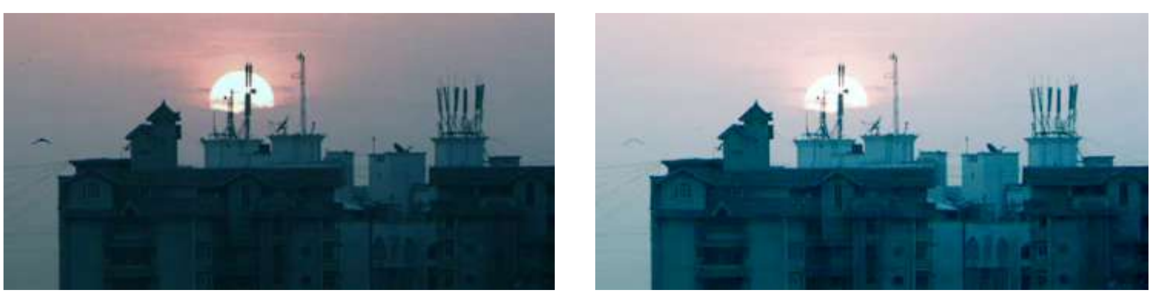

Fig-6: MCC outdoor image without and with high dynamic range processed

Higher Levels Data Products from MSM: MSM will measure Methane concentration in the Martian atmosphere with an accuracy of 10 ppb. However the outputs generated by data products viz. Level-0 (Raw qualified payload data along with the ancillary information, time tagged and calibration information) and Level-1 data (Calibrated/ corrected and geometrically mapped along with ancillary info), will be used by the PI to generate the Methane concentration. The derived methane concentration will be mapped on the Martian surface and used for dissemination or public outreach. These methane concentration maps are called high level product of MSM and archived at ISSDC as well as SAC-POC.

Higher Levels Data Products from TIS: Thermal Infrared Imaging Spectrometer (TIS) is a grating based spectrometer which makes use of an un-cooled micro-bolometer array as the detector. One of the main advantages of using the micro-bolometer is that it does not require cooling. This aids significantly in reducing the payload size and weight in keeping with the requirements of a planetary mission. The spectrometer will have a minimum of 12 bands in the spectral region 7-14μm. TIS will measure the thermal emission from Martian surface.

The TIS data will be useful in mapping surface composition and mineralogy of Mars and to detect hot spots which indicate underground hydro thermal systems. There are total 8 mode of operation defined for TIS depending on the binning of frames and spectral bands. The higher level products planned for TIS are:

1. Brightness Temperature Product
2. Land Surface Temperature Product
3. Emissivity Product

The algorithms for these higher level products will be provided by PI. At the end of the mission mineral composition map preparation for Mars (using TIS data) is also envisaged. These higher level products will be generated only at SAC POC and the final results will be transferred to ISSDC for public outreach purposes at a later date.

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References:

- MOM SAC DP Team, High Level Software Requirements Specification (SRS) for MARS Data Processing System (MSM,MCC,TIS), SAC/SIPA/MOMDP/SRS/V 1.0/Mar 2013
- Preliminary Design Review document on Methane Sensor for Mars (Vol-1) (SAC-MOM-01-Aug12)
- Preliminary Design Review document on Mars Colour Imager (Vol-3) (SAC-MOM-03-Aug12)

ADVANCED GEOSPATIAL SYSTEMS DEVELOPMENT

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Introduction: In recent years, remote sensing and Geographic Information System (GIS) has been accepted as an indispensable tool in the field of agriculture and land studies. Any Geospatial software comprises functions for spatial analysis based on vector and raster data sets, database queries, image processing, as well as conventional and innovative image processing algorithms. This kind of tools caters to the need of present requirement of data analysis for the application in land, agriculture and environment studies. In this regard the software/tool should give the power to visualize the images, spatial data (raster and vector) geographically for standard analysis, and provide all the tools needed to download the data, perform image processing, classification, aggregation, and give suitable outputs in an effective manner. In addition, solve the geo-locational and attribute based queries, present the results of work in the form of publication-quality maps and create interactive displays that link reports, graphs, tables, and other elements to the data. Space Applications Centre, ISRO, Ahmedabad recently developed a geospatial system for operational use in crop forecast studies, which is described here in a general as well as specific way.

Models, Computing, Software components of advanced Geospatial systems: An advanced geospatial system may have the following technology elements (Table-1) capturing details described in the introduction.

Table – 1: Advanced Geospatial system technology components

Software technology components	Geospatial Techniques Components	Algorithm Components
1. Geospatial desktop and web applications 2. Plug-in architecture to support add-ons and segregated functionality 3. Platform independent, GUI agnostic approach 4. Data archive vault 5. Scripting systems 6. Geospatial data advanced theme viewers 7. Software redesign and reuse.	1. Three dimensional accuracy and preservation of information 2. Native file access to geospatial formats 3. Avoid limitations on the number and size of files 4. Parameter based image processing chains 5. Functionality embedded in layered libraries - used in applications 6. Geospatial database creation for spatial and attribute data 7. Vector to vector, vector to raster, raster to vector, raster to raster processing.	1. Basic and Advanced image processing and GIS algorithms 2. Image Classification advanced techniques 3. Image transformations 4. Numerical methods 5. Machine learning algorithms 6. Geo processing algorithms 7. Iterative Image processing chains 8. Regression methods

Geospatial Framework and Tools: It needs to establish a geospatial approach to rationalize a competent methodology for quantifying parameters of study theme. SAC, ISRO recently built and operationalized an advanced geospatial system workflow engine needed for crop production forecast which involves. This multi date remote sensing data analysis system, known as FASALSoft, is shown in Fig-1. It comprises of a windows based software engine which includes, desktop geospatial tools, web servers, web applications, web based job scheduling etc. In any geospatial processing, data management is a primary task, handling different raster and vector data formats, handling the metadata and attributes, will be extremely difficult without a background database application. This engine implements Data Access, Pre-Processing, Image Classification and Symbolization requirements which are a formal common processing platform for any remote sensing application.

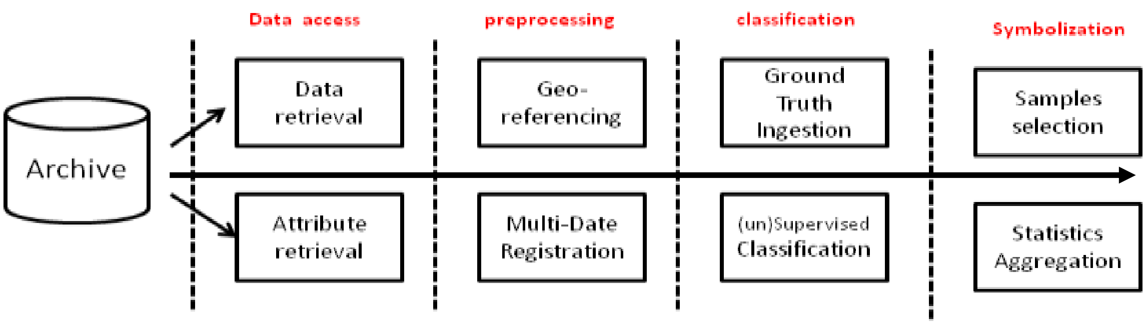

Fig-1: FASALSoft Remote Sensing Data Analysis Framework

Multi date IRS Data Analysis for Crop Studies: In India, operational use of remote sensing for crop inventory started with the definition and implementation of Crop Acreage and Production Estimation (CAPE) project (Navalgund et al., 1991; Dadhwal et al., 2002; Dadhwal and Parihar, 2002). The aim was to generate district-level crop production forecast. The project used stratified sampling approach, training statistics extracted from area marked on image based on field visits, maximum likelihood classifier for single date cloud-free multispectral data corresponding to optimum bio-window to classify the image and statistical aggregation to arrive at district-wise area of a crop - mostly winter crops as cloud-free optical data were usually not available during monsoon season. The concept of FASALSoft is to have a reliable and data dependent software system for in-season multiple forecasts at different crop stages from sowing to maturity using information from different sources like remote sensing, meteorology, econometry and land observations. Primary data source for these studies are single/multi date satellite remote sensing data such as RESOURCESAT-1 &2 LISS-3 or AWIFS data sets of different dates of acquisition suitable for study. Multi date RISAT-1 MRS data sets use in FASALSoft was recently added for Rabi/Kharif Rice forecast analysis. The essential geospatial tasks to be performed on the primary data sets are a) georeferencing, b) multi date image registration, c) supervised classification and d) aggregation (Fig-2). In addition, despeckle, calibration processing steps are essential for microwave data sets. There are also other geoprocessing tasks that involve raster and vector data layers together. So therefore the tool set meant for doing land and crop studies should include these functionalities. Multi date image registration is required to bring multi date images into geometric confirmation before going for any further processing of multi date image layers together. It is possible that georeferencing step and image registration step can be accomplished by a single step. If multispectral data sets are involved, creating NDVI information layer is always required to support image classification process. Image classification is a crucial task to group image pixels of similar kind that belong to objects of interest say image pixels that represent an agricultural crop after training with crop sample pixels in supervised manner. Many classification techniques are required to deal with crop forecasts. Classification tools such as maximum likelihood, Rule Based, K-Means, Hybrid schemes are needed. Classifying only required image portions is a typical requirement by specifying a shape file. Raster under vector layer operations are geospatial tasks which are often done. Beyond this point, processing steps are related to aggregating pixels based on attributes and conditions.

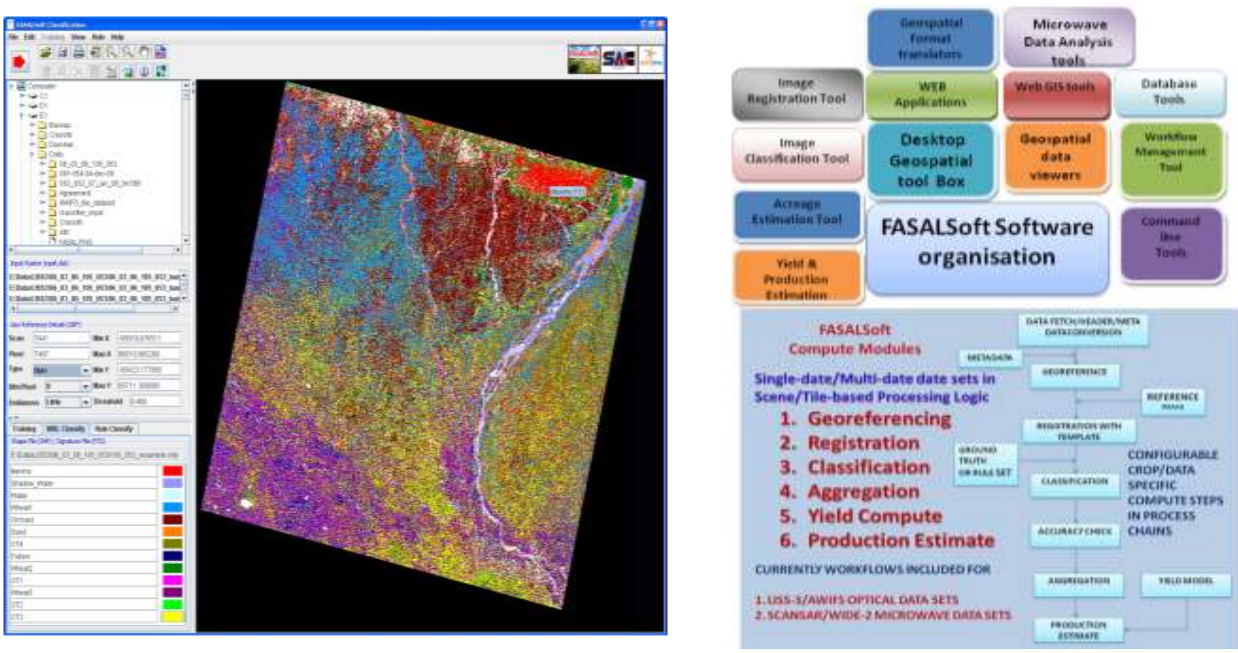

Fig-2: FASALSoft Software Organization and Sub Systems

Advanced Geospatial capabilities: There is always a need for a systematic regular repository to keep track of all data used and results generated in each year in crop forecasts. Improvements are expected for making the results available to the concerned central ministry personnel in a timely fashion, and performance characteristics, such as speed, throughput, volume and frequency needed. Commensurate with such requirements, following capabilities are built into FASALSoft system:

- ✓ A common operations environment for estimating the acreage of all the study crops in different crop seasons.
- ✓ Elaborate geospatial toolbox to do multi date data analysis (georeferencing, registration, classification, aggregation etc.)
- ✓ A central archival system and multiple regional archival systems which will update central archive at schedules (Fig-3).
- ✓ A central administrative system to monitor the entire operations and to keep track of the processing status at all times.

- ✓ An online web based query system to provide the acreage, yield and production forecast to the end users.

FASALSoft Development: FASALSoft framework was realized by amalgamating and adopting available open source geospatial tools and fresh software developments which can perform the required image processing and geospatial operations in an effective way. This is a first of kind custom geospatial software to do crop acreage and production forecast at national level built by SAC/ISRO. It is a turnkey solution to be written about it shortly. The FASALSoft S/W is now operated at Mahalanobis-National Crop Forecast Centre (M-NCFC established by Ministry of Agriculture with a mandate to perform national crop forecast. The same software framework depicted in Fig-1 can be used to address similar tasks demands national level assessment for e.g change detection analysis. FASALSoft complexities are given in Table-2.

Database Requirements: Geospatial information, attributes, workflow data and vector data are data units are difficult to maintain without a background data base engine in an application setup. An advanced geospatial system should include a robust database scheme per task basis. FASALSoft application has implemented distributed data base clusters and also support database cloning node to node. FASALSoft databases maintain work order data workflow data, raster metadata, vector data sets, process states, results and reports generated at multiple nodes. FASALSoft uses open source Postgres and Postgres-Slony frameworks to implement data base requirements.

Table-2: FASALSoft Complexities

Item Description	Complexity
Integrated software framework	National level **geospatial data processing and publishing** application. Distributed software with central and regional nodes (Fig-3) & automation-intensive system for forecasting agricultural output using space, agro meteorology and land based observations.
Desktop Application	Geospatial data processing and analysis suite on windows (Fig-2)
FOSS used	GDAL/OGR, SHAPELIB,PSQL,GEOTOOLS
SAC Software Libraries for FASALSoft Processing	Map Projection Library, Resampling package, Georeferencing tools, model estimators, least square fit, feature extractors, image registration suite, image classification tool, microwave data preprocessing, registration and calibration packages, statistical aggregation, and regression models for yield and production estimation utilities.
Real Time Database	Distributed Database Clusters with more than 75 tables
Remote Sensing data sets supported	Optical : Resourcesat-1/2 LISS-3, & AWIFS, Microwave: Radarsat-2 ScanSAR and WIDE-2 , Risat-1 MRS
Data Formats handling	Many geospatial data formats (CEOS, GEOTIFF, and HDF etc.)
Configurable Web Workflows	Variable data units processing, workflow data modeling, workflow scripting

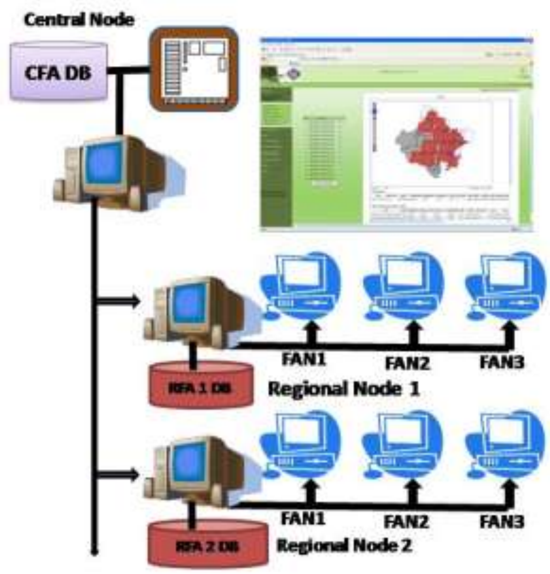

Fig-3: FASALSoft Deployment Architecture with central and regional node configurations

Conclusion and summary: SIPA pursues the need to continue to build expertise in making use of robust free and open source software projects (FOSS) and in house tools for building advanced geospatial systems. Many geospatial computations performed through open geospatial tools clearly illustrate open system architecture, organization of software libraries, object model, software customization for building complex application, the orchestration of the interaction between open source software, the performance of integrated system and a matter of concern to function limitations or bugs in the software, but very rewarding at the end of such a software expedition. The techniques, development exercises and system source code in this work can be used for many software development projects in similar applications domain.

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References:

- Chakraborty, M., Patnaik, C., Panigrahy, S and Parihar, J.S. (2006). Monitoring of wet season rice crop at state and national level in India using multidate synthetic aperture radar data. Proc. of SPIE Vol. 6411 6411023 Agriculture and Hydrology Applications of Remote Sensing, edited by Kuligowski, R.J., Parihar, J.S. and Saito, G. (doi: 10.1117/12.693900).
- Dadhwal, V. K., Singh, R. P., Dutta, S. and Parihar, J. S. (2002). Remote sensing based crop inventory. Tropical Ecology, vol. 43, pp 107-122.
- Navalgund, R.R., Parihar, J.S., Ajai and Rao, P.P.N. (1991). Crop inventory using remotely sensed data. Current Science, 61, 162-171.
- Manthira Moorthi S., Indranil Misra, Ramakrishnan, R. and Srivastava, P.K. (2011). Discovery of software systems for composition and their customizability in free and open source geospatial software environments – A Case Study. Map World Forum 2011, Hyderabad, India.
- Manthira Moorthi, S., Markand P Oza, Nikunj P Darji, Indranil Misra, Rajdeep K Gambhir, Neha Misra, Dinesh K Jain, Debajyoti Dhar, R. Ramakrishnan, Santanu Chowdhury and Jai Singh Parihar "FASALSoft - An ISRO software framework for crop forecast using remote sensing data analysis", ISRS National symposium, Dec,2012,New Delhi, India.
- Misra Indranil, Manthira Moorthi, S. Rajdeep K Gambhir and Ramakrishnan, R. (2011). Evolutionary Rapid Development using open source framework for Geospatial Data Processing, Trends in Information Management (TRIM), SSN:0973-4163, Jan-June 2011, Vol.7 No.1,p 31-40.

NEW GEOMETRIC CORRECTION FRAMEWORK FOR OPTICAL IMAGING SENSORS

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Introduction: Pre-processing of remotely sensed data acquired from Earth Observation Satellites has come to a maturity with radical shift in demands of user community. Accordingly, processing techniques and algorithms, requirement of turn-around time and system infrastructure have changed over the years. In today's scenario, images acquired from Earth Observation Satellites are extensively used in the fields of urban planning, agriculture, natural land resources monitoring, marine resources monitoring and also disaster management. Many such applications require quick dissemination of data to the end user so that data can be used more effectively. High quality data products, information products and derived geo-physical parameters are of prime importance because they can be utilized readymade without requiring any further post-processing at user end. Hence, it is obvious that most of the post-processing functionalities are also shifted back to the pre-processing stage itself, where data service providers are required to supply data products which are readily usable by the users without any further processing. The present scenario of satellite data pre-processing services encompasses the capabilities of producing value-added information products in addition to the traditional pre-processing steps that the remote sensing data has to undergo. In short, the expectation of remote sensing user community from the Data Providers is ready to user high-quality basic data products, Information products that can be directly used in applications and on-demand data acquisition and quick dissemination of data to the user. The pre-processing software which was consisting of only basic sensor-level corrections in the past , now has been broadened its scope to include not only basic sensor calibration and physical rigorous sensor model, but also automatic geo-location accuracy improvement with correction for terrain relief, thus the final image is ortho-rectified.

Software Framework: An integrated Pre-Processing Library is conceptualized and designed to suit multi-CPU and multi-core system architecture, and also to promote fine-grained reusability of software components so that rapid prototyping and sensor modeling can be done to considerably reduce the pre-launch development and post-launch validation period. The framework design includes many popular and advanced software architectural design aspects and patterns so that both vertical and horizontal development can happen to enrich the functionalities and capabilities of the library by incorporating new classes into the Core library as well as new algorithms can be developed and plugged-in independently to enhance the usability of the whole package. The new geometric correction model is implemented using a new approach of the concept of imaging ray emanating from a CCD element intersects the earth surface. A series of coordinate transformation happens from sensor to Earth Centered Earth Fixed to get the corresponding ground coordinate after using the terrain height. The implementation of rigorous Physical Sensor Model classes are fully parameterized so that sensor specification and description along with corresponding mete data are kept outside the basic implementation that makes it easy to incorporate new sensor model by just describing the sensor parameters externally. The prime features of the new technique include usage of Digital Terrain Model, Optimization of Sensor Model when provided with a set of match points, Harris Corner detector based feature extraction and outlier rejection based on RANSAC algorithm. All these three techniques are employed to improve the geo-location accuracy by collecting a set of match points using the reference image, then rejecting wild points by outlier rejection method and feeding those tie points to optimize the sensor model to estimate a set of interior and exterior sensor orientation parameters. With this software framework it is possible to model any pushbroom and whiskbroom sensor both as a part of Core library or as a dynamically sharable object.

Sensor Modeling: The Sensor modeling is somewhat of a misnomer since what is being modeled is the entire acquisition process, not just the physical sensor. Other parameters include platform position and velocity, alignment angles of the sensor with respect to payload common reference and platform biases. In effect, the goal of a sensor model is to capture the entire process of acquiring an image, and therefore be able to accurately map a pixel on the image to a point on the ground. Furthermore, sensor model also provides the capability of adjusting critical parameters to correct for observed geometric errors on the image. Sensor model is also termed as interpolation model because it consists of a collection of numerical "grids" covering the image that are interpolated bilinearly to arrive at the desired projection solution. The grids are initialized with the corresponding rigorous model. The advantage gained is in speed of execution, since the projection solution is a simple linear computation versus a complicated, non-linear rigorous equation [1][3]. Thus if the interpolation model grid is generated using a rigorous model, then it can be considered essentially a rigorous model as well.

Adjustable Parameters in Sensor Model: Rigorous Sensor Model models the imaging ray from the sensor, through the optics, down to the ground with a set of rigorous equations. In order to correct for errors in acquisition, and prior to implementing the sensor model, it is to be identified the sources of error are that can affect the final orientation of the imaging ray in space. These error sources are then parameterized in the projection equations. Given some reference data, these parameters can then be adjusted so as to minimize the residual geometric error in the image. So for a rigorous model, it is crucial that proper set of adjustable parameters must be selected that capture all the sources of error down to the sub- pixel level. Furthermore, these parameters must be sufficiently independent of each other to avoid redundant adjustments and potential numerical problems. Adjustable parameters as implemented in the projection equations should be zero-biased. Associated with each adjustable parameter is its error uncertainty, or sigma value. This quantity indicates the standard deviation uncertainty of the adjustable parameter initial value (of zero). Along with the adjustable parameters and their sigma values, there are two arrays for storing the name of the parameter and the units associated with the parameter. In short, each adjustable parameter has five attributes: Name, Sigma, center, adjustable parm and calculated value. For Resourcesat-1, OCM-2 and Resourecesat-2 sensor model, following adjustable parameters, its unit and default sigma values defined as shown in Table-1.

Table-1 Adjustable Parameters and its Unit and Sigma values

Adjustable Parameter	Unit	Sigma
Roll Offset	radian	0.001
Pitch Offset	radian	0.001
Yaw Offset	radian	0.001
Roll Rate	radian/sec	0.0001
Pitch Rate	radian/sec	0.0001
Yaw Rate	radian/sec	0.0001
Focal Length Offset	percent	0.001

Interpolation Grid Model: As mentioned earlier, sensor models can be implemented either as rigorous model or as interpolation model. When interpolation model grid was generated using a rigorous model, then the adjustable parameters are established identical to the rigorous model that is used to create the grids. There are several interpolation grids that are referenced to compute a ground point from an image point.

The first pair of grids is the latitude and longitude grids with respect to input pixel and scan line number in the image plane. Hence, it provides the reverse mapping of ground coordinates to image points. The grid interval itself is adjustable, though by default it is created in nearest of every 32 pixels and 32 scan lines. It is to be noted here that image coordinate of grid points are not always integral number , in fact most of the time it will be floating-point numbers. It is so because, the first image point i.e. (0,0)th image point is always taken as first grid point and the (0,(n-1))th image point is the last grid point, where n is the number of pixels in the input image (i.e. number of CCD detectors in the array). So the number of grids in pixel direction is $\left\lceil \frac{n}{32} \right\rceil$ and grid interval is $\frac{n}{32}$ pixels. Similarly, number of grid points and grid interval can be computed in scan direction. At each grid point, the corresponding ground coordinate is computed from rigorous sensor model. A second pair of grids contains the partial derivatives of latitude and longitude with respect to the height. These define the horizontal shift with respect to a vertical movement along the imaging ray, and are used for intersecting the ray with an elevation surface. The remaining grids contain the partial derivatives of latitude and longitude with respect to the adjustable parameters. These define the horizontal and vertical shift corresponding to a parameter adjustment. Since there are seven adjustable parameters defined by Resouresat-2 sensor model, there will be seven pairs of grids created to take care of the effect of these adjustable parameters.

Another important improvement in interpolation grid generation process is splitting of equi-spaced grids into smaller sized grids based on the terrain height undulation. It implies that a grid intervals are not always same long and across the imaging direction, but primarily depends on the underneath terrain height undulation. When the terrain surface covered by the area of primary grid is highly undulating so that interior points within this primary grid points cannot be bilinearly interpolated, the primary grid is split into equi-spaced grids and all the resultant grid points are computed from Sensor Model along with height partials. This grid splitting process continues until interior points are bi-linearly interpolable or grid interval reduces to 2 x 2. Hence, it is imperative that while processing an image of highly undulating terrain, more number of grid points will have to computed from Sensor model, and that in turn results in more processing time.

Geo-location Accuracy Improvement : On the course of geo-location accuracy improvement, three major techniques are used – feature detection using Harris Corner Detector, outlier rejection with RANSAC algorithm and Sensor Model Optimization using Levenberg-Marquardt nonlinear optimization technique.

For geo-location accuracy improvement Ortho-rectified Carto-1, LISS-4, LISS-3 (over Indian region and its neighbors) and LANDSAT ETM Ortho-corrected (28.5m resolution, and for rest of the world) images are used. (Ground resolution of 28.5m) are used. Multi-scaled hierarchical image matching technique is used here to capture ~1 km of geo-location inaccuracy in the Resourecsat-2 image. This implies that even if the geo-location inaccuracy using system level ephemeris and attitude knowledge of the image is about 1km, multi-scaled image matching technique will be able to capture the interest points for sensor model optimization. The extent of the input image is determined using the Sensor Model and corresponding reference image is prepared from the reference image database. The mosaicing of multiple reference images into single reference image followed by re-projection of input image into the same map projection of reference image is carried out on-the-fly. Initially, both the input image and reference image is up-sampled by factor of 2, thus increasing the ground resolution and adjustable parameters are estimated by Sensor Model optimization. Subsequently, the input image is geo-referenced with those intermediate adjustable parameters and same feature matching technique is used in full resolution to refine those adjustable parameters. Thus, adjustable parameters are estimated in two stages to capture large geo-location inaccuracies in input image.

Tie Points (or interest points or feature points) are detected between the Mosaiced Reference Image (Master) and Band-3 of target image (Slave). Tie points generation process involves feature extraction with Harris Corner Detector (keeping Corner Density parameter as 0.002) and correlation in sub-pixel accuracy with Normalized Cross Correlation. Slave image is brought into same resolution and map projection of that of Master image before feature extraction. Tie points extracted may have wild points which need to be located and discarded. Outliers are rejected using RANdom SAmple Consensus (RANSAC) algorithm iteratively using inlier ratio of 0.7, 0.6, 0.5, 0.4 progressively. If no inlier is found even within inlier ratio of 0.4, then outlier rejection is done using mean and standard deviation. These inlier tie points are fed into the Sensor Model of target image and the model is optimized using Levenberg-Marquardt non-linear optimization technique[2] to estimate first six adjustable parameters namely attitude roll, pitch and yaw, attitude roll, pitch and yaw rate.

LISS-4 Bands Co-registration: LISS-4 payload of Resourcesat-1 and Resourcesat-2 consists of three detector arrays, separated by a distance equivalent of 2.1 sec along the track. Due to such configuration, time of imaging for same ground point by three bands are different, so the look direction vectors for imaging same ground point by the three detector array is not same. Both terrain height and residual attitude rates play an important role in achieving the co-registration of bands in the final data products.

Roll tilt and highly undulating terrain mandatorily requires Terrain Correction as seen in Figure-1 and Figure-2. Different look directions in three CCD arrays result substantial co-registration error in highly undulating hilly terrain when only earth ellipsoid is used for imaging ray intersection instead of using any DEM. The generic Sensor Model and LISS-4 specific Correction Model jointly corrects for terrain releif and estimates resiudal attitude rates to achieve bands co-registration of LISS-4 MX images.

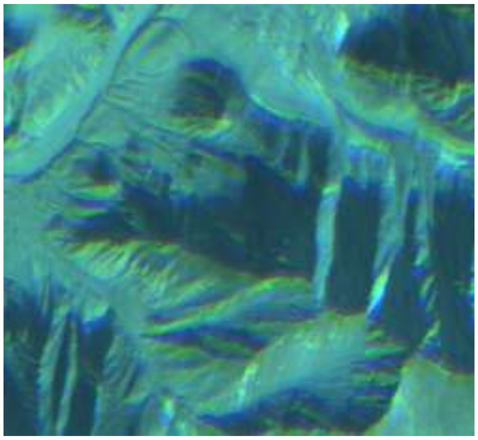

Figure -1: Terrain uncorrected Image of Resourcesat-1 (tilt angle: -12.56^0)

Figure -2: Terrain Corrected Image

Conclusion : Since multi-resolution image matching technique is adopted for feature extraction, there is no restriction to use reference image of coarser resolution to correct for finer resolution image e.g. for 5.8 m LISS-4 image, reference image of 25m (LISS-3 reference images) or 28 m (ETM reference images) can also be used. This approach is adopted, especially for scenes of outside Indian region for which LISS-3, LISS-4 or Cartosat-1 ortho-rectified reference images are not available. In fact, for correcting each sensor images of Resourcesat-2, there is a stack of reference image sets (from finer to coarser resolution) defined that determines the search sequence for getting the reference image sets corresponding to the extent of the image to be corrected. Two stage residual bias estimation processes is used to capture about 1000 m of geo-location inaccuracy and the final product is produced within 1 pixel for LISS-3 and AwiFS and within 2-3 pixels for LISS-4 both in Resourcesat-1 and Resourcesat-2. Internal Distortion of the final product achieved is also within 1 pixel for majority of the products. The same Sensor Model framework can be used to model the imaging process of sensors from geostationary orbit like INSAT-3D.

Acknowledgements: The authors would like to thank Director SAC, Shri Santanu Chowdhury, Deputy Director, SIPA, for technical support and guidance.

References:

[1] Linear Pushbroom Cameras Rajiv Gupta, R.I. Hartley IEEE Transaction on Pattern Analysis and Machine Intelligence Vol 19 Issue 9, Sep 1997

[2] **Robust** LM (Levenberg-Marquardt) algorithm and its application in Satellite Image Geometric correction Pengshan Chen et.al

[3] Satellite Geometry Handbook S-NT-73-12-SI , Edition-1-Revision-0

SATELLITE IMAGERY DATA QUALITY EVALUATION AND ANALYSIS

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Introduction: Series of Indian remote sensing imaging satellite is providing useful global coverage data from medium to coarse resolution for more than two decades which is continuously being used in various applications like agriculture, forestry, meteorology, disaster management, cartography and many more. Before disseminating this data to user, essentially it is required to assess its quality by an independent system. Data Quality Evaluation System (DQE) is responsible for the assessment of payload and platform performance and data product quality by quantitative and qualitative means. DQE regularly monitors the radiometric and geometric accuracies of the user product and provides feedback to mission, payload and data product team. This article discusses in brief about data quality evaluation system and parameters for optical and microwave sensors.

DQE Parameters: There are two main aspects of remote sensing image quality; radiometric quality and geometric quality. For optical sensors, the radiometric quality is affected by sensor characteristics and detector responses resulting striping, line drops, noise. Microwave image quality refers to the impulse response properties of Radar and to the response of system to distributed scatterers.

Geometric quality depends on sensor characteristics as well as platform parameters like attitude, position, velocity and perturbations. Earth's terrain or surface relief is one of the important factors affecting Geometric quality of the images. Residual band to band or polarization-polarization mis-registration and image to map mis-registration, residual stagger between multi spectral band images or ports are main geometric data quality parameters.

RISAT-I is the recent mission in active microwave mission category which carries a C- Band SAR which is a multimode multi-polarization sensor, with a phase array antenna onboard with 288 TR module pairs to transmit and receive backscattered energy from the target.

DQE of microwave radiometers and meteorological missions is evolving and significant work is done for Megha-Tropiques L-0 data analysis to study and monitor the payload performance. For upcoming mission INSAT-3D, L-0 data analysis methodology is formulated and parameters are identified. For any new mission DQE initiates with the understanding the system in order to identify the quality parameters to be monitored regularly as per the sensor, platform and data product specifications.

Data quality evaluation system is broadly classified into three categories; Radiometric DQE; Geometric DQE and Calibration DQE. Each of this is discussed in brief in subsequent sections of this article.

Data quality evaluation team at SAC is responsible for the design and development of an integrated software system which is operationalized at NRSC, Shadnagar. For reliable assessment semi-automatic approaches for quality assessment are generally followed in operations although auto-DQE software is available for evaluation of quality parameter which requires minimal human intervention.

Radiometric DQE (RDQE): Radiometric data quality evaluation is carried out on radiometrically corrected product and homogeneous targets are monitored regularly to study their spectral behavior. For optical sensors - radiance, SNR and apparent reflectance is computed whereas for RISAT-1 SAR sigma-0, speckle index and radiometric resolution is evaluated for the selected uniform target. For a given data product scene dynamic range in terms of max-min counts and radiances/sigma-0 is also evaluated.These numbers are stored into DQE results database to study the trends of radiances/sigma-0 over a period of time.

Global radiometric sites (as per CEOS) like Sahara desert, Yaman desert, Tuz golu, Bonneville Salt Flats, Lake Frome are monitored for RDQE of optical sensors. For RISAT-1 SAR, Amazon rain forest data is being studied.

An indigenously built software tool for RDQE (Fig.1) provides handle to select target on image and computes the radiometric parameters. This tool provides facility to visually interpret the imagery by visualizing the image histogram, data dump, scan-pixel profiles and spectral profiles.

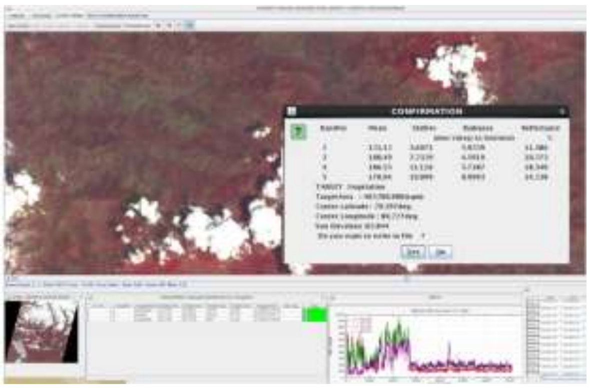


Fig. 1 Radiometric Data Quality Evaluation Tool

For RISAT-1, raw data analysis is done to monitor the sensor performance for all beams and polarization of FRS-1 mode. Quality parameters (fig.2) such as Mean I/Q, Std Dev I/Q, Power and Phase imbalance in echo data, antenna beam width, pointing, shape from antenna pattern (Fig: 2), squint estimation using Doppler centroid frequency, replica analysis to monitor the transmitted chirp signal (I/Q samples) and its bandwidth are being studied and monitored regularly.

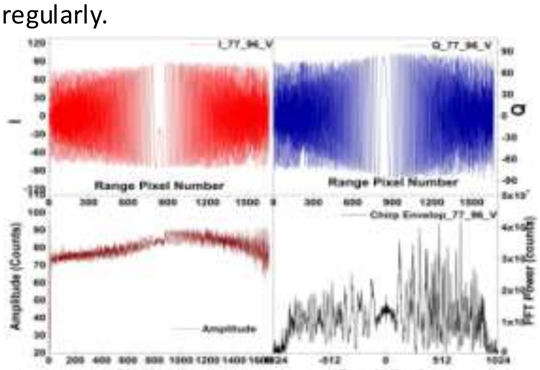


Fig.2 FRS-1 -Orbit 77 Scene 67, DOP-1st May 2012, VV, Beam: 96

Geometric DQE: Location accuracy is one of the most significant GDQE parameter which is computed for at least three scenes per orbit at operations centre.

This activity is carried out with the help of well proven mathematical procedures which uses the high accuracy reference images and digital elevation model (DEM) for Indian/Global coverage at various resolutions. Location related parameters are along/across track location error, scale, internal distortion and attitude biases. DQE trend reports for the location parameters are studied by peers and appropriate biases are applied for the system corrected product generation.

This activity is carried out using an interactive tool for ground control point identification. Sample report is given in Fig.3.

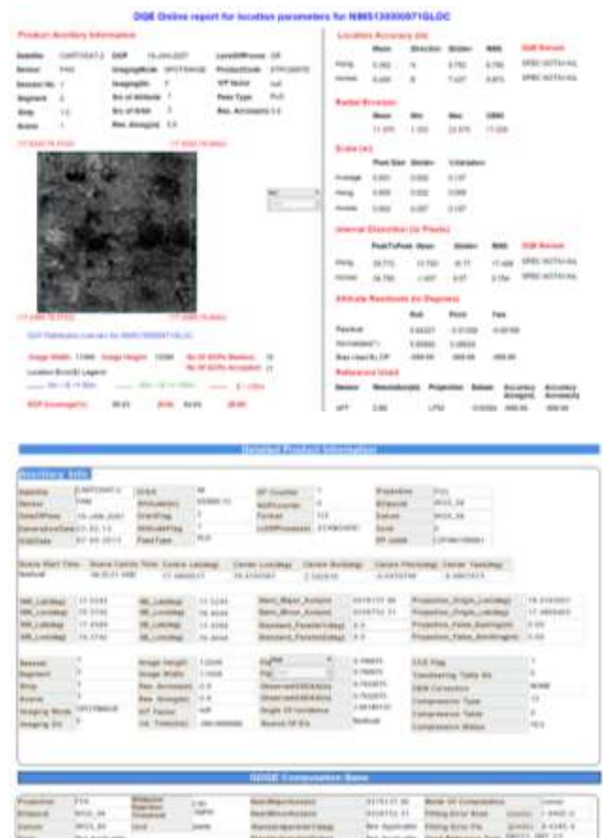


Fig. 3 Geometric DQE Report Sample for Location Error

Band-to-Band/Polarization.-Polr. Registration and stagger error is estimated by correlation based algorithm using semi-automatic software tool (Fig.4).

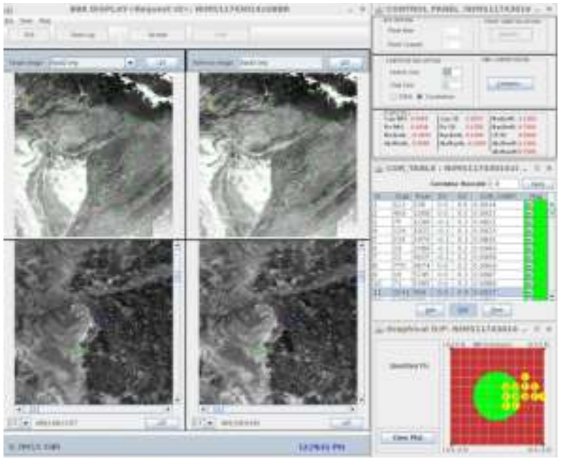


Fig.4 Geometric DQE BBR Estimation Tool

Similarly, using indigenously built software tools other geometric DQE are evaluated regularly, dynamic trends are captured and reported for the corrective actions to data product generation team.

Estimation of the RISAT-1 SAR impulse response is performed using a customized tool (Fig. 5). Corner reflectors based point targets acquired in satellite imagery is used as input for computing peak to side lobe ratio, integrated side lobe ratio, right/left side lobe ratio, geometric resolution and signal to clutter ratio. RISAT-1 point target data acquired in FRS-1 mode for the sites Nalsarovar, Ahmedabad (SAC), Shadnagar (NRSC) and Narkhoda is analysed.

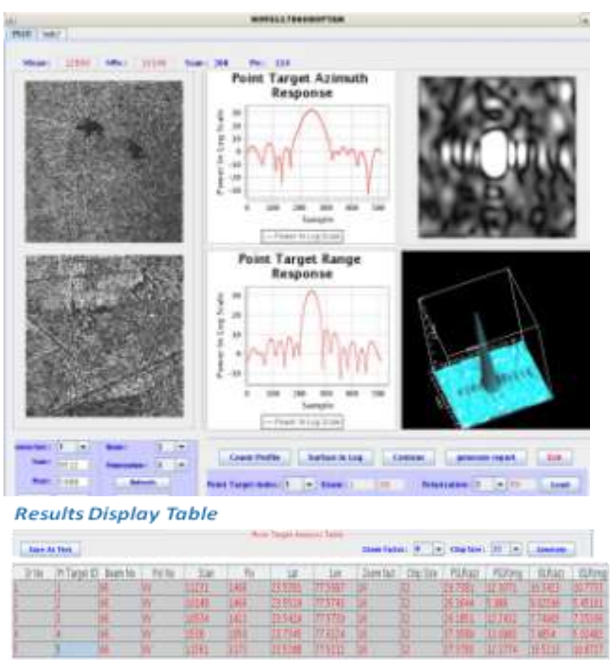
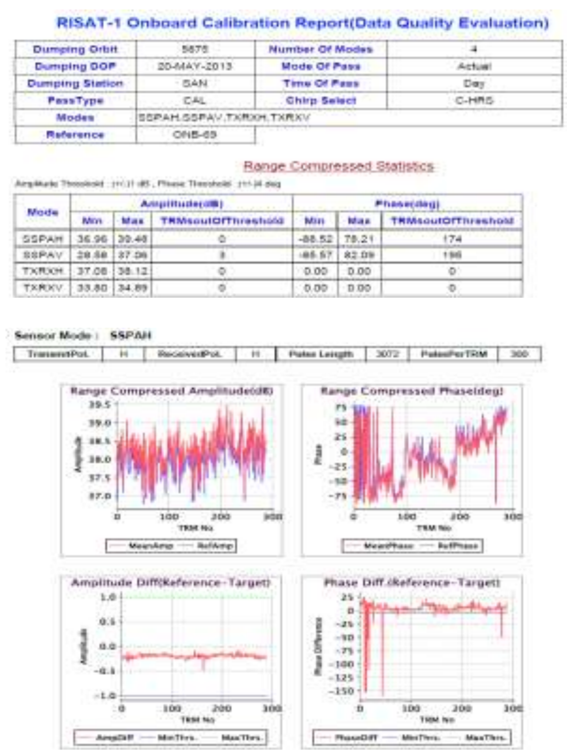


Fig.5 Point Target Analysis Tool

Onboard Calibration DQE: Each optical sensor defines its own onboard calibration scheme for monitoring the health of CCD arrays and similarly, for active RADAR RISAT-1, a special onboard calibration scheme is defined to monitor the health of Transmit Receive-modules. Data quality evaluation software for onboard calibration DQE of optical sensor computes the statistical parameter for data acquired at different exposure/gain and reports the deviations with respect to reference data. Based on statistical analysis, degraded or failed detectors are flagged and feedback is given to data product team for RAD look up table updation.

Onboard calibration DQE package for RISAT-1 evaluates range compressed amplitude and phase, power, power imbalance and phase imbalance using onboard calibration data (SSPA and TxRx) to monitor the health of TR modules. After comparing with the laboratory measured calibration data, first day onboard calibration data is made as reference and subsequent cal-pass data is being compared with the reference data. Sample report for RISAT-1 SAR onboard calibration DQE report sample is shown in Fig.6.



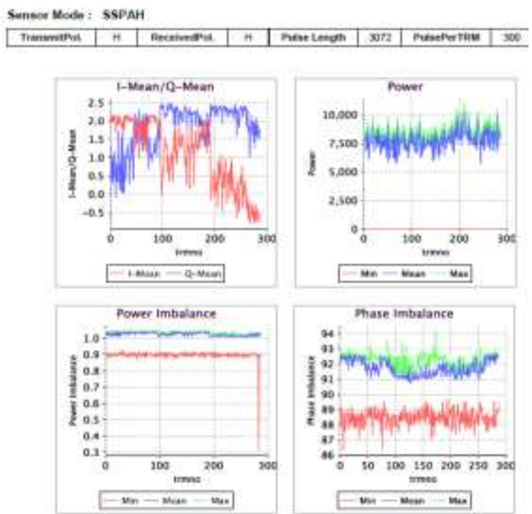


Fig.6 RISAT-1 Onboard Calibration DQE Report

Microwave Radiometers: L-0 data analysis : DQE system for Passive sensors Megha-Tropiques MADRAS and SAPHIR monitors (i) the Level-0 raw data in terms of earth view and calibration data, (ii) reference load temperatures (iii) temperature related to other onboard electronics, (iii) auxiliary information to continuously keep track of the payload health and performance (Fig.7).

Fig. 7 MADRAS Payload Data Analysis Tool

DQE studied the MADRAS data related anomalies and provided tools to visualize the MADRAS data in order to clearly notice the jumps or channel mixing. Seeing the MADRAS anomalies DQE has come up with a special report which provides a quick overview of L-0 data based on pre-defined threshold values (fig 8).

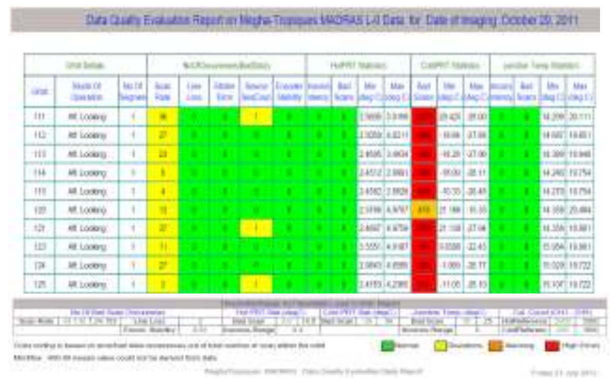


Figure 8: MADRAS DQE Daily Report on L-0 data

Conclusion: Data Quality Evaluation is an important activity for Earth observation missions. It is dependent on the sensor characteristics and specifications based on which DQE system is devised. DQE system is monitoring the payload and platform performance of ongoing optical and microwave missions and providing a regular feedback to mission, payload and data product teams regarding sensor health and corrective actions to be taken.

REFERENCE IMAGE GENERATION

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Introduction: Data Quality Evaluation (DQE) system provides important feedback to mission about platform performance regularly using system corrected user product as an input for all Earth Observations Satellites of ISRO. DQE system has matured over the years in terms of tools, techniques and procedures it follows over the last three decades and has become an essential sub-system of the whole IRS mission operations. One of the major feedbacks it provides to the mission is the geometric quality of the acquired imagery. The DQE system has to utilize the accurate ground references for evaluating data products for determination of absolute accuracy of the product. Hence, the major requirement for the computation and quantification of DQE parameters is the availability of accurate ground reference, which gives information about location, in terms of latitude, longitude and height, on earth surface.

Under CARTODEM project, Orthoimages are generated covering Indian landmass with a planimetric accuracy within 15 m and height accuracy within 8 meters, using precise Ground Control Points. It was decided to generate REFERENCE IMAGES with various resolutions using CARTODEM orthoimages as ground reference. IRS-P6 L-3 (Fig: 1) and AWiFS (Fig: 1) reference images were generated for Indian landmass for prior to launch of RESOURCESAT-2. All the reference images generated had gone through a qualification process using operational Data Quality Evaluation procedures. The location accuracy achieved was better than a pixel whereas internal distortion was within 2 pixels for 90 % of cases. These references are operationally used for RESOURCESAT-2 improved accuracy product generation as well as data quality evaluation of RESOURCESAT-2 products as well as for Geo Location Assessment for MRS products of recently launched RISAT-1 mission.

Figure-1: India mosaic of IRS-P6 L-3 reference images

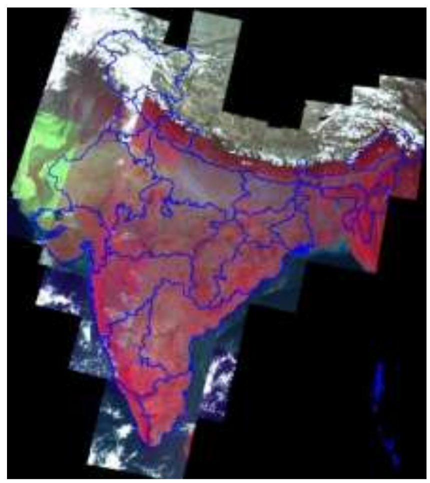


Figure-2: Full India mosaic of RESOURCESAT-2 AWiFS reference images

In April 2011 RESOURCESAT-2 was launched with improved radiometric resolution for all three cameras as compared to IRS-P6. Meanwhile CARTODEM database was also updated with DEM covering Jammu and Kashmir and North – eastern states. Hence we decided to generate RESOURCESAT-2 LISS-3 and LISS-4 FMX reference images covering Indian landmass as

- The information will be latest (2011 – 2012)
- Improved radiometry (10 bit)

- Reference generation software was fine tuned For improving internal distortion

276 reference images (Path-Row based) each having a swath of 140 x 140 km, and with output resolution of 25m are generated using RESOURCESAT-2 LISS-3 data acquired between October 2011 and March 2012. As done earlier, for terrain correction of these images CARTOSAT-1 Orthoimages (down sampled to 30m resolution) were used for Polarimetric information and CARTODEM was used for height (elevation) information. The specifications of generated reference images are as follows.

- Map projection: UTM
- Datum: WGS-84
- Output Resolution: 25m (L3), 5m (L4)
- Output format: GeoTiff

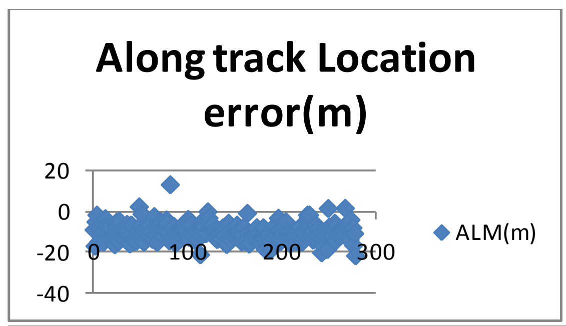
Similarly, 1075 reference images (Path-Row based) each having a swath of 70 x 70 km, and with output resolution of 5m are generated using RESOURCESAT-2 LISS-4FMX data acquired between October 2011 and December 2012.The geometric accuracy specifications decided for reference images was that the geo-location (location accuracy) should be within one pixel of output resolution and internal distortion (variation in geo-location in a given image) should also be within one pixel. Operational IRS-DQE software was used for computing geometric accuracy of above mentioned reference images.

Following three parameters were computed and stored in a report.

a. Location accuracy (geo-location)
b. Scale variation
c. Internal distortion

For computing the geometric accuracy one has to identify Ground Control Points (GCPs) in target image (LISS-3/4 reference image) and ground reference (CARTOSAT-1 Orthoimages generated under CARTODEM project). In operational DQE procedure such GCPs are marked manually through a GUI. For qualification of large number of reference images, GCPs were identified automatically using the AUTO-GDQE software. In few cases point selection was erroneous and in few cases sufficient well distributed points were not selected. For such cases, erroneous points were rejected interactively and new points were added manually to ascertain proper GCP distribution.

Our goal was to achieve location accuracy and internal distortion of resultant LISS-3 reference images within one pixel of output resolution, that is, 25m. For 97 % cases this specifications of location accuracy (Fig: 3) and internal distortion has been achieved. Internal distortion has gone up to 1.8 pixels in few cases which may be due to hilly region, uncertainty in point selection during generation and qualification, DEM unavailability in some part of the given image.



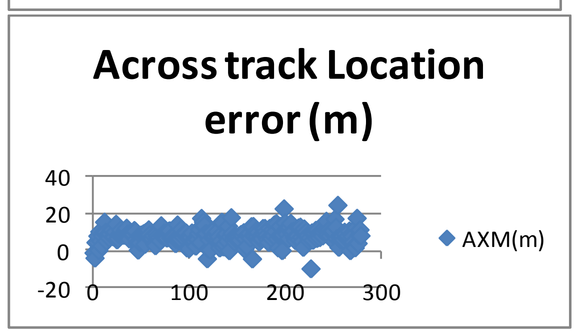


Figure-3: Error plot showing along & across track location accuracy (in meters) for 276 L-3 reference images

ROLE OF SOFTWARE ENGINEERING STANDARDS IN THE EVOLUTION OF ISRO'S DATA PRODUCTS SOFTWARE

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1 History & Background: The objective of this article is to highlight the role of software engineering standards in the evolution of data products generation software in ISRO. Image Processing and Analysis Division IPAD headed by Shri DS Kamat in the late 70's happens to be the pioneering team which initiated and nurtured the development of computer software for data products generation in ISRO by processing data received from sensors onboard the ISRO's remote sensing satellites. The team consisting of Shri DS Kamat, Shri AKS Gopalan, Dr. CVS Prakash, Dr. KL Majumder, Shri NT Unnikrishnan, (late) Dr. NK Vyas, Shri VH Patel, and Shri KS Dasgupta played a pioneering role in experimenting with hardware and software for image processing in ISRO. They were instrumental in establishing a state of the art computing facility in SAC for image processing with VAX-11/780 and COMTAL image display systems. They also felt the importance of adopting Software Engineering for the software development efforts undertaken by that team.

Three senior authors of this paper along with a few of their contemporaries played a significant role in developing operational software for the generation of data products from the then to-be-launched first operational Indian Remote sensing satellite IRS-1A. This was preceded by a series of lectures delivered to the team members on Software Engineering with the sole purpose of improving quality and productivity in software development. The practice of documenting the software requirements, interface specifications, software architecture, choice of algorithms and their mathematical formulation, detailed design, test plan, and user manuals; and instituting a host of formal review procedures; identification of teams to discuss and resolve interface issues and for the management of ground software subsystems developed across the ISRO centres; were all put in place. Coding guidelines and documentation standards were developed, reviewed and adopted. Structured programming principles prescribing single entry and single exit, high cohesion and low coupling, one-page, *goto* less, information-hiding modules with meaningful variable names, were adopted with a mix of top-down and bottom-up development and integration approaches, as much as possible, by the software development teams. In 1984, an ISRO level team with participation from Data Products team came out with Software Quality Assurance Guidelines SQAG-84. This contained guidelines for software life cycle, software documentation and review process. This was followed up by the ISRO Software Engineering Standard ISES which was released for adoption during 1992. ISES-92 prescribed standards for: software development, verification & validation, quality assurance, configuration management and project management. Object-oriented design and programming paradigm with its several added advantages over functional programming were fostered by Dr. PK Srivastava, who was instrumental in introducing this practice in the Data Products team during late 90's. ISRO Software Control Board in 2006 adopted the IEEE-12207 software life-cycle process standards for ISRO by suitably tuning them differently for the seven different categories of software development undertaken in ISRO, of which Image Processing is one among them, as the ISRO Software Process Document (ISPD). A four-member Software Quality Assurance team was identified in 2007 in the current Signal and Image Processing Area (SIPA) which eventually grew into a dedicated cell named Software Process Engineering Cell (SPEC) for the practical adoption of ISRO Software Process Standard 2006 in SIPA.

SPEC team enhanced the process definitions set forth in ISPD for their practical adoption by elaborating the tasks, identifying teams involved along with their respective roles among others. This team also developed in consultation with representative software practitioners from SIPA different document templates, their review checklists, coding standards for C, C++ and Java language implementations, and served all these artefacts through an intranet web portal for 24 x 7 accesses among SIPA team members. SPEC team arranged an external audit for the level of compliance to software quality standards in SIPA and identified a few areas which need to be further strengthened. SPEC team introduced the adoption of CASE tools, integrated with a suite of open source software tools in SIPA encompassing the entire software development life cycle. Of the several tools put in place, the use of *Test Link* and *Bugzilla* respectively in designing the test cases and in reporting and sharing software errors identified during testing were immediately recognised and appreciated by all concerned. In 2012, SPEC was instrumental in organising an ISRO level colloquium on Software Quality named ICSQ-2012 at SAC, in which software teams from all ISRO centres took part. This event also witnessed several expert talks on this subject chosen from academia, industry and another Government institution.

2. Best Practices Identified During External Audit:

2.1 *Project Milestone Reviews*: Milestone Reviews of software projects are formally being practiced through PDR, DDR and Acceptance T&E involving concerned stakeholders in ISRO-DOS, invariably for all operational software projects undertaken.

2.2 *Internal T&E Practices*: Internal Test & Evaluation (T&E) of software is being practiced invariably before delivery of the software products for final integration/use at the designated target operational environment, involving concerned stakeholders within SIPA.

Internal audit report cited the following additional items as best practices.

2.3 *Design Document Practices*: Bringing out document on Algorithms, Theoretical Basis & Definitions (ATBD Document) as a part of new types of projects, taken up for the first time in the Area; and bringing out interface control documents (ICD) containing data formats are considered to be best practices in SIPA.

2.4 *Internal Peer Reviews*: Formal (peer) review processes undertaken during development in some of the recent projects should be continued for all projects as a standard practice.

3. Excerpts from the Executive Summary of ICSQ-2012:

3.1 *Next version of ISPD*: "Quality is never an accident; it's always the result of high intention, sincere effort, intelligent direction and skilful execution; it represents the wise choice of many alternatives." Keeping this in mind, next version of ISRO Software Process Document needs to be brought out taking into account the different relevant factors.

3.2 *Strengthening SQA & Independent V&V*: Software quality assurance (SQA) and Independent Verification &Validation (IV&V) activities need to be strengthened in each centre.

3.3 *QA Audits*: Audits should be invariably carried out independently within each centre.

3.4 *Use of Software Metrics*: Metrics collection, classification and analysis towards continuous process improvement should be taken up in each centre.

3.5 *Project Websites*: A co-ordinated effort across all centres and at ISRO HQ should be initiated at the earliest towards realising project-specific web portals to share best practices evolved through experience in each centre as well as lessons learnt through intranet web-sites.

4. Quality Improvements in Data Products Software over the Years: Due to the adoption of appropriate software engineering standards which emphasise reviews, verification and validation throughout the software life cycle, there were several improvements incorporated into both the software products as well as the software development and related support processes, over the years. Software products were tuned/re-engineered for deployment in several international ground stations. In this section, we shall try to list them, each with a brief description.

4.1 *Software Product Improvements:*

[1] Configurable Parameters File Provision for file paths, valid product options, processing station code, etc., making the software easily testable, portable and installable on different configurations other than the target configuration.

[2] Editable XML Formatted Product Context File so as to enable the software product easily testable with different input parameters.

[3] Exhaustive Error Exits for All File & Device I/O so as to enable the software easily recoverable from error conditions in operational mode.

[4] Scheduler GUI with default user inputs making the software product user-friendly.

[5] Concise & Detailed Operational Reports making the software product user-friendly.

[6] Standard set of data products with all basic corrections either applied, or computed and provided separately as Rational Polynomial Coefficients for user end processing enabling the output products compatible with COTS software.

[7] Separate set of Value Added Products making the software product user-friendly as the processing time for standard products are not compromised.

[8] Human readable ASCII Product Metadata File making the software product user-friendly enabling both for computer and human consumption.

[9] Media Label Contents identifying the Specific Output Device, User Order reference & Product details for ready retrieval and analysing error conditions, if any.

[10] Media Label barcode provision for easier archival/ retrieval making the software product user-friendly by enabling automation.

[11] Log file provision for all SW executables for easier error localisation and recovery

[12] Installation Kit provision with licensing features for independent testing and independent deployment

[13] Device configuration provision in scheduler for site-specific adaptation.

[14] Automatic generation of standard products with the quality of value added products in terms of geometry with the use of national databases built over time.

4.2 *Software Process Improvements:*

[1] Preparedness for contingencies: Provision for initial phase calibration and software tuning to match actual onboard system performance and preparedness for different contingencies

[2] Development of Testing Tools: Versatile image display software for test output verification with a rich set of analysis provisions

[3] Continuous optimization efforts in reducing the processing time: Adoption of quality standards enabled optimization efforts to be successfully carried out by independent teams other than the original design teams.

[4] Standardisation of Interface File Formats to the Extent Possible

[5] Simulation of non-existent interface files and the input image data simulation ahead of launch to qualify the software product.

[6] Modular software design enhancing portability, modifiability and maintainability.

[7] Evolution from functional programming to object-oriented programming

[8] Different programming languages for different software components

[9] Adoption of language-specific coding standards

[10] Unit, integration and system testing by development team independent qualification testing by internal T&E team before deployment and/or integration with other inter-centre subsystems.

[11] Internal T&E error reporting format enabling statistical metrics collection and post-facto analysis for process improvement

[12] Continuous informal and formal review processes extending throughout the software life cycle

[13] Adoption of documentation standards and review procedures for software artefacts

[14] Deployment of web portals across the development teams across all projects for sharing software process standards and document templates.

5. Future Perspective: In April 2013, SPEC team which was a part of SIPA was moved to Systems Reliability Area in SAC with a mandate to perform software QA activities for all software products developed, customized or outsourced in the centre for ground applications. This will make sure that internal SQA teams are put in place for each project and the team will involve themselves during (i) the project planning activities for addressing SQA functions, (ii) before each milestone review for conducting an independent SQA audit, and (iii) the independent system qualification test and evaluation before the software products are shipped from the centre for their intended target use.

Acknowledgements: Authors acknowledge the role played by SIPA colleagues in the evolution of data products generation software in ISRO and particularly the role played by various Directors of SAC from time to time including Shri AS Kiran Kumar, current Director, SAC, Shri Santanu Chowdhury, Deputy Director, SIPA, Shri RK Dave, Deputy Director, SRA and the Heads of Divisions in SIPA: Shri TP Srinivasan, Shri Debajyoti Dhar, Dr. B. Kartikeyan, and Shri Kirti Padia. The roles of other seniors have been acknowledged within this article.

References:

[1] Software Quality Assurance Guidelines, SQAG-84, December, 1984, ISRO HQ, Bangalore

[2] ISRO Software Engineering Standards, ISES-92, May, 1992, ISRO HQ, Bangalore

[3] ISRO Software Process Document ISPD, Oct. 2006, ISRO HQ, Bangalore

[4] Proceedings of the ISRO Colloquium on Software Quality ICSQ-2012, Held at SAC during Nov. 22-23, 2012 (Two DVD Volumes), Dec. 2012

EFFICIENT COMPUTING & PERFORMANCE IMPROVEMENT IN DATA PROCESSING

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Introduction: As satellite technology is advancing, large volumes of high resolution data are being acquired via remote sensing. This data has to be processed within a specified period and has to reach the user as soon as possible. Indian Remote Sensing (IRS) programme launched Technology Experimental Satellite (TES) in the year 2001 with a geometric resolution of 1 meter. This satellite produced large amounts of image data which had to be processed in computer systems which were less powerful compared to the computers today. The hardware systems 10 years back had low RAM and slower CPUs which were a bottleneck for performance. The operating system used initially was UNIX. After that, came Linux which was popular due to the fact that it could run on Intel architecture. The combination of Intel and Linux gives an opportunity to provide solutions which are highly economical than the earlier solutions. Advancements in software engineering have also enabled us to design software in a better way resulting in high quality software.

Satellite Data Processing: Generally, Satellite Data Processing comprises of a sequence of operations to be performed on the data. The data could be image data, the processing of which can be visually be seen on the computer screen or after taking hard copy prints. The Pipe and Filter software architecture can be easily selected for such data processing software in which the data flows from one module to the other and data gets corrected according to the function of the module. This approach is followed by the authors, and such architecture is selected for the data processing software packages described here. Apart from this, a controller software is also used which controls the data pipeline or data processing chain. The controller software contains a Scheduler whose responsibility is to execute modules according to the sequence specified.

Need for Performance Improvement: Around 10 years back when UNIX was being used, the hardware was slow due to the technology at that time. Less RAM would result in loading smaller portions of data in memory. Slower CPUs would result in more time to process data.

The performance of the software was acceptable at that time because the volume was less compared to what we get today. Cartosat-1 single pass is around 40 GB in volume. This high volume of data needs to be processed within a short period of time as there are urgent needs of the data. For example, one of the usages of data is disaster management and this data needs to be processed as soon as possible.

Planetary Data Processing software: Chandrayaan-1: In October 2008, Chandrayaan-1, the first planetary mission to moon was launched and it acquired data for a little less than a year. The data acquired during this time is of a high scientific value. Chandrayaan-1 data processing software developed at Space Applications Centre (SAC) handles two payloads called Terrain Mapping Camera (TMC) and Hyper Spectral Imager (HySI).

In Chandrayaan-1, the total data volume is 18 TB. The data was processed initially with a single server in around 40 days. TMC data is high in volume but less compute intensive, compared to HySI data. The image registration operation in HySI requires a lot of compute power. If there is an updation in the algorithm in the data processing software the entire software has to be rerun to regenerate the output which placed a need for improving the throughput of the system. This was the basic need for improvement in Chandrayaan-1 software. This article further describes the software which was used to process this data with an emphasis on performance.

Possible Ways of improvement: Many options were looked into which are listed below

- *Upgrade hardware*: By augmenting the servers with faster CPUs and more RAM we could increase the throughput. The speed of the CPU was limited to the latest technology in the market. The number of CPUs was limited by the Physical Server which was being used. Motherboards allow only up to a certain number of CPUs. In this case we could not upgrade the servers with more CPUs as all the slots were already full.
  Increasing RAM was an option which does not guarantee improvement in performance unless the software is changed to use the additional RAM present.
- *Modify Algorithm/Software*: One option was to modify the algorithms and the software used to process a single data set. The risk involved in this was to retest the entire software and the time involved in doing so.
- *Distributed computing*: Another option was to retain the existing algorithms and to partition the data in smaller sets. Each set would be assigned to a different server with central software to control the assignment of jobs and monitoring them.

Standalone Software : The first version of the software was a standalone package which was running on a single server. This setup was unable to meet the throughput requirements. The limitation was the existing hardware which was unable to handle the amount of processing work to be done.

The second version of the software was to distribute the data on separate servers with manual control and monitoring. The software was replicated on multiple servers with external disks attached to each server. This increased the throughput but also increased the amount of work for operators. They had to ensure that the hard disks were having sufficient space so that the output could be written to it. Apart from this, the hard disks had to be replaced once they were full. There were human delays associated due to this and the utilization of the servers was poor.

Distributed Software: A distributed software system contains software components located on remote networked computers and they communicate and coordinate their actions by passing messages. The components interact with each other in order to achieve a common goal. [2].Distributed computing is used to achieve high performance along with high availability. In our case the intention was to have a higher throughput by utilizing the servers in the network. One of the disadvantages of distributed computing is the increase in complexity of the software as well as the handling of the operations. Since many components (servers, storage hardware, networks, etc.) are involved, special care needs to be taken care of to make them work seamlessly and reliably.

The current version of the software is with distributed processing with a central storage. All input data is kept in the central storage and the output is written onto the same storage. The block diagram in Figure 1 depicts the architecture of the distributed processing software for Chandrayaan-1. The main Data Processing software contains a set of executables which are executed in a sequence for a data set. These executables form a Pipe and Filter architecture and data is processed as they flow through them. The sequencing of these executables is done by a component called Scheduler. The Scheduler has the capability to execute modules on the local machine or on a remote machine.

A node is a software component which resides on a server and waits for a command to be executed. The Scheduler gives a command to a remote Node to execute an executable. Distributed computing is achieved by this mechanism. There are multiple nodes running on a single server to utilize multiple cores and these nodes run on multiple servers also. Therefore to scale the system, one can add as many servers as are available.The throughput achieved through this software with 11 servers was 15 times more than what was achieved with a single server.

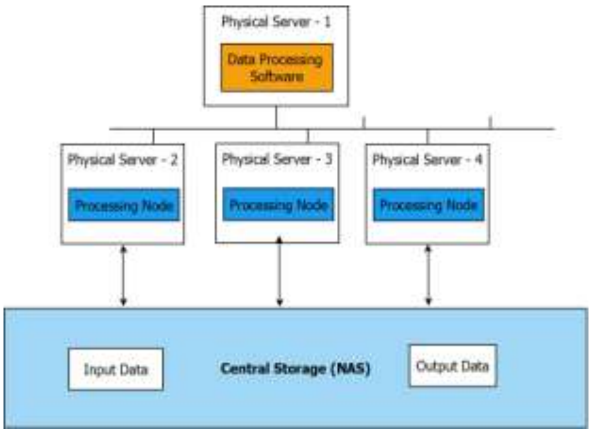


Figure 1: Distributed Processing Block Diagram

The software gives a central user interface which the operator monitors to see the status of the processing. The actual processing is done on remote servers and their status can be seen on the main server labelled as "Physical Server – 1" in the block diagram.

The user interface is shown in Figure 2. It contains the list of products which are running along with the names of the executables for each product. The operator can view the status of each executable along with the parameters for each product.

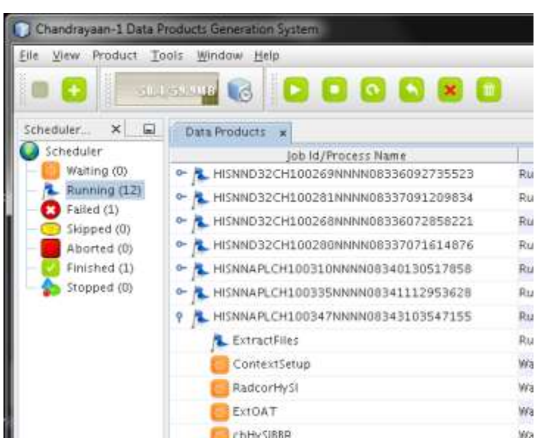


Figure 2: User Interface for Data Processing Software

Lunar Digital Elevation Model (LDEM) generation using Chandrayaan-1 data : One of the major and important activities identified at Payload Operations Center (POC) in SAC is Lunar Digital Elevation model generation using Chandrayaan-1 TMC data towards Lunar Mapping. The main objectives set for this project are generation of (i) Digital Elevation Model (DEM) at 25 meter grid interval and (ii) ortho image at 5 m resolution. The software package uses radiometrically corrected TMC stereo image pair as main input and produces DEM and Ortho image as output in classic and Big TIFF image file formats with pack-bits compression enabled.

Techniques and Software Development: Development of techniques such as, full orbit sub-pixel level stereo image matching, RPC based model for lunar data processing (first ever attempted) for equatorial data, physical sensor model for polar data processing, manual Lunar Control Point (LCP) identification using Clementine image and LOLA heights and kd-tree based scattered point interpolation. To cater to the processing requirements of more than 1000 orbits of data, very meticulously designed and developed a complete software package with standalone and distributed processing capability on multiple compute nodes. This also supports web-based application for monitoring of DEM generation process, defining custom workflows, ingesting jobs and performing online quality evaluation.

High Throughput Computing (HTC): Data size of each stereo pair is of ~10GB and the processing applied on these images are 'Interest Point Generation', 'Conjugate Point Generation', 'Space Intersection', 'Point Interpolation' and 'Geometric correction Grid & Resampling'. Each of these processes are highly computational and IO intensive. Since most of the core modules are legacy in nature and they are not having the parallel processing capability, we decided on HTC technique rather than HPC, to get desired throughput within a stipulated time frame. Without this option it would have taken around 300 days to process all the datasets.

Execution of multiple processes on different datasets in parallel on multiple compute nodes using distributed processing helped greatly to achieve processing of all the datasets within 60days for 25meter grid interval DEM generation excluding data quality evaluation task.

Distributed Job Scheduling: Java based daemon process takes care of distributing jobs on multiple compute nodes using round robin algorithm, because of this all of the computes nodes are equally loaded. Each compute node is connected with master node using SSH (Secure SHell) and separate logical sessions are maintained between them.

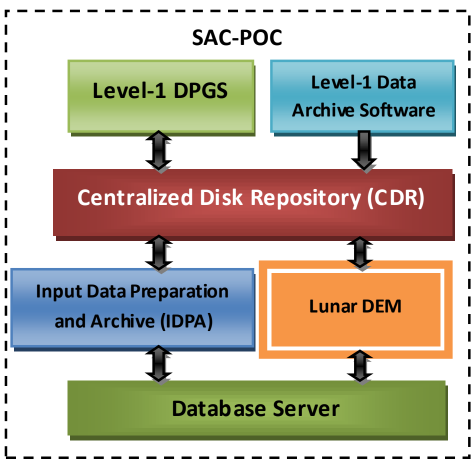


Figure-3: DEM Generation Workflow

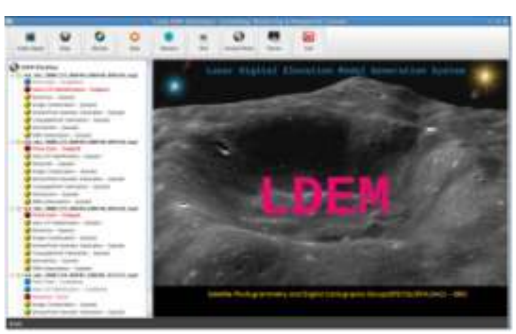


Figure-4: Scheduler User Interface Generation Workflow

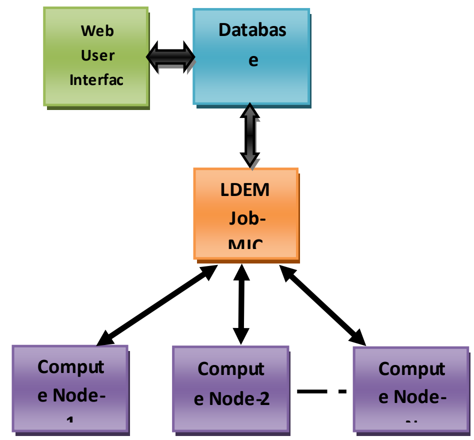


Figure-5: Multi-node Scheduling

As mentioned in **Figure 3** Lunar DEM software is the central package, which comprises of core processing modules, single and multi-node distributed scheduling. Multiple compute nodes have been identified with different hardware architecture and primary memory configurations. The multi node Job scheduling system has been designed in such a way that it can handle heterogeneous hardware platforms. This design also increased throughput of the LDEM system and the no. of orbits processed per day increased from 2 to 6 orbits with 3 compute nodes.

The key features of Multi-node Job-MIC system are listed below,

- Platform Independent
- No special software installation required on local and remote compute nodes
- Compute node specific job scheduling
- Compute node specific processing queue length setting
- Web interface for scheduling, monitoring and management of Jobs
- Defining custom workflow for a set of orbits
- Very easy add-on and removal of compute nodes
- Can be configured to run on single system
- Can be configured as Linux service
- Supports any number of nodes

Figure 4 represents the user interface for single user, which gives facility for the user to schedule the jobs on a local compute node. Figure 5 illustrates the distributed scheduling architecture in which LDEM software is getting operated. The web user interface can be accessed from LAN and gives interface for viewing the jobs categorized in to various queues. The desired list of jobs can be selected and a list of processes to be run on that job can also be defined and subsequently it can be slotted for processing. The ingested jobs immediately go into the ingest queue then to queued jobs; based on the current system availability it pushes the job for processing. The processing queue length of each compute node can be set specific to each node (**Fig.5**).

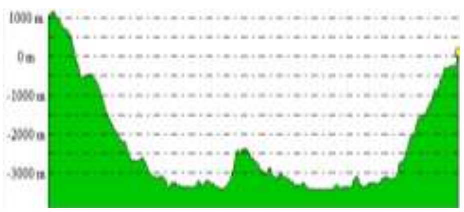
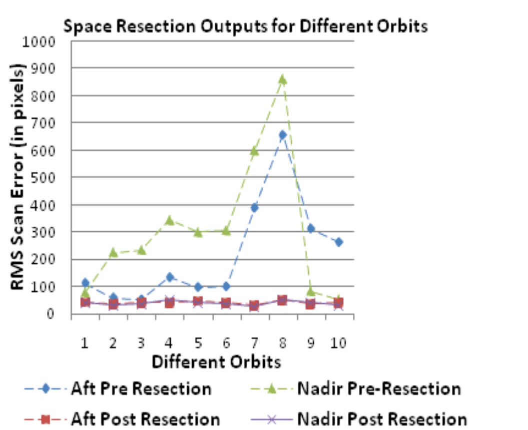


Figure-6: Height profile of Tycho crater

Observations and results : The LDEM software generated 756 orbits of DEM and Ortho image with 25 meter grid spacing. DEM location accuracy is around 200 Meter. This improvement achieved using the lunar control points and the achieved improvements are illustrated in the Graph 1. **Figure 7** illustrates DEM, Colour coded DEM and corresponding ortho image of one of the craters Tycho. **Figure 6** illustrates the height profile of a central peak of Tycho crater.



Graph-1: Typical Example of planimetry improvement achieved using Control Points

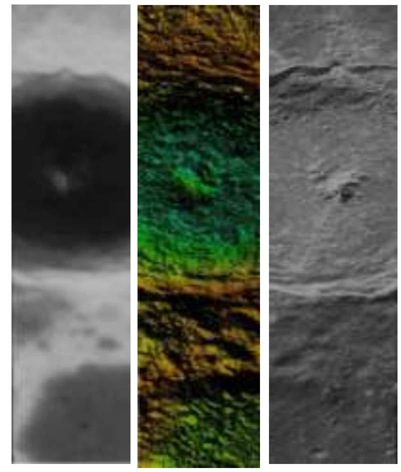


Figure-7: DEM, Color coded DEM and Ortho Image (Tycho crater orbit number-2878)

Addressing computing needs with Graphic Processing Units: One of the most challenging tasks in the DEM generation process is the ability to find the conjugate points between the overlapping images. This requires both precision and speed. The LDEM S/W employs an algorithm which uses image pyramids to tackle complexity of image matching. The construction of pyramids using sub-sampled images facilitates coarse to fine conjugate point identification, but also consumes substantial memory and computational power. The needs are further throttled to maximum by the enormous volume of planetary datasets such as from Chandrayaan-1 TMC triplet camera.

To tackle this complexity, LDEM S/W utilizes an advanced GPU accelerated implementation of the Hierarchical image matching method **[1]** as an option. By utilizing the philosophy behind the computing technique called General purpose computing on Graphic processing units (GPGPU), the algorithm is benefited by a 14X performance in most of the datasets. Average to High speedups can be achieved either with workstations having consumer grade GPUs or with server class GPUs. The introduction of this approach facilitated fast generation of DEMs for systems without access to any servers. **Figure 8** shows the complete image matching procedure and **Figure 9** shows the speedup achieved for the dotted box for a single matching instance. The module for GPU based image matching is developed on the NVIDIA Compute Unified Device Architecture (CUDA) –C. The software also incorporates many advanced GPU programming concepts like multi GPU switching, texture based image fetching and online data partitioning for handling large data volumes.

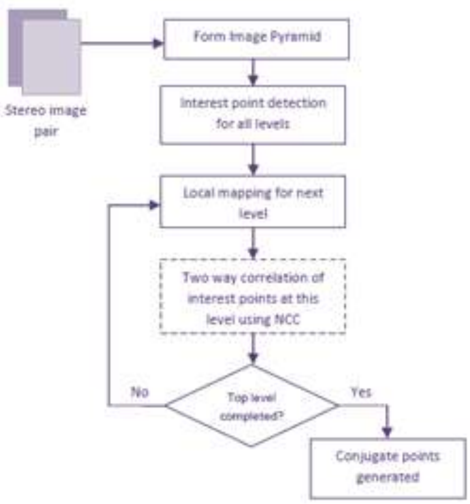


Figure-8: Procedure for Hierarchical Image matching

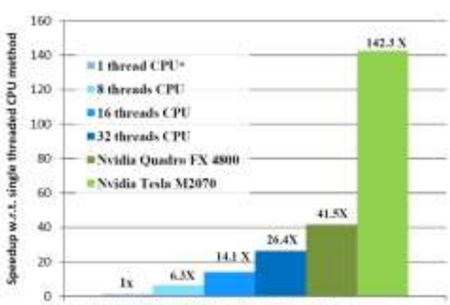


Figure-9: Speedup for Single Normalized Cross correlation with respect to multithreaded CPU programs

Conclusion: Efficient computing for data processing is a need in the field of remote sensing due to the high resolutions achieved by the latest satellites and the high volume of data to be processed. For the Chandrayaan-1 mission optimization of code and increase in throughput was achieved with the help of GPGPU and distributed processing. The significant throughput improvement has helped in realizing the projects in the anticipated timeframe. For Chandrayaan-1 Data Products Generation System, the throughput improvement has been around 15 times and for Indigenous Lunar Digital Elevation Model Software had a throughput and turnaround time improvement of 3 times and 14X respectively.

Acknowledgements: The authors would like to thank Shri Santanu Chowdhury, Deputy Director, Signal & Image Processing Area, for supporting the activities undertaken by HRDPD. The authors would like to thank Shri. B. Gopala Krishna, Group Director, Satellite Photogrammetry and Digital Cartography Group and Shri. T. P. Srinivasan, Head, High Resolution Data Processing Division for giving us this opportunity to work on this project and giving directions and support. The authors would also like to thank HRDPD members for providing support whenever required throughout this project.

References:

[1] "A GPU Based Image Matching Approach for DEM Generation using Stereo Imagery", Ashutosh Gupta, S. Devakanth Naidu, T. P. Srinivasan, B. Gopala Krishna, *IEEE International Conference on Current Trends in Technology*, 8-10 Dec.,2011, vol 2., Ahmedabad, India.

[2] Wikipedia

[3] Scheduling, Monitoring and Management Console with Distributed Processing for generation of Lunar Digital Elevation Model (DEM) from Chandrayaan-1 (Chandrayaan-1/DP/SAC/SIPA/SPDCG/HRDPD/TR-16/ Dec. 2012)

METEOROLOGICAL IMAGE ANALYSIS SOFTWARE (MIAS) - AN INTERACTIVE DATA ANALYSIS AND VISUALIZATION FOR METEOROLOGICAL DATA

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Introduction: MIAS (Meteorological Image Analysis Software) has been developed as part of IMDPS (INSAT-3D Meteorological Data Processing System) to analyze and visualize data from current generation of Indian Geostationary Weather satellites:

- Kalpana-1 [VHRR]
- INSAT-3A [VHRR & CCD]
- Upcoming INSAT-3D [Imager and Sounder].

It goes one step further to bring satellite data, model data and surface observations on one platform to enable users to carry out comprehensive data analysis. It is a Java based platform independent software built on top of the VisAD [1] (Visualization for Algorithm Development) and Unidata IDV [2] (Integrated Data Viewer) library. It provides Jython (Python Implementation in Java) scripting interface to allow user to carry bulk data processing. It has capability to seamlessly access local and remote datasets. OIAS supports a number of scientific data-access protocols: ADDE (Abstract Data Distribution Environment), OpenDAP (Open-source Project for a Network Data Access Protocol), and WMS (Web-Map Service) in addition to FTP and HTTP. It follows plugin based architecture to add support to future satellite datasets.

Dataset Support: Broadly MIAS supports following types of datasets:

1. Gridded datasets (e.g. Model Output)
2. Swath Datasets (e.g. Satellite Data)
3. Point Observations (e.g. AWS Data)
4. Radial Datasets (e.g. Radar Output)

As far as formats are concerned, it supports HDF-4, HDF-5, HDF-EOS, GRIB-1/2, NetCDF, Geotiff (limited support), Shapefile, McIDAS AREA, ASCII, Quicktime, BUFR (evolving currently). New formats can be added by writing plugins. To support the current and the upcoming weather satellite data, plugins have been developed to ingest Kalpana-1, INSAT-3A and INSAT-3D. The datasets include:

1. Level-1 (Standard Products)
2. Level-2 (Sector Parameters)
3. Level-2 (Geophysical Parameters)
4. Level-3 (Binned Geophysical Parameters)

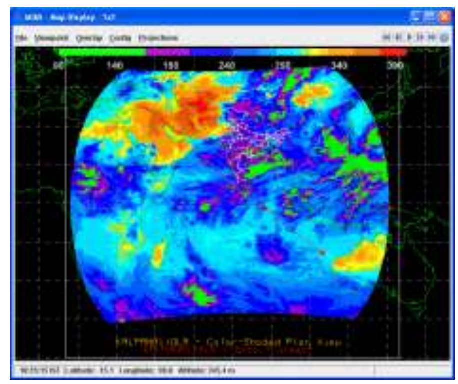


Fig. 1 Kalpana-1 OLR; 04 Aug, 2012 0700

The plugin capabilities include:

1. Conversion of count to BT/ Radiance for TIR, MIR and WV channels (Kalpana-1 VHRR, INSAT-3A VHRR/CCD and INSAT-3D Imager & Sounder)
2. Conversion of count to Albedo Imagery for Visible and SWIR channels (Kalpana-1 \VHRR, INSAT-3A VHRR/CCD and INSAT-3D Imager & Sounder)
3. Generate Wind Vectors/ Barbs from U-Component, V-Component of Winds (Kapana-1 VHRR, INSAT-3A VHRR/CCD and INSAT-3D Imager)
4. Thermodyanamic Diagrams (Skew-T, stuve, emagram) from INSAT-3D Sounder Profiles
5. Ingest all the geophysical parameters for Kalpana-1, INSAT-3A and INSAT-3D.

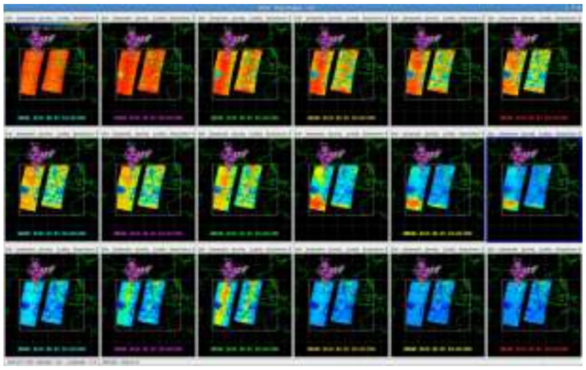
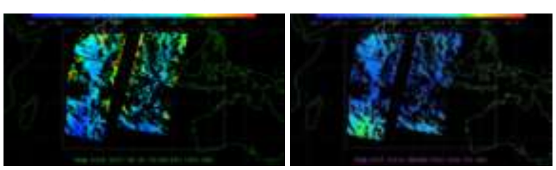


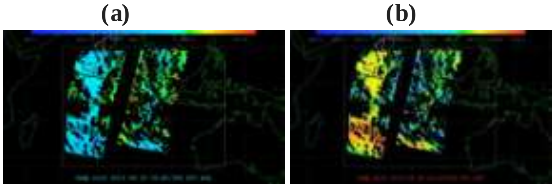
Fig. 2 INSAT3D Sounder (Simulated from IASI) 18 IR Channel Display in MIAS.

Data Visualization and Analysis: The data visualization and analysis capabilities include:

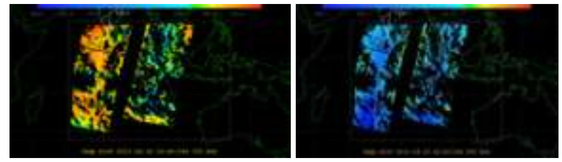
1. Image, contour, filled-contours display of single or sequence of datasets (animation)
2. Image Processing (Linear Stretch, Lookup Table Application, Transparency control)
3. Data Probe and Time Series Analysis (Minima, Maxima, Average, Merging of Time Sequences)
4. Derived Parameters (Vorticity, Advection, Divergence, Mixing Ratio, etc.)
5. Dataset Arithmetic, Formula creation
6. Vertical Probe, Vertical Cross-Sections
7. Iso-surfaces, Volume Rendering
8. Wind Barbs/ Vectors and Streamline display
9. Interactive 2D and 3D (globe) displays
10. Overlaying cyclone tracks.
11. Subsetting Capabilities: Spatial, Temporal and Channel selection.



(a) **(b)**



(c) **(d)**



(e) **(f)**

Fig. 3 INSAT3D Sounder Temperature Profiles (Simulated from IASI) (a) 1000 hPa (b) 100 hPa (c) 250 hPa (d) 500 hPa (e) 700 hPa (f) 950hPa Date/Time of Pass: 25 Apr, 2013 14:49:59 Z

Jython Scripting : Jython (Java's Implementation of Python) Interface has been provided in MIAS to carry out user defined computation on the datasets. MIAS also provides server mode in which user can submit the computation request in form of jython scripts from a remote machine and can get the results back. MIAS already provides a large number of formulae that helps to derive parameters (as described in Point 4 in Section 3). New algorithms developed by scientists can be tested by using jython scripts. Jython interface also provides capability to carry out batch processing of large number of datasets.

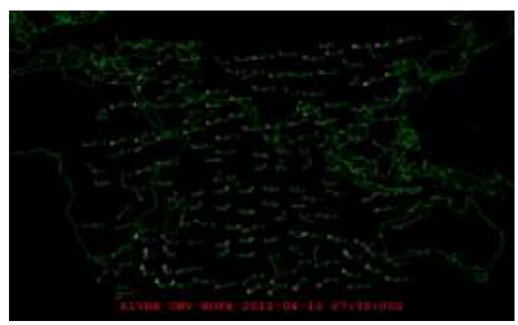


Fig. 4 Derived Parameters in MIAS. Wind Bars derived from U and V Components available in Kalpana-1 Winds BUFR File. Date/ Time of Pass: 10 Apr 2012 07:30 UTC

Summary: MIAS is next generation weather data analysis and visualization tool focused to support current and future Indian Geostationary weather satellites. It has a plugin based architecture that enables user and developer to define its extensions to add new types of datasets and formulae to carry out analysis. In addition it supports model output, radial datasets and point observations. Scripting interface has been provided in Jython to allow user to define its own formulae and carry out batch processing of datasets.

Acknowledgements: The authors would like to thank Director SAC, Shri Santanu Chowdhury, Deputy Director, SIPA, for technically support and encouragement to realize the indigenous Package for Visualization of IRS, INSAT Data.

References

- Java distributed components for numerical visualization in VisAD William Hibbard, Curtis Rueden, Steve Emmerson, Tom Rink, David Glowacki, Tom Whittaker, Don Murray, David Fulker, John Anderson, *Communications of the ACM* 48, No. 3, 2005, 98-104.
- The Integrated Data Viewer: a Web-enabled application for scientific analysis and visualization. Murray, D., J. McWhirter, S. Wier, S. Emmerson, 2003, Preprints, 19th Intl Conf. on IIPS for Meteorology, Oceanography and Hydrology.

RETRIEVAL ALGORITHMS

ALGORITHM FOR GEOPHYSICAL PARAMETER RETRIEVAL FROM REMOTE SENSING DATA

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Introduction: Satellite remote sensing today is defined as the use of satellite-borne sensors to observe, measure, and record the electromagnetic radiation reflected or emitted by the Earth and its environment for subsequent analysis and extraction of information. A number of interactions are possible when Electromagnetic energy encounters matter, whether solid, liquid or gas. The interactions that take place at the surface of a substance are called *surface phenomena*. Penetration of Electromagnetic radiation beneath the surface of a substance results in interactions called *volume phenomena*. The surface and volume interactions with matter can produce a number of changes in the incident Electromagnetic radiation; primarily changes of magnitude, direction, wavelength, polarization and phase. The science of Remote Sensing detects and records these changes. The resulting images and data are interpreted to identify remotely the characteristics of the matter that produced the changes in the recorded Electromagnetic radiation.

The following interactions may occur:

i) Radiation may be *transmitted*, that is, passed through the substance. The velocity of Electromagnetic radiation changes as it is transmitted from air, or a vacuum, into other substances.

ii) Radiation may be *absorbed* by a substance and give up its energy largely to heating the substance.

iii) Radiation may be *emitted* by a substance as a function of its structure and temperature. All matter at temperatures above absolute zero, 0°K, emits energy.

iv) Radiation may be *scattered*, that is, deflected in all directions and lost ultimately to absorption or further scattering (as light is scattered in the atmosphere).

v) Radiation may be *reflected*. If it is returned unchanged from the surface of a substance with the angle equal and opposite to the angle of incidence, it is termed *specular* reflectance (as in a mirror). If radiation is reflected equally in all directions, it is termed *diffuse*. Real materials lie somewhere in between.

Our eyes inform us that the atmosphere is essentially transparent to light, and we tend to assume that this condition exists for all Electromagnetic radiation. In fact, however, the gases of the atmosphere selectively scatter light of different wavelengths. The gases also absorb Electromagnetic energy at specific wavelength intervals called *absorption bands*. The intervening regions of high energy transmittance are called *atmospheric transmission bands,* or *windows*.

Radiance measured from a satellite-borne sensor results from the integrated effects of surface emission and reflection, absorption and emission by atmospheric gases, and absorption, emission and multiple scattering of cloud and precipitation particles. To accurately describe the atmospheric signatures, a radiative transfer model with full inclusion of the aforementioned effects is required. The Theory of radiative transfer basically describes the interaction and propagation of radiative energy in a medium. As radiation is the most important source of energy for driving all the atmospheric processes and also atmospheric dynamics is strongly influenced by how solar and the terrestrial radiations are scattered, absorbed and emitted by the earth's surface and the atmosphere. Thus the knowledge of radiative transfer is most fundamental in the retrieval of atmospheric and earth's surface parameters in space-borne remote sensing.

Radiative Transfer Model: The mathematical description of the radiation propagation and emission processes that lead to an observed radiance by a remote sensing platform is often referred to as the "forward" model. The basic premise is that the observed radiance is a function of the scene in view and the composition and thermodynamic state of the intervening atmosphere. The inverse problem (otherwise known as retrieval theory) is the one in which the parameters affecting radiation are inferred from the observed radiance. The radiometric formulation of radiative transfer is fairly standard across the literature with the exception of the notation used. The radiance reaching a sensor is the sum of the contributions from different propagation paths. The propagation paths depend on the region of the electro-magnetic spectrum of the radiation.

In the reflective region, the dominant paths are:

A) Direct sunlight hits a target and reflects,
B) Sunlight scatters in the atmosphere and reaches a target and is then reflected,
C) Sunlight scatters in the atmosphere and reaches the sensor, and
D) Sunlight reflects off the background, reaches the target, and is then reflected.

In the thermal region, the dominant paths are:

E) Thermal photons emitted by a target reach the sensor,
F) Thermal radiation from the atmosphere reaches the target and is reflected,
G) Thermal photons from the atmosphere reach the sensor, and
H) Thermal photons from the background reach a target and are reflected.

Atmospheric models need to account for:

- the complex, time and space varying composition of the atmosphere, and
- The wavelength dependent interactions experienced by the radiance reaching the sensor.

A generalized form of the radiative transfer equation in the reflective part of the electromagnetic spectrum, is given below (this equation is wavelength dependent):

$$L_{sensor} = \underbrace{E_0 * \cos(\theta) * t * r/p}_{\text{Ground}} + \underbrace{E_d * t * r/p}_{\text{Reflected}} + \underbrace{L_{path}}_{\text{Path scattered}}$$

Where

Lsensor = Radiance received at the sensor
E0 = Solar radiance at the top of the atmosphere
θ = Incidence angle of solar radiance on the surface (0 for vertical, 90 for horizontal)
t = Transmittance factor
r = Reflectance factor
Ed = Scattered background radiation (of the sky)
Lpath = Path scattered radiation reaching the sensor

The radiative transfer equation is often implemented to some degree in computer models that use databases containing molecular and particulate absorption and scattering characteristics. Various models exist with different degrees of spectral resolution, number of atmospheric constituents, cloud models, etc.

The general radiative transfer equation in the thermal region of the electromagnetic spectrum is given below (the equation is wavelength dependent):

$$L_{sensor} = \underbrace{e_{earth} * E_{earth} * t/p}_{\text{Surface emission}} + \underbrace{e_{sky} * E_{sky} * r * t/p}_{\text{Surface Reflected}} + \underbrace{L_{path}}_{\text{Path Thermal}}$$

Where

Lsensor = Radiance received at the sensor
eearth = Surface emissivity (usually between 0.7 to 1)
Eearth = Emittance of radiance of the surface according to Plank's law (as a black body)
t = Transmittance factor (of the atmosphere)
r = Reflectance factor (of the surface; according to Kirchof's law, equals to 1- **eearth**)
esky = Sky emissivity (usually between 0.5 to 0.75)
Esky = Emittance of radiance from the sky according to Plank's law (as a black body)
Lpath = Upward Path emitted radiance

Basic Blocks of Retrieval Algorithm: The algorithms are developed in 2 parts: in the first part forward simulations of Radiance for sensor channels using a plane parallel radiative transfer (RT) model with numerical weather prediction (NWP) model derived surface and environmental parameters as inputs is carried out. In the second part, the development of regression based inverse schemes for retrieval of Geophysical Parameters (GP) is carried out. We divide the simulated database in equal parts for training and test purposes. We add a Gaussian distributed random noise equivalent of expected noise equivalent temperature (NEΔT) for each of the channels to the corresponding brightness temperatures of the training and test datasets. With training dataset, we establish the retrieval equations for each of the parameters by regression or other advanced techniques. These equations are then applied to the simulated brightness temperatures of the training and test dataset to retrieve the GPs. The theoretical accuracy of the retrieval is established by comparison of these retrieved GPs with corresponding environmental parameters in the training dataset. The basic blocks of geophysical parameter retrieval schemes are given in Fig.1

Although the "Inverse problem" of retrieving geophysical parameters from measured radiances is difficult, the reverse – the simulation of radiances with given geophysical parameters is much easier. The physics is well known and there are multiple radiative transfer models available that can quickly simulate radiances. The relative ease of the forward simulation is the basis of many physics based retrieval methods such as iterated minimum variance (IMV). At each iteration, IMV guesses at geophysical parameters, simulates the resulting radiances, and adjusts the guess based on the difference of simulated and actual radiances. One of the practical advantages of this approach is that errors due to instrumental noise or uncertainty in the model can be accounted for. Unfortunately, the algorithm takes many time consuming iterations until convergence, even with a good first guess of the parameters.

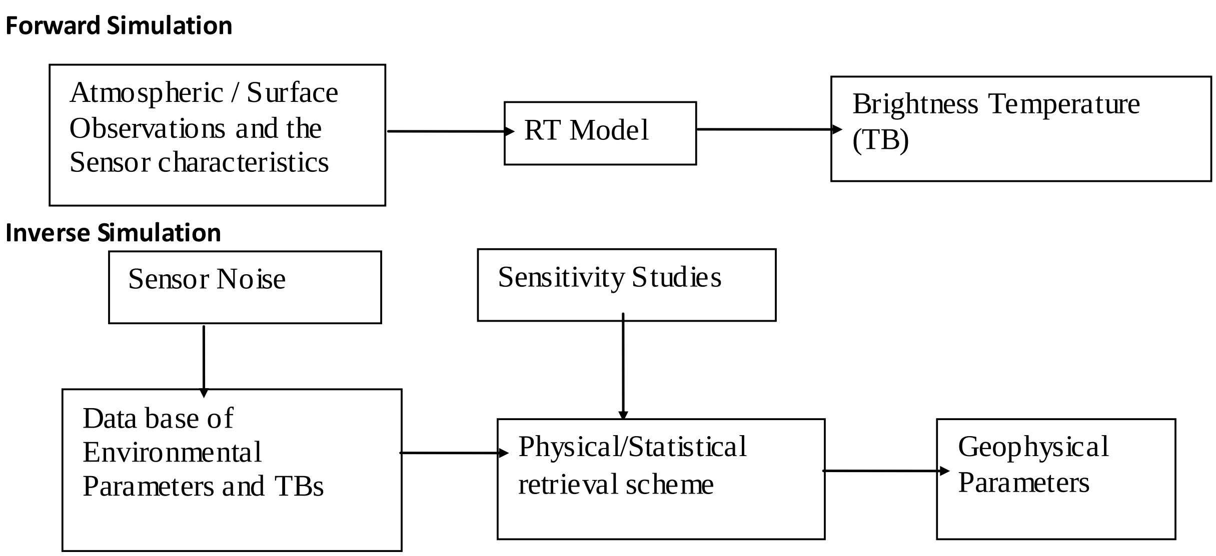

Fig 1: Schematic diagram for retrieval of Geophysical Parameters from Remote Sensing Data

The slowness of the physical retrieval methods motivates the search of alternative methods for retrieval of geophysical parameters. As the forward simulation is relatively easy, it allows us to build up large datasets of simulated data. Geophysical parameters from the thousands of in-situ observations or from numerical Weather prediction model analysis can also be synced with satellite observations to create datasets. With the easy availability of large datasets, it is natural to look at statistical retrievals as an alternative to physics based inversion. As long as the training dataset is comprehensive enough, statistical retrievals should give good accuracy while taking much less time to generate geophysical parameters. Linear regression has been used to retrieve parameters of interest from radiances from satellite instruments since at least the 1970s. Recently more advanced techniques like Neural Network, Genetic Algorithm have been applied in the context of remote sensing, primarily because in many applications they are much superior in speed and at least equal in accuracy to physics The above mentioned methods have been applied in Space Applications Centre (SAC) to develop algorithms for retrieval of geophysical parameters from sensors onboard Indian Satellites like KALPANA, INSAT-3A, Oceansat-2, Megha-Tropiques. Algorithms have also been developed for the Imager and Sounder of forth-coming satellite INSAT-3D, to be launched in July 2013, and tested with simulated data. These algorithms are made operational at SAC and India Meteorological Department (IMD) for regular generation of various parameters in real time

RETRIEVAL ALGORITHMS FOR MICROWAVE SENSORS

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Introduction: Microwave remote sensing, with its cloud-penetrating capabilities, has become an integral part of many operational applications and research related to global monitoring and prediction of weather, climate, ocean-state and the processes encompassing earth-atmospheric system.

Indian Space Research Organization (ISRO) has been launching microwave remote sensing sensors since the launch of BHASKARA-1 satellite in 1979 carrying onboard the first microwave payload SAMIR (Satellite Microwave Radiometer), a passive microwave sensor. Subsequently, very soon in 1981, similar sensor onboard BHASKARA-2 satellite was launched. These first two payloads provided observations only at two/three microwave frequencies which were used to derive atmospheric water vapour and cloud liquid water contents useful for the monitoring of atmosphere.

Subsequently, OCEANSAT-1 satellite, also known as IRS-P4, was launched in 1999 carrying onboard the Multi-frequency Scanning Microwave Radiometer (MSMR) operating at four channels with dual polarization. Observations from MSMR were used to operationally derive sea surface temperature, surface wind speed, water vapour and cloud liquid water over the global oceans.

ISRO, in addition to the passive microwave sensors, launched in 2009, its first Ku-band microwave scatterometer, an active microwave payload providing global radar backscatter measurements used for operationally deriving vector winds over global oceans in near-real-time.

Another first active microwave sensor, the Synthetic Aperture Radar was launched onboard RISAT satellite by ISRO in 2012 providing high resolution images of radar backscatter in various polarizations having various important applications related to agriculture, forestry, hydrology, oceanography and others.

In 2011, ISRO launched the Megha-Tropiques satellite in equatorial orbit, a Joint Indo-French satellite, carrying a five-channel dual-polarized microwave radiometer MADRAS, a jointly developed sensor, and microwave humidity sounder SAPHIR along with other two sensors ScaRaB (sensor for measuring Earth's radiation budget) and a radio-occultation sensor ROSA. Microwave radiometric observations from MADRAS are used for deriving surface wind speed, water vapour and cloud liquid water over the global tropical oceans and the rain rate over tropical oceans as well as over land. Measurements from SAPHIR have been used for deriving vertical profile of atmospheric humidity over global tropics.

In 2013, ISRO also launched the SARAL satellite, a French satellite carrying a Ka-band radar altimeter, useful for monitoring global sea-level, ocean surface wind speed, wave-height and currents.

Majority of the aforementioned applications and utilization need observations from space-borne microwave sensors to be transformed into geophysical products through an important process known as retrieval involving understanding and modeling of interactions of electromagnetic waves with various atmospheric constituents and the surface.

In the case of passive microwave radiometry, the retrieval process primarily makes use of forward modeling involving radiative transfer theory followed by statistical inversion. In the case of radar remote sensing (Scatterometer and altimetry), empirically derived relationships between the radar observations and the geophysical parameters, known as Geophysical Model Functions (GMF), are established for retrievals involving complex numerical approaches. Retrieval algorithms for both passive and active microwave sensors are summarized here.

Retrieval Algorithms for Passive Microwave Sensors: As briefly introduced above, algorithms for retrieving various geophysical parameters from microwave radiometers including sounders are developed in two steps. The first step pertains to forward simulation of the radiation at sensors' specifications like frequency, polarization and the observational geometry through radiative transfer model requiring information about the physical state of the atmosphere and the underlying surface. A data set comprising the geophysical parameter of interest and the associated simulated radiation is created encompassing near-realistic and the widest possible ranges/situations. The second step deals with the development of relationship between the geophysical parameter as predictant with associated simulated radiation data as predictors based on the analysis of the sensitivity of sensor's channels at various frequencies, polarization and the geometry. The selection of optimal functional form of the aforementioned relationship between the predictor and the predictant heavily relies on the understanding of the geophysical parameter or the phenomena and its impact on the radiation measured by the sensor. Equally important is the understanding of various processes leading to a peculiar behavior of the emitted radiation. The emitted radiation is governed by atmospheric absorption due to various dominantly participating atmospheric constituents and by emissivity of the surface. The atmospheric absorption and the surface emissivity are heavily dependent on the properties of atmosphere and the surface making the measurements useful for their sensing or the retrieval. The two key elements absorption and emissivity have natural peculiarities in terms of frequency spectra and dependency on polarization and the observation geometry necessitating use of specific type of sensor for sensing specific type of geophysical parameter.

The absorption spectrum has several characteristics peaks associated to the resonance frequencies of molecular oxygen and water vapor while absorption due to water in liquid and solid states changes nonlinearly with frequency.

Radiometers operating at frequencies close to the highly absorbing resonance frequencies of molecular oxygen and water vapor, known as sounders, are used for retrieving profiles of temperature and humidity of the atmosphere over oceans and land surface.

Passive microwave sensors operating at relatively less absorbing frequencies, known as imager, are used for retrieving bulk quantities of the atmosphere like water vapour content, cloud liquid water and rain-rate as well as surface parameters like temperature, winds and salinity only over oceans.

As the radiation emitted by the earth-atmospheric system is dependent on numerous parameters like the profiles of temperature, pressure, humidity, clouds, rain and ice in the atmosphere and various surface parameters like temperature, salinity and winds over oceans, and surface types and temperature over land, multiple (numerous in principle) measurements of radiation are required for deriving various geophysical parameters from them. In a way, inversion of these parameters from space-based observation is an ill-posed problem dealing with less number of known variables than the unknown variables. Thus, majority of the inversion techniques are based on statistical regression approach.

The core of the retrieval algorithm is of statistical nature, however, the underlying functional form of the relationship between geophysical parameters and the satellite observations is established through sensitivity analysis as mentioned above.

Apart from the statistical techniques, some of the other techniques used for retrieval are neural-networks and Bayesian technique-based 1 3-Dimensional Variational (1D-VAR or 3D-VAR) techniques. All these techniques have certain advantages and limitations. For most of the operational purpose statistical techniques are found to be advantageous over other techniques.

Retrieval algorithms are developed based on simulated data incorporating noise as per the sensor's specifications governing the retrieval accuracies. Forward modeling biases and deviation from the true nature of relationship also contribute to the final retrieval accuracies. The bias in simulated data is corrected using the actual observations and the data simulated through radiative transfer model using collocated and concurrent numerical model prediction data. Validation of geophysical products with necessary fine-tuning and bias corrections are incorporated for the operational retrievals.

Retrieval Algorithms for Active Microwave Sensors: Similar to microwave radiometry, retrieval of geophysical parameters from active microwave sensors also needs specific relationship between the radar backscatter and the parameter of interest. The major difference is that unlike radiative transfer models used for simulations of radiation have matured to a great extent the surface scattering models have certain limitations in fully representing the radar measurements from the known geophysical conditions. This poses a need for empirically derived relationships for the retrieval purpose.

Majority of the retrieval process utilizing radar backscatter need empirical relationships known as GMF as mentioned above. There are other radar measured quantities related to the time delay, phase history and return pulse information which are used for constructing the image of the target area which in turn is interpreted as per the requirements and are not discussed here.

The major use of radar backscatter is in deriving ocean surface wind speed and direction in the case of scatterometer while radar backscatter from altimeters is useful for deriving ocean surface wind speed only. Both the technologies need GMF for retrievals.

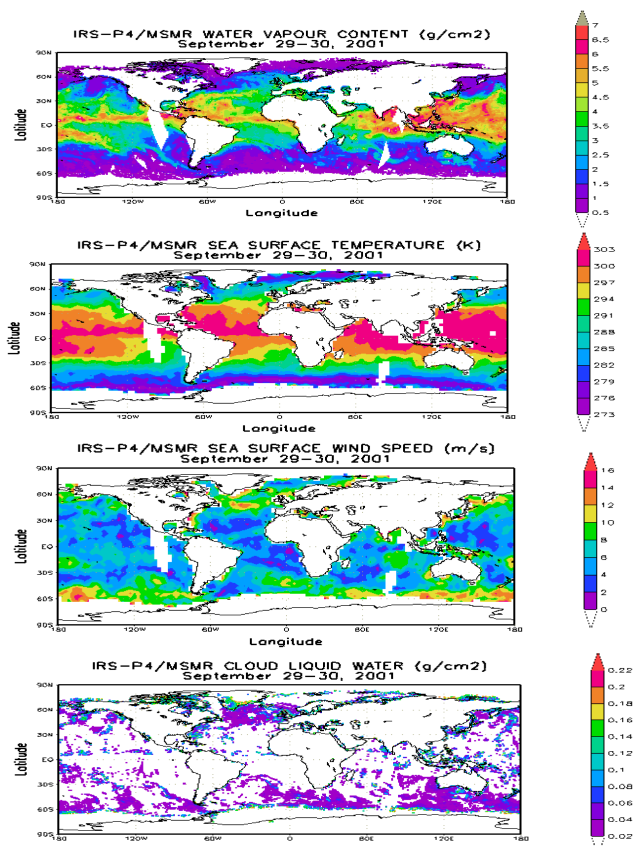
Retrieval of ocean surface vector winds from scatterometer is based on Bayesian technique involving estimation of probability of an assumed wind vector case from a given set of observation and the GMF. Prior to the retrieval, the GMF is developed using radar backscatter from satellite and the collocated and concurrent numerical model analysis data. The retrieval process is iterated for the entire range of wind vector to find the maximum likelihood or the highest probability case yielding the most probable wind vector solution from the data. Since the radar backscatter depends on the wind speed by a power-law and is bi-harmonically dependent on the wind direction, the backscatter measurements yield multiple solutions of wind speed and direction in which speed solutions are very much similar while direction solutions are quite different but one of them represents the true direction while others are ambiguities or aliases. For noise-free simulated data (based on GMF and known wind vector condition), the most probable wind vector solution always represents the true wind vector but for noisy data (or in real situation), the first two highest probable wind solutions represent the true wind vector in majority of the data cases. This needs median filtering techniques for removing directional ambiguities.

Retrieval of wind vector from scatterometer is a two-step process in which point-wise wind vector solutions are derived first followed by field-wise filtering of ambiguities. Advanced techniques are used for removing the localized ambiguities emanating from the localized noise in the data.

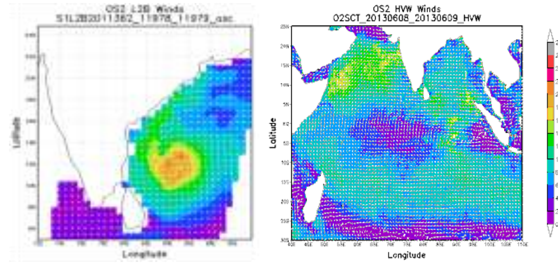
In the case of retrieval of ocean surface wind speed from altimeter data, the GMF is developed in a similar way as that of scatterometer; the only difference here is that wind direction is not used as altimeter being a nadir looking radar. The oceanic wave height is derived based on the slope of the leading edge of the return pulse constructed using multiple return pulse. The sea-level is derived from time delay with many essential atmospheric and surface corrections.

In the case of Synthetic Aperture Radar (SAR), high resolution wind speed is obtained from the known GMF where wind direction is supplemented from other source like model forecast/analysis wind direction.

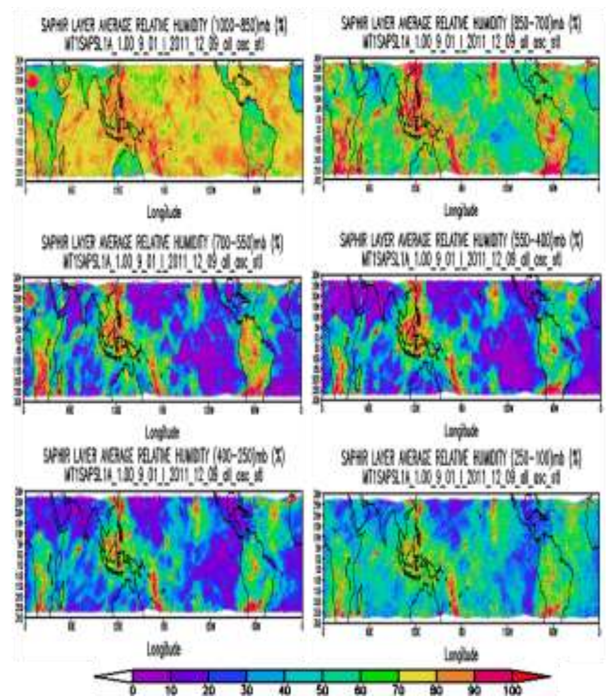
Typical Examples of Geophysical Products from Indian Satellites:



The operational products like sea surface temperature, ocean surface wind speed and contents of water vapour and cloud liquid water over oceans derived from **MSMR onboard Oceansat-1 Satellite** (IRS-P4) for May 26, 1999, are shown above.



Snapshots of operational product of ocean surface vector winds from **Oceansat-2 scatterometer (OSCAT)** for “THANE” cyclone formed in the Bay of Bengal on 29th December, 2011 and the high density wind product over Indian Ocean on June 08, 2013 depicting monsoonal wind flow are shown above. The OSCAT operational products are available at www.nrsc.gov.in while the high density winds are available at www.mosdac.gov.in.



Typical example of humidity profiles derived from **Megha-Tropiques SAPHIR** data for December 09, 2011, are shown above for the six layers between the pressure levels 1000-850 mb, 850-700 mb, 700-550 mb, 550-400 mb, 400-250 mb and 250-100 mb, respectively, indicating characteristically high humidity in the layer close to the surface, low humidity in the middle troposphere while moderate humidity in the top layer excepting the cloudy regions associated with saturations.

Acknowledgements: Contributions from Oceansat-2 and Megha-Tropiques Retrieval, Validation and Data Products teams are thankfully acknowledged.

RETRIEVAL ALGORITHMS FOR WEATHER PREDICTION AND CYCLONE WARNING

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Introduction: Knowledge of the Land-Atmosphere-Ocean parameters is very important for the weather prediction and cyclone warning. The tropical weather systems such as cyclones, monsoon etc. have their origin in oceans. Knowledge of surface and upper air observations is very important for understanding and predicting the local weather beyond one or two days. This has resulted in a network of stations all over the globe for measuring basic meteorological parameters twice a day at synoptic hours. However, there is a dearth of similar observations over the vast oceanic regions, particularly over the southern hemisphere (Fig.1).

Satellite observations have proved to be the only means for acquiring repeated observations from such inaccessible regions. Satellite systems have provided more versatile, coordinated and uniform measurement system over the globe with high reliability, repetivity and uniformity. April 1, 1960 heralded a new era in meteorological observations with the launching of TIROS-1 satellite. A new platform for synoptic and repetitive coverage over vast oceanic areas and inaccessible land became available for the forecaster. Satellites have given a new thrust and hope for improved weather forecasting by providing a uniform quality of data over the globe with a much higher spatial and temporal resolution.

Signals from earth / ocean surfaces, cloud top and atmospheric constituents are received at satellite altitudes by sensitive detectors through the processes of reflection, emission and scattering in the different part of the electromagnetic (EM) spectrum. These EM signals are modified by the constituents of the intervening atmosphere before reaching satellite. Therefore, a complex inversion algorithm is required involving radiative transfer models to retrieve useful information from the satellite measurements.

Data Needs for Meteorological Studies: Operational weather prediction models require timely analysis of the ever-evolving state of the global atmosphere, which are created from a wide array of in-situ and remotely sensed observations from a number of sources around the world that are assimilated into a global model to produce a single, consistent representation of the global atmosphere at a particular point of time. A series of these analyses represent the best historical estimates of the evolution of the global atmosphere. For short-term weather forecasting initial atmospheric conditions is the major determinant of the evolution of weather over periods of hours to a few days. For medium range weather forecasting and climate simulation and prediction, the land surface and ocean boundary conditions play a more important role, such as sea surface temperature, soil moisture, snow cover, vegetation cover etc.

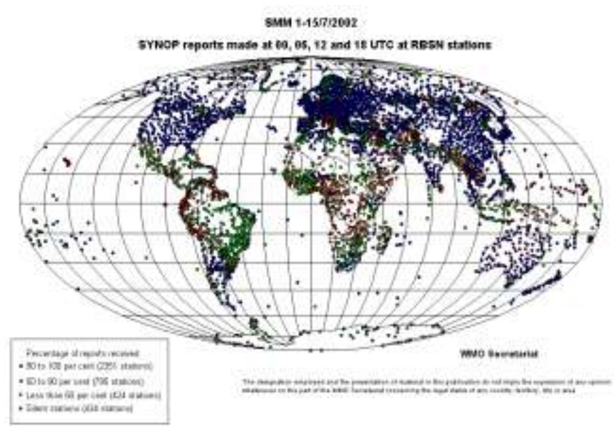

Fig 1: Locations of synoptic surface observations

TABLE-1: Satellite input for NWP Model

Parameter	Satellite/Sensors
Wind field	Profile: INSAT/VHRR, GOES, GMS, METEOSAT Sea surface: Scatterometer (ERS, QuikSCAT, ADEOS-2, Oceansat-2), Radiometer (SSMI, MSMR, TMI, AMSR)
Temperature and Humidity profiles	ATOVS, AMSU, AIRS, MODIS, GIFTS, IASI, GOES, INSAT-3D, Megha-Tropiques

All the above type of data can be obtained using various current/future satellites with a variety of sensors and techniques with a high temporal and spatial resolution (Table-1). The following surface parameters are available from satellites: Soil moisture (SMMR, MSMR, AMSR, TMI, SMOS), Vegetation (MODIS, IRS-LISS/WiFS, AVHRR), SST (TMI, AVHRR, MODIS, MSMR, AMSR, INSAT-3D), snow cover (SMMR, MSMR, SSMI, AMSR) and ocean salinity (SMOS, Aquarius). Although satellites are capable of collecting the data over a wide area with a high horizontal resolution and repetivity, they have the basic problem of poorer vertical resolution. Also subsurface measurements are very difficult to make.

Meteorological Parameter Retrieval: Retrieval of different meteorological parameters from satellite measurement requires interpretation of radiometric data in different regions of EM spectrum. The satellite instruments measure reflection (VIS), emission (IR and MW) and scattering (UV, VIS). Two basic approaches are used for retrieval from the satellite measurements:

(i) Statistical Retrieval: Statistical relationship between in-situ observation of parameters and satellite radiances are established using a collocated matchup dataset. This approach has a limitation since large simultaneous database of satellite radiances and in-situ data is needed. This problem is overcome by theoretical simulation of satellite radiances using radiative transfer calculations for a statistically representative set of atmospheric and surface conditions.

(ii) Physical Retrieval: This technique makes use of on-line radiative transfer computation to minimize the differences between the satellite observations and first guess radiances computed from NWP forecast.

Following sections describe the method for retrieval of different meteorological parameters:

Atmospheric Temperature and Humidity Profiles: Atmospheric sounding is one of the most important applications of satellite measurements in meteorology, which involves retrieving vertical profiles of temperature and atmospheric constituents. This is done by making observations at wavelengths that have significant absorption in the atmosphere. If a sensor makes observation at the center of absorption band where atmosphere is optically thick, the radiances received by the sensor will be characteristic of the upper atmosphere. Conversely, observations at the wings of absorption band where atmosphere is optically transparent, the radiances received will represent surface and lower atmosphere. Therefore, by making observations at a number of wavelengths in a broad absorption band, different altitudes in the atmosphere can be investigated. By using instruments of much higher spectral resolution, such as interferometers or grating spectrometers (e.g. AIRS, IASI), it is possible to achieve spectral resolutions closer to the widths of the atmospheric absorption lines. In this way instruments with several thousand channels and much sharper weighting functions can be built for retrieval of high-resolution vertical profiles retrieval.

In order for atmospheric temperature to be inferred from measurements of thermal emission, the source of emission must be a relatively abundant gas of known and uniform distribution, e.g., 13.5-15 µm CO_2 band and 50-60 GHz O_2 bands). Wavelengths that are sensitive to these gases are used to retrieve atmospheric temperature. For trace gases measurements, such as O_3 and water vapor, radiance measurements in the absorption band of these gases are used (6-8µm for H_2O, 9.8 µm for O_3 and 183 GHz for H_2O). However, observations in the limited number of channels added by noise make retrieval equation ill-posed/under-constrained since the atmospheric state is a continuous function of temperature and constituent gases. We need a priori information, such as numerical model forecast, in addition to the measurements in order to reach a solution. There are several approaches for retrieval of atmospheric profiles from sounder observations: 1) statistical retrievals, 2) physical retrieval, and 3) hybrid retrievals.

In statistical retrieval, a training dataset comprising of matchup pairs of radiosonde observations and satellite soundings are used to establish a statistical relationship. In absence of actual observations a simulated database from radiative transfer model is used.

In physical retrieval, a first-guess temperature profile is chosen either from statistical retrieval or numerical model forecast. The forward RT model is used to estimate the first guess radiances in each channel. If computed radiances match the observed ones (within noise) then the first guess is accepted as the solution, else the first guess profile is iteratively modified to minimize the residual.

Hybrid retrieval methods are much like statistical retrievals, but they do not require a large training dataset. They use weighting functions like physical retrievals, but do not directly involve integration of the RTE.

Retrieval of Sea Surface Temperature (SST): Accurate knowledge of SST is of significant importance to a number of scientific applications, such as boundary conditions in NWP models, fisheries, ocean currents etc. Sea surface temperature may be retrieved from satellite observations in IR and MW bands.

Infrared Techniques: SST measurement using IR radiometers make use of the 10-12 µm bands, which coincides with the wavelength where earth's radiation peaks. This region being nearly transparent to the emitted radiation is known as the 'Atmospheric window'. However, week absorption in this band due to highly variable atmospheric water vapor makes SST retrieval erroneous. To correct for the WV absorption the split window channel (i.e. 10.3-11.3 µm and 11.5-12.5 µm) observations are employed. Absorption in the second split window channel is higher than the first channel; therefore, difference of observation in these two channels gives quantitative estimate of atmospheric water vapor that is used for the WV correction. A simple dual channel algorithm has the following form:

$$SST=A_0+A_1.T_{11}+A_2.(T_{11}-T_{12})+A_3.(T_{11}-T_{12}).(\sec\theta-1)+A_4 \sec\theta$$

Where, A's are regression coefficients. These coefficients may be derived using either actual or simulated matchup dataset of SST and satellite measurement at these channels. Since water vapor absorption is strongly dependent on the observation zenith angle (θ), the relation needs correction for the zenith angle variation. Observation at 3.7 µm window channel is highly sensitive for surface temperature variations. However, during daytime this channel cannot be used due to contamination from reflected solar radiation. During nighttime this channel along with the split-window channels provides accurate SST retrieval. A sample equation using 3 channels has the following form:

$$SST=A_0+A_1.T_{11}+A_2.(T_{3.7}-T_{12})+A_3.(T_{3.7}-T_{12}).(\sec\theta-1)+A_4\sec\theta$$

The retrieval process involves four steps: (1) Finding Detection of cloud-free pixels, (2) applying the appropriate SST retrieval algorithm, and (3) quality check. Typical retrieval accuracy of SST from infrared measurements is 0.3K with spatial resolution less than 10 km.

Microwave Techniques: Passive microwave radiometers normally operate in 1-200 GHz frequency. MW frequencies have little absorption/scattering by the atmosphere or aerosols, haze, dust or small water particles in the clouds. Therefore, MW sensors have effectively all-weather sensing capability, although liquid water in the form of precipitation does scatter the radiation and can render the atmosphere opaque.

The major disadvantage of the MW sensors is that the signal received at the sensor is weak, thus has higher instrument noise. To overcome this problem MW sensors have a larger field of view leading to coarser spatial resolution. Emissivity of the sea in MW is also very small and varies with the dielectric properties of sea water, and the surface roughness. Operationally, 6 and 10 GHz Channels have been used from satellite sensors to retrieve SST (SMMR, MSMR, TMI, SSMI, AMSR). A typical algorithm for retrieval of SST makes use of multi-channel MW observations to correct for sea surface roughness, atmospheric water vapor, cloud liquid water etc, and has the following form:

$$SST = A_0 + A_1.T_{6H} + A_2.T_{6V} + A_3.T_{10H} + A_4.T_{10V} + A_5.T_{18H} + A_6.T_{18V} + A_7.T_{21H} + A_8.T_{21V}$$

Where, A's are coefficients derived empirically, and T_{nH} and T_{nV} are H and V-polarization brightness temperatures at 6, 10, 18, 21 GHz. Accuracy of SST retrievals from microwave radiometer are poorer then infrared observations, but they have advantage due to its all weather capability. Typical MW retrieved SST has accuracy of about 0.5K with spatial resolution of 50 km.

Atmospheric Winds: Atmospheric winds from satellite observations can be inferred using successive cloud imageries and measuring the cloud displacements. Geostationary satellites provide frequent observations of cloud movements, typically every 30 minutes. Height of the wind estimated is assigned from cloud top temperature. It is assumed that passive cloud tracers move with the wind flow related to cloud level. Small cumulus (CU) or stratocumulus (SC) is ideal tracers. Large developed cumulus or cumulonimbus are not suitable tracers due to their fast growth and decay. Automotive techniques are now available and these involve the following steps: (1) selection of a triplet of high resolution satellite images separated by 15 to 30 minutes with good geometric fidelity, (2) tracer identification, (3) computation of cloud tracer movement in target image with accuracy better than one pixel, (4) height assignment, and (5) quality control.

During day time visible tracers can also be used for cloud tracking and then height assignment using contemporary IR image can give good quality CMVs due to finer resolution of visible imagery. Current geostationary satellite (GOES, METEOSAT, INSAT) have water vapor channel in addition to visible and infrared channels. This provides opportunity to derive water vapor winds (WVWV) even from the areas that are free from clouds, where no CMVs are available.

Sea Surface Winds: The ocean surface wind is the main driving force for ocean circulation and for generation of waves and surface currents. Sea surface wind vectors can be obtained only from a microwave Scatterometer that operates at 5-14 GHz. This part of the spectrum has advantage of obtaining data under almost all weather conditions. The physical basis for the measurement technique is the Bragg scattering of microwave energy from capillary waves of the oceans created by the action of the surface winds. The strength of the radar backscatter is proportional to the capillary wave amplitude, which is assumed to be in equilibrium with the wind friction speed. Moreover, the backscatter is anisotropic; therefore, wind direction can be derived from radar backscatter. Scatterometers can provide the sea surface wind with an accuracy of 2 m/s. ERS-1 satellite carried a C-band scatterometer, ADEOS a Ku-band scatterometer. The recently launched Indian satellite Oceansat-2 carries a scatterometer - OSCAT.

The radar backscatter has a harmonic dependence on wind direction which results into multiple solutions of wind vector from a given radar backscatter data. Among these multiple wind vector solutions, only one solution corresponds to the wind vector while others are ambiguities. Although, the wind speed solutions are very close to each other, the direction solutions are quite apart. The solutions are prioritized with certain criterion and the performance of the algorithm is evaluated in terms of percentage of highest priority solutions correctly identifying the true directions out of the total number of data cases processed.

Rainfall: Visible and Infrared Techniques: Digital image data from polar orbiting and geostationary meteorological satellites have now become the major tools to monitor rainfall from space. Cloud images in the visible and thermal IR bands - provide reasonably direct information on cloud extent, type and growth/decay. The Visible/IR sensing from space does not permit direct measurement of raindrops and hence provides essentially indirect inferences from which useful estimates of rainfall may be derived. The basic assumption for rainfall estimation using Vis/IR imageries is that raining clouds can be distinguished from non-raining ones as they are usually thick and tall producing high visible band reflectance and cold cloud top temperatures. The available schemes use visible/IR imagery and time evolution of cloud characteristics, e.g. merging of cumulus clouds, cloud bands, anvils etc., seen in hourly/half hourly images. These techniques works best for convective type of rain. In general, all rain estimation techniques are based on an empirical relation between cloud top albedo/temperature and rainfall measured at the ground. Combining positive features of different techniques it may be possible to provide rainfall estimation with accuracies approaching ~30-40%, when estimates are averaged over sufficiently large time and space scales. However, due to the intrinsically indirect nature of sensing rainfall, the visible/IR algorithms are not portable from one season to another or from one region of globe to another.

Passive Microwave Techniques: Microwave radiations achieve better penetration and interact strongly with the raindrops present in the cloud. These measurements provide a direct physical basis for rain estimation. Also microwaves, barring very high frequency, are largely insensitive to the presence of thin cirrus clouds but they have disadvantage due to poor resolution capability. Microwave radiances reaching satellite altitudes from precipitating clouds contains effects of ice, combined phase hydrometeors and the background atmosphere (cloud liquid water, water vapor and gaseous constituents) within the instrument field of view. The upwelling radiation observed by a microwave radiometer is expressed as an equivalent brightness temperature and the ability of passive microwave radiometer to infer rainfall depends largely on the contrast between the observed brightness temperatures over raining and non-raining areas.

Oceans, due to their small and uniform emissivity, offer an ideal background to observe the emission from rain at its equilibrium temperature. Land, on the other hand, has high and variable emissivity and measurements against this warm and variable background are inadequate for retrieving information of rain. Large (in relation to wavelength) raindrops and ice particle lower the brightness temperatures by scattering the upwelling radiation away from the sensor at this frequency. Theoretical calculations, as well as observations reveal that Tb over ocean tend to increase with thermal emission for low rainfall rates, saturate and finally decrease due to scattering from large drops and ice particles above the freezing level. Thus a given observed Tb would correspond to two values of rainfall. This ambiguity could be resolved using multi-frequency observations. Utilizing different frequencies and polarizations of passive microwave measurements from space, it has been successfully demonstrated that satisfactory rainfall retrievals both over land and oceanic areas are feasible.

Soil Moisture: Microwave radiometry at low frequencies in the L-band (1.4 GHz) is regarded as promising technique for soil moisture estimation. At microwave frequencies the brightness temperature (T_b) measured by satellite sensor is given as:

$$T_b = \varepsilon . T_s$$

Where, ε is the emissivity of surface, and T_s is surface temperature. Emissivity of soil exhibits a large contrast at lower microwave frequencies varying from 0.6 for wet (saturated) soils to greater than 0.9 for dry soils. Therefore, the variation in brightness temperature is very much larger than the noise sensitivity threshold of microwave radiometers (<1 K). Theoretically, by consideration of radiometer sensitivity alone, and for a bare smooth soil surface, moisture estimation accuracies of better than 1-2% by volume should be feasible in principle. However, such accuracies are difficult to achieve in practice. The soil brightness temperature is also affected by soil surface roughness, attenuation and emission by vegetation cover, surface and subsurface heterogeneity. These perturbing factors introduce varying amounts of uncertainty into the relationship between brightness temperature and soil moisture, thereby limiting the accuracy with which soil moisture can be estimated. However towards the lower-frequency region of the microwave spectrum (< 5 GHz) the effects of vegetation and roughness are much reduced.

SATELLITE PRODUCTS FROM INSAT FOR LAND APPLICATIONS

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Introduction: The operational land products are increasingly important for weather and crop yield forecasting, agro-meteorological advisory services to farmers, ecosystem services, assessment and management of energy and water. The updated land products in real-time improve the land surface diagnostics through surface processes and thereby quality of weather forecast. The meteorological and biophysical products can be directly ingested to ecosystem, hydrological and crop models for improving the energy and water budgeting, vegetation carbon pool assessment and crop yield prediction. Moreover, synoptic information on land surface states over large area on real-time have the potential to assess the ground situation to aid in farmers' advisories. During last decade international and national efforts have been made to use satellite – based products for some of the above-mentioned applications. Some of these products are considered as essential climate variable (ECVs). The time-series analysis of the ECVs helps in regional long-term trend analysis and identification of change 'hot spots'

Land products from suite of INSAT satellites: Presently, different products are available daily for land applications with spatial coverage at continental scale from suite of Indian geostationary satellites (Kalpana-1, INSAT 3A). These products are normalized difference vegetation index (NDVI) at 1 km (Figure 1), land surface temperature (Figure 2), land surface insolation and rainfall at 8 km. These are operationally generated through an automated processing chain known as INSAT Meteorological Data Processing System (IMDPS). The last three products will be available at much finer resolution between 1 and 4 km after forthcoming launch of INSAT 3D having six-channel 'Imager' and 19-channel 'Sounder'. The product accuracy is expected to be better. In addition to these, fire product will be an important input for diurnal monitoring of fire progress and issue real-time alarm.

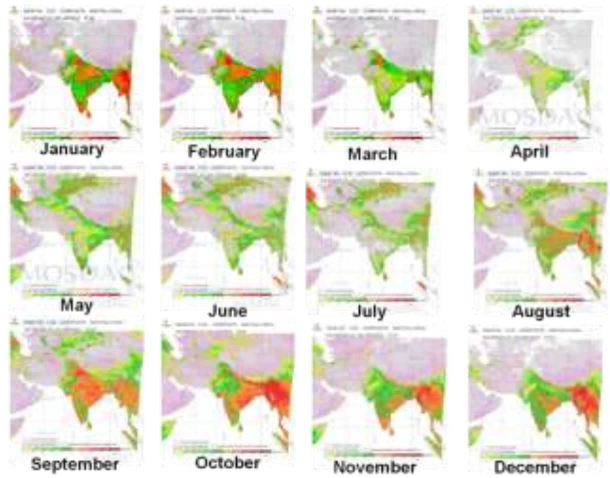

Figure 1. Examples of INSAT NDVI composites in a year

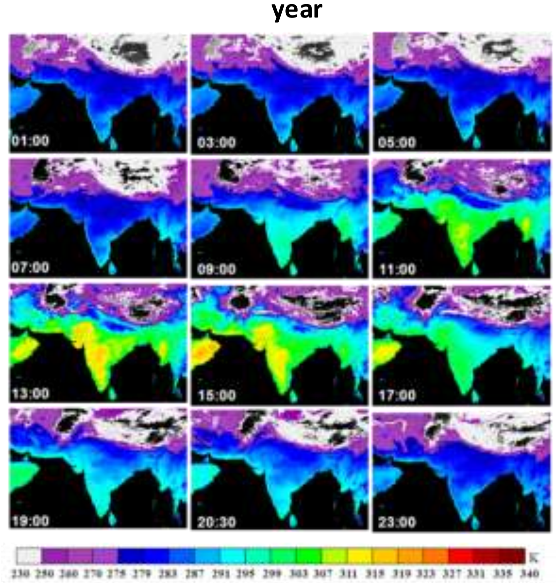

Figure 2. Example of diurnal LST from Kalpana-1

Applications of current land products from INSAT:

Weather forecasting: Indian economy is largely dependent on the agricultural productivity and thus influences the trade among the SAARC countries. High-resolution and good-quality regional weather forecasts are necessary for planners, resource managers, insurers and national agro-advisory services. The assimilation of vegetation fraction from INSAT 3A NDVI improved the low-level 24 hr temperature (~18%) and moisture (~10%) forecast in comparison to control run with climatological vegetation fraction. The 24 hr rainfall forecast (Figure 3) was also improved (more than 5%) over central and southern India (Kumar et al, 2013) with the use of updated vegetation fraction from INSAT 3A NDVI. There was net improvement in surface heat fluxes also.

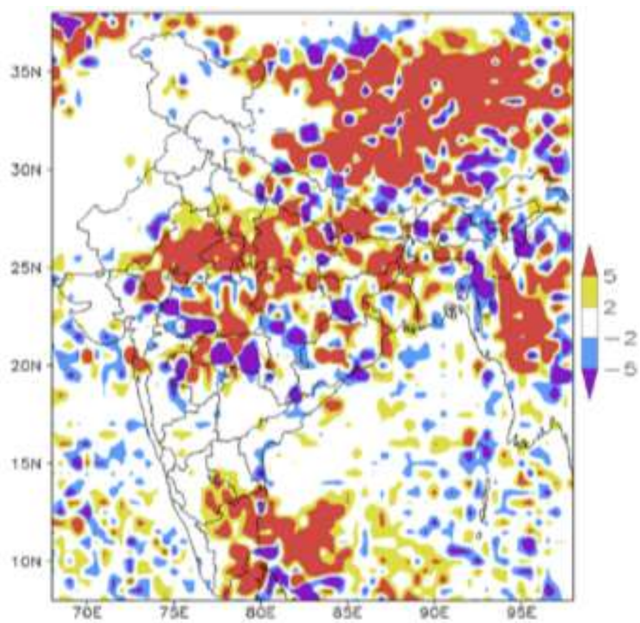

Figure 3. Per cent Improvement in rainfall forecast after assimilation of INSAT 3A NDVI

In-season agricultural assesment: In-season progress of *rabi* cropped area over north, north-western and central India was assessed for last four years with the quicker availability of high-temporal NDVI from INSAT**.** Fitted cubic model over temporal profile of NDVI was used.

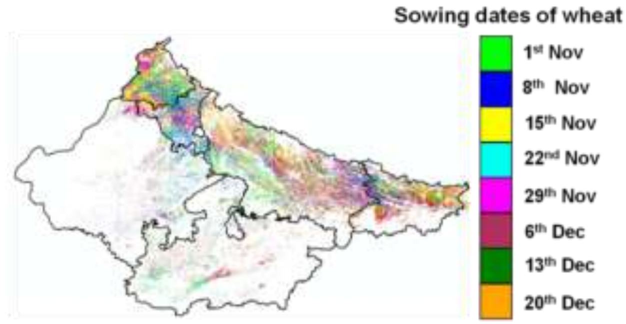

Figure 4. Spatial distribution of wheat sowing dates from NDVI temporal profile of INSAT 3A

The parameters vary across different agro-climatic zones. Using the NDVI profile transition from Kharif to rabi, wheat sowing dates (Figure 4) over homogeneous agricultural patch were extracted with reasonable accuracy (Vyas et al, 2013).

Crop yield prediction**:** The scope of improving the crop yield prediction has been increased with the availability of daily insolation from Indian geostationary satellite Kalpana-1 as a product. The ingestion of daily insolation from Kalpana-1 VHRR into a crop simulation model proved to show better spatial variability (Figure 5) and accuracy in predicted district wheat yield (5 – 10%) as compared to current practice of using interpolated solar radiation estimates.

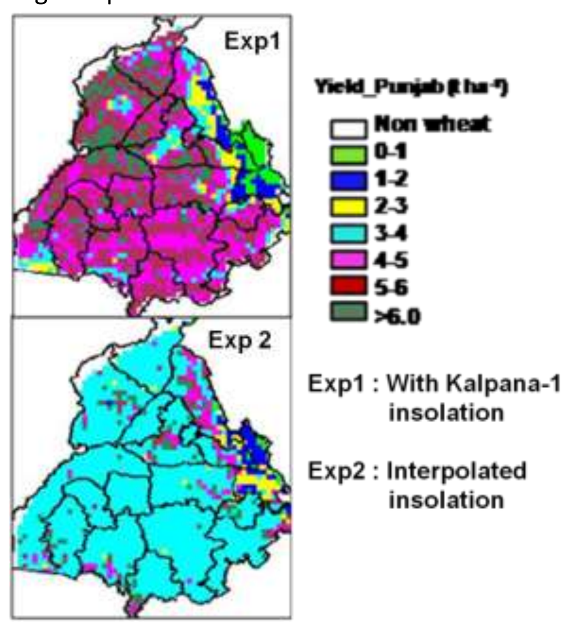

Figure 5. Impact of Kalpana-1 insolation on crop yield

Drought assessment: Anomaly of fortnightly and monthly NDVI and rainfall sum or their combinations could provide valuable information of districts or blocks affected by drought. This has been demonstrated by inter-year comparison of INSAT 3A CCD NDVI and Kalpana-1 rainfall at national scale during 2009 (drought), 2010 (normal), 2011 (normal), 2012 (drought) and district level over Madhya Pradesh. Though the year, 2010 is normal one, the deficit of JJAS (June-July, August, September) rainfall led to NDVI deficit in a small pocket over north-west India (Figure 6a). Drought (solid line) and flood (dotted line) impact (Figure 6b) could be seen by comparing ten-day NDVI composite product from INSAT 3A during September month of 2011 and 2012.

Cold and heat waves: The anomaly of land surface temperature (LST) is a potential tool to identify the spatial extent and persistence of cold wave and heat wave. It helps in issuing remedial measures to farmers to protect crop health as well as human health.

Renewable energy assessment: The relative insolation from Kalpana-1 insolation product over three years were used to estimate the assured annual solar exposure and identifying the hotspots (Bhattacharya et al, 2013) over India. The processing of long-term Kalpana-1 data and insolation would help in building the reliable climatology of digital solar energy availability in India.

Advanced products for agro-meteorological and hydrological applications: A strong demand has emerged from user agencies to provide advanced land products based on solution of radiation and energy budgeting with the INSAT 3D products. These include surface net radiation, potential and actual evapotranspiration. These products are very much required for water budgeting, constructing aridity anomaly index and water requirement satisfaction index for water planning and monitoring in 'green' and 'blue' water use in rain-fed and irrigated agricultural areas.

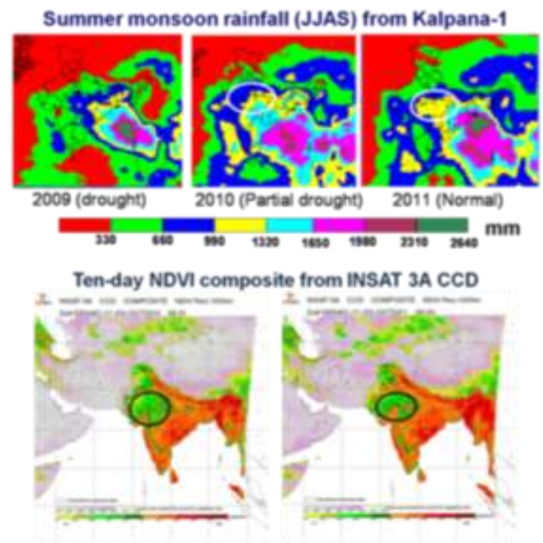

Figure 6a. Deficit rainfall leading to deficit NDVI

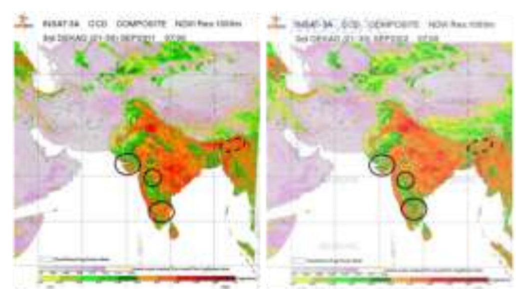

Figure 6b. Drought and flood impact from INSAT NDVI

Conclusion: ISRO has planned a high-resolution Geostationary Imaging Satellite (GISAT) during 2015-16 with ~ 100 m multi-spectral, ~ 500 m hyperspectral and ~1.5 km multi-thermal bands to assess heterogeneity and dynamics of land surface diagnostics, processes for enhanced modelling and forecasting.

Acknowledgements: Author(s) are thankful to Dr. Mehul Pandya, Dr Rahul Nigam, Dr. Rojalin Tripathy for sharing some of the outcome from INSAT product and applications

References:

- Kumar, P., Bhattacharya, B. K. and Pal, P.K. (2013). Impact of vegetation fraction from Indian geostationary satellite on short-range weather forecast. *Agricultural and Forest Meteorology*, 168, 82-92.
- Vyas, S., Nigam, R., Patel, N.K. and Panigrahy, S. (2013). Extracting regional pattern of wheat sowing dates using multi-spectral and high temporal observations from Indian geostationary satellite. *Journal of Indian Society of Remote Sensing* (accepted and in press). Article id 266
- Bhattacharya, B. K., Nigam, R. and Vyas, S. (2013). Energy security challenges and role of Indian geostationary satellites, *Signatures*, 25(1), 150 - 152

RISAT-UTILISATION PROGRAMME

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Introduction: Efforts within Department of Space had been consistently towards providing the improved remote sensing capabilities for satisfying various demands of user community. With the experience in the microwave sensor development, data processing and data analysis techniques, ISRO launched the Radar Imaging Satellite (RISAT) addressing the improved remote sensing capabilities like course to fine resolution, multi-polarization and multi-incidence angle. RISAT is India's first space borne SAR sensor operating at C-band. RISAT is not only capable of acquiring data in multi polarisation mode, including quad linear polarisation, but it will also be first of its kind to operate in hybrid circular polarimetric mode for earth observation.

In order that a larger user community uses the data for various applications, a utilization plan for RISAT data was envisaged. It is expected that RISAT utilization programme will be initiated with optimum potential for management of the natural resources. As a precursor to RISAT-Utilisation programme, a project on utilization of SAR in collaboration with various user agencies was done during 2004-2007. The project called 'Joint Experiments Project (JEP)' created awareness and expertise in developing applications of SAR through 32 planned experiments covering various resources like agriculture, soil, forestry etc. Providing SAR data from foreign satellites like Radarsat, ENVISAT etc, supported the experiments. As a follow-on programme of JEP, it is expected that RISAT utilization programme will be initiated to identify potential areas for operational usage and identify areas for technique development. Accordingly, a plan for RISAT data utilization has been preparedcomprising of various projects with their respective Principal Investigators from all concerned DOS centres. The projects have focused on the development of applications with collaborating agencies, demonstrate various applications, develop trained manpower towards use of such data and create necessary infrastructures in the country for utilization of such data. Basic input has been taken from JEP experience.

Major goal of RISAT-UP is to maximize the potential of RISAT SAR in:

- Demonstrating the operational / quasi-operational applications
- Development of new techniques towards the advancement of SAR applications
- Improving understanding by conducting new experiments
- Capacity building in SAR data analysis
- Larger participation by users of different category including fundamental research

Based upon this, various projects have been taken up to address the use of SAR as a viable alternative of earth observation. There are 42 application projects which have been categorised under nine themes viz. Agriculture, Soil Moisture, Snow and Glaciers, Flood, Forestry, Topography and Terrain, Geology, Oceanography and Polar Science and Advanced Techniques.

The application projects basically concern to the following aspects:

a) **Land surface parameter retrieval**: Soil and snow wetness, snow water equivalent, Biophysical parameters of rice, cotton, groundnut, soybean and sugarcane, forest

b) **Ocean parameter retrieval**: winds, waves, coastal bathymetry

c) **Pre-harvest crop acreage**: Rice, Jute, Groundnut, Cotton, Soybean, Sugarcane

d) **Disaster management**: Flood and damage, probabilistic flood inundation map, landslide, land subsidence, earthquake surface deformation, oil slick, and drought

e) **Sub surface imaging**: Buried features covering parts of Thar Desert

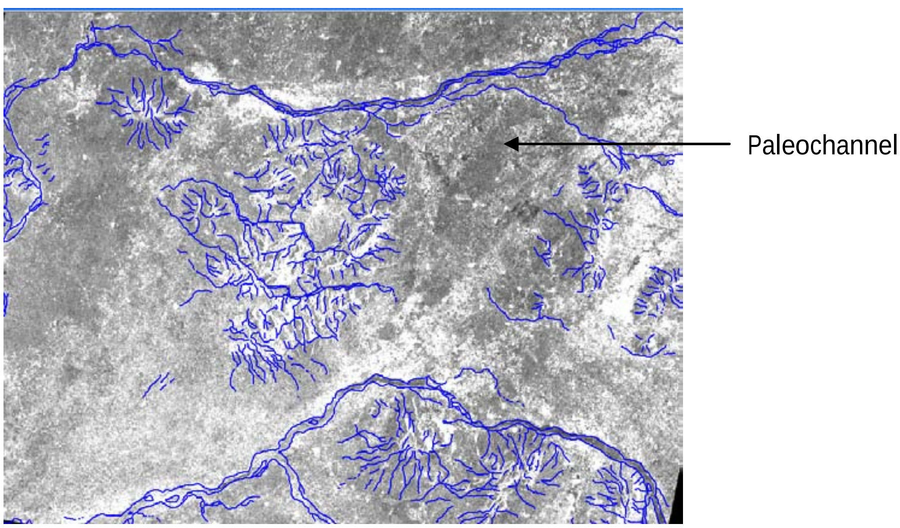
f) **Target detection**: Ship and oil slick detection

g) **Observations**: Onset of snowmelt and progression, kharif cropped area and progression, polar ice seasonality

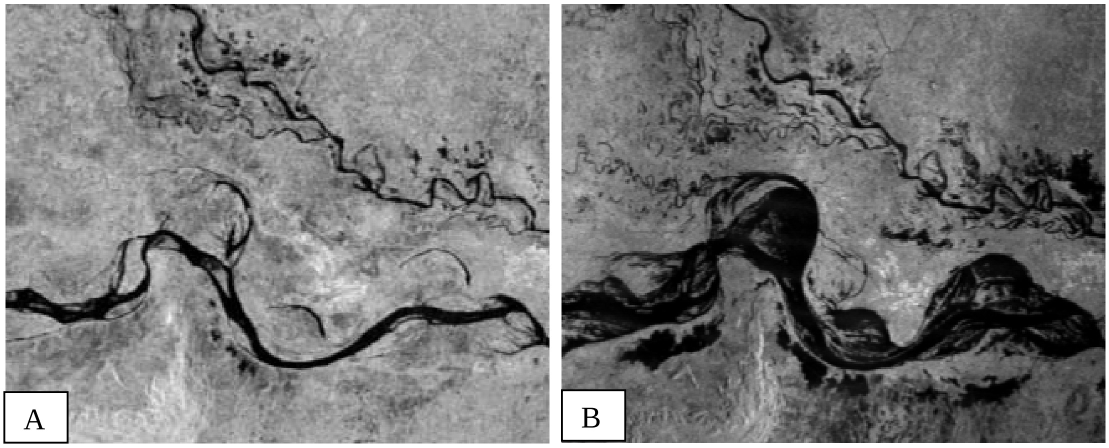
h) **Mapping**: Geological Structural and lithological mapping, homestead, mangrove, wetland and forest, kharif land use, soil moisture zoning and relation with crop growth status, Glacier lakes, Snout mapping of glaciers, glacier crevasses covered by seasonal snow, tide line, polar ice map around Maitry station

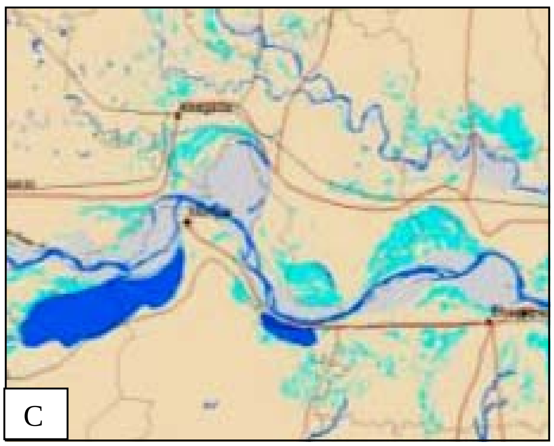
i) **Science and advanced techniques**: Dielectric model of Indian soil, vegetation models, Signature, Polarimetric signatures and polarimetric analysis techniques, glacier mass balance, soil profile moisture estimation techniques, DEM techniques, glacier motion

Developing and upgrading the skills of the scientific and user community is the key to the successful utilization of data from any new sensor. This is more relevant for the SAR sensor that is entirely different from the optical sensor in terms of data processing, interpretation, ground data collection etc. It is expected that the professionals trained in this specialized programme will develop adequate expertise to use SAR data for various applications as envisaged to be supported by RISAT. Under the RISAT-UP, capacity building was done in a big way and about 215 persons from over 90 organizations were trained in the basics of SAR, data processing and analysis by well experienced scientists. Proper software needed for the handling of hybrid polarimetric SAR data and the various tools for processing RISAT SAR data have also been developed under this utilization programme. The same is being used and evaluated by the PIs to bring forth improvements so that a larger user community is benefited.



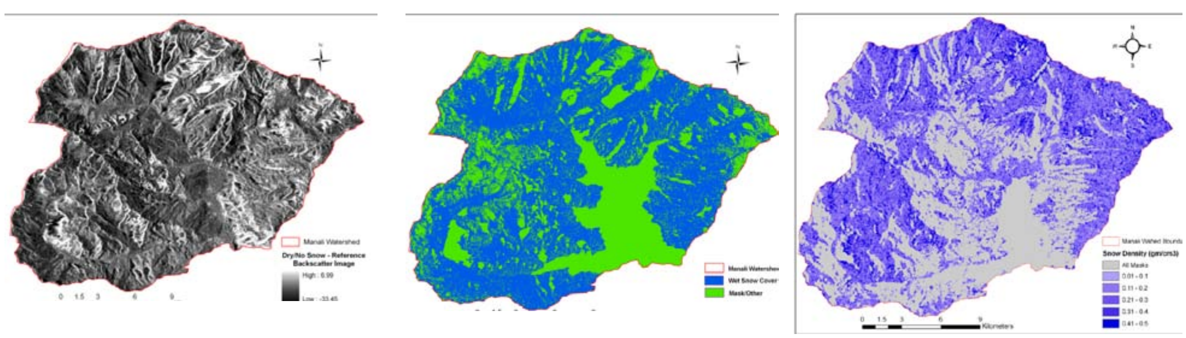
Use of RISAT data for detection of lineaments (marked in blue lines) and paleochannels





Use of RISAT data for flood monitoring

A: Pre flood situation in Bihar
B: Post flood situation in Bihar, Sept. 2012
C: Flood inundation map generated



Manali sub-basin as seen by a)(left) RISAT SAR; b)(middle)wet snow cover (in blue) and c) (right)snow density of the area.

GENERATION OF LAND GEOPHYSICAL PRODUCTS FROM OCEAN COLOUR MONITOR

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Introduction: Ocean Color Monitor (OCM) in Oceansat-2 mission operating in Visible-Near Infra-red (VNIR) spectral range at 360 m spatial resolution with 12 bits per pixel radiometry for operational use of generating products for identification of potential fishing zones. Even though the sensor characteristics are fine tuned to capture minute variations in ocean surface water radiance, many of the eight bands do provide very useful data over land which can be exploited for many applications. In particular, the 2-day repeat cycle with an image swath of 1400 km are highly useful for rapid monitoring of vegetation growth when compared to longer cycles of some of the specific land missions (Landsat TM, Resourcesats 1/2 etc.). In this note, we explain two such geophysical products – vegetation fraction and surface albedo – realized from this sensor acquired over the land in both local and global area coverage modes data.

The VF is the fraction of vegetation occupying a given ground area in vertical projection. It is generally treated as the comprehensive quantitative index in applications in forest management and vegetation. Field measurement has been the traditional method of estimating it; however, the reliability of such measurements for the vegetation fractional coverage is questionable. In the last decade, there is an increase in utilization of spaceborne data for estimating the VF. Similarly, monitoring the change in surface albedo is important to infer atmospheric radiation absorption and in overall estimation of radiation budget effected by surface heterogeneity.

Satellite Data Preprocessing: The overall flow diagram for operational VF products generation as shown in Figure 1 which include: 1) sun and view angle normalization - The sensor view and sun elevation angles for a given pixel available with the products were taken for normalization to the centre pixel value to avoid high variations due to wide swath of 1420 km. 2) ortho-rectification, 3) cloud masking - Cloud identification and masking is an important step toward successful generation of clear-sky composite images. Our cloud masking approach is similar to thresholding scheme proposed by Vermote et.al. (2001) for SeaWIFS. And 4) atmospheric correction with the help of DOS-COST method to obtain ground reflectance. The advantage of this method is that all necessary inputs to carry out the atmospheric correction can be obtained from the data product itself and ideally suited for operationally generating the OCM-based land products.

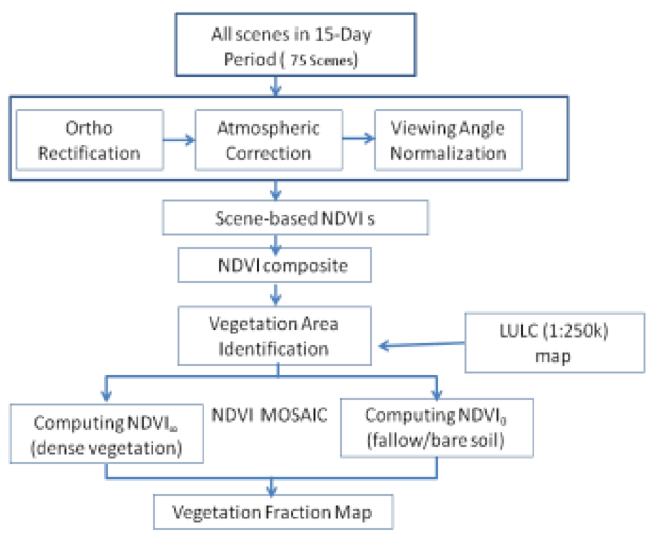

Fig. 1. Data flow diagram for OCM NDVI and VF products

NDVI map generation: The NDVI is used to measure plant growth, vegetation cover and biomass production from multispectral sensor data. Though there are several indices defined with different spectral combinations, the most common formula followed is as follows:

NDVI = (NIR – R) / (NIR + R) = $(\rho_8 - \rho_6) / (\rho_8 + \rho_6)$ (1)

Where ρ_k is the OCM satellite band atmospherically corrected ground reflectance in band *k*.

There are two versions to generate the NDVI map. The first is a scene-based approach. For monthly assessment, selection of datasets with data passes around middle of the month was considered. Accordingly, day 15th of each month +/- 3 or 4 days were first checked for cloud free conditions upto 99% to select scenes to cover the country boundary. The second is a NDVI Maximum Value Composite (MVC) method. Since the computation of the NDVI is sensitive to atmospheric conditions, cloud coverage and aerosol scattering, the MVC method is suitable to minimize these effects.

Vegetation Fraction Estimation: The method followed here is similar to the one by Liang et al. (2008) based on Gutman's mosaic pixel model to get fast estimation of the vegetation fraction. As opposed to uniform pixel mode, the mosaic pixel model permits the pixel to be variable density variation besides dense and nondense vegetation, thus provides a realistic model for estimation of the VF.

The VF can be derived from:

$$VF = \frac{NDVI - NDVI_0}{NDVI_{\infty} - NDVI_0} \qquad (2)$$

Here the $NDVI_0$ and $NDVI_\infty$ represent the signals that receive from dense green vegetation and from bare soil respectively. Both these are constants to be estimated from the NDVI for each scene, but these may vary depending on the seasons. Maximum NDVI values vary seasonally with the cropping pattern followed in the country. Thus, the fraction of vegetation cover can be estimated by setting VF = 0 for NDVI $\leq$ 0.2 and VF = 1 for NDVI $\geq$ 0.9. These values were used in Eqn. (2). The VF product for second half of April 2012 is shown in Fig. 2.

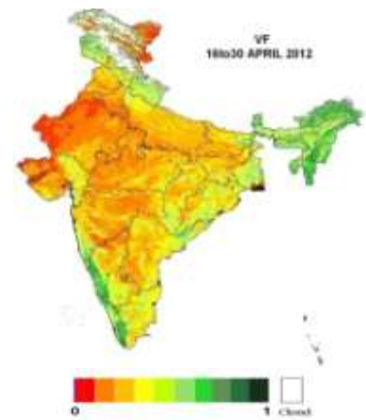

Fig 2. OCM VF product for second 15-day of April 2012.

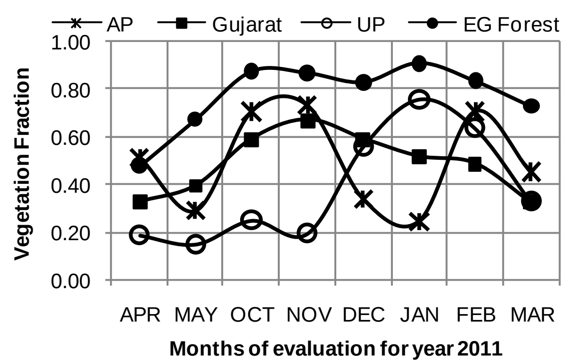

Fig. 3. Variation of the VF values as a function of months for Indian agriculturally active states.

Variation of the VF values as a function of months for Indian agriculturally active states. Here AP has typically double/triple crops patterns, while the Gujarat and UP have crops in Kharif and Rabi seasons respectively. The evergreen (EG) forest depicts almost similar VF value after the leaf shed month of April.

Surface Albedo Estimation: The Broadband (BB) surface albedo is determined for the entire short-wave range (0.3-3µm), satellite sensors provide only filtered albedo for some narrow spectral regions. If a surface is assumed to be Lambertian, the retrieved surface reflectance of different spectral bands is equivalent to surface spectral albedos. The broadband surface albedo is calculated form narrowband satellite data by integrating band reflectance across the short wave spectrum (Tasumi et al. 2008) as given in eq (1).

$$\alpha = \sum_{b=1}^{8} \rho_b \bullet w_b \qquad (3)$$

Where $w_b = \int_{LW_b}^{UW_b} R_\lambda d\lambda \Big/ \int_{0.3}^{4.0} R_\lambda d\lambda$

Here ρ_b is the surface reflectance of band b (b=1, 2...8 for OCM2 sensor) and w_b is the weighting coefficient representing the fraction of at surface solar radiation occurring within the spectral range represented by a specific band as given above. R_λ is the at-surface spectral hemispherical solar radiation for wavelength λ and UW_b and LW_b are the upper and lower wavelength bounds for band b.

The weighting coefficients were computed with the inclusion of all wavelength regions that occur between sensor bands. Broad band albedo was computed for the region 0.3- 3 μm and the visible albedo was computed for the region 0.3-0.7 μm. The regions between satellite bands were arbitrarily divided between band edges as in Table 1.

Table 1. OCM Bandwidths and Ranges for lower and upper wavelength bounds

Band	OCM2 Band limit	Applied low and up bounds for BB Albedo	Applied low and up bounds for Vis Albedo
1	0.403-0.429	0.3-0.43	0.3-0.429
2	0.429-0.455	0.43-0.46	0.429-0.465
3	0.478-0.5	0.46-0.5	0.465-0.5
4	0.5-0.524	0.5-0.53	0.5-0.535
5	0.545-0.569	0.53-0.588	0.535-0.588
6	0.606-0.633	0.588-0.68	0.588-0.7
7	0.725-0.763	0.68-0.8	NA
8	0.843-0.89	0.8-3.0	NA

The weights for the conversion of spectral albedo to broad band and visible albedo were computed using 6S atmospheric correction code (Zhao et al. 2000). Fig. 4 shows BB albedo and visible albedo images for the month January 2013.

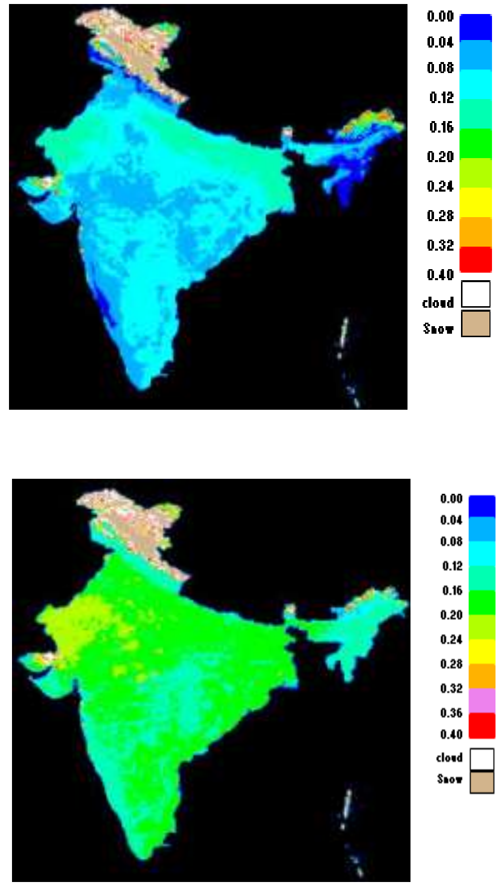

Fig. 4 Derived visible and broadband albedo for Jan.2013

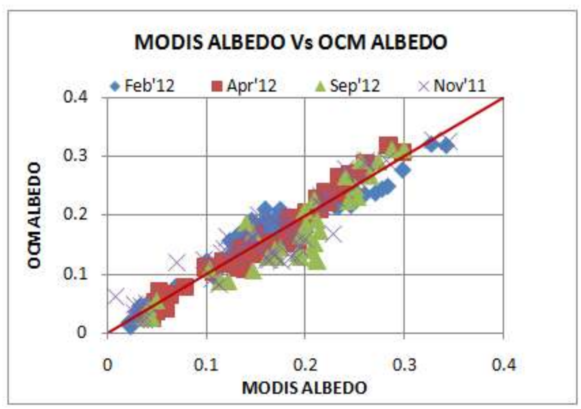

Fig. 5. OCM BB albedo vs. MODIS-MCD43 products

Conclusion: In this note, an extended application for Ocean Color Monitor to monitor vegetation and surface albedo applications is demonstrated. The problem of cloud coverage is minimized by adopting with the maximum value composite technique. These products are available in Bhuvan webpage [NRSC, 2012]. Work is in progress to apply these for the OCM global area coverage data acquired at 1km to realize global geophysical products once in a month cycle.

Acknowledgements: Author thanks the team members of Geophysical and Special products Group who successfully realised the OCM geophysical processing system. I gratefully acknowledge the encouragement provided by the management, Sri. D.S. Jain, DD-SDAPSA and Dr. V.K. Dadhwal, Director NRSC, during the course of realization and implementation phases.

References:

Liang, Z. et al., (2008). A study on fast estimation of vegetation fraction in three Gorges emigration area by using SPOT5 imagery. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B8. Beijing 2008.

NRSC. 2012, Geophysical product of Vegetation Fraction: OCM2: in http://bhuvan-noeda.nrsc.gov.in

Tasumi, M., et al., (2008). At-surface reflectance and albedo from satellite for operational calculation of land surface energy balance, Journal of Hydrological Eng., vol. 13, 51-63.

Vermote, E.F. et al. (2001), A SeaWiFS global monthly coarse resolution reflectance dataset. International Journal of Remote Sensing, vol. 22, 1151-1158.

COASTAL PROCESSES AND SEDIMENT TRANSPORT MODELLING

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Introduction: One of the major requirements of planning coastal protection work is to understand coastal processes of erosion, deposition and transport of sediments which occur due to natural processes, anthropogenic activities as well episodic events like cyclones, storm surges, floods, etc. Monitoring and understanding of sediment transport is important in relation to several engineering aspects like reduction of sediment supply to estuaries due to damming of rivers upstream and consequent shoreline changes, seasonal blockage of estuaries, changes in shoreline due to construction of coastal structures like breakwater, jetties, ports, harbors, etc., backfilling of dredged navigation channels, development of shoals and sand bars hazardous for navigation, degradation and death of living resources not adapted to high sedimentation like coral reefs, overall changes in near-shore morphology due to changes in long-shore and onshore-offshore sediment transport rates, etc. The anthropogenic causes due to changes in landuse/landcover in the coastal zone as well catchment areas of rivers accelerates the process of sediment transport like urban development, deforestation or increased agricultural activity in river catchments, aquaculture development, clear cutting of coastal mangroves or poorly planned coastal development close to reef areas, etc.

Regular monitoring of sediment dynamics is essential and the ways and means by conventional point measurements using ships or boats are limited which may provide accurate concentration measurements but provide extremely poor spatial coverage that too of a particular time. Moreover, the costs of conducting such surveys are very high. Ocean colour sensors onboard satellites provide synoptic view, high repetivity and are excellent tools to map and monitor sediment patterns, estimate relative changes in sediment concentrations and retrieve sea surface velocities using sediments as a tracer in sequential images The retrieved information can be utilised for preparing efficient shoreline/sediment/coastal zone management plans.

Retrieval of Suspended Sediments Concentration (SCC) using OCM data : OCM collects data in eight spectral channels (402-422, 433-453, 480-500, 500-520, 545-565, 660-680, 745-785, 845-885 nm) with spatial resolution of 360 m, every alternate day for the same region at local time around 12 noon with radiometric resolution of 12 bits. Each OCM scene covers 1420 km by 1420 km ground area.

Silicon Graphics Workstation with ERDAS Imagine, OCM Processing and SEADAS software are utilised for processing of the OCM data. It is well known that in the case of ocean remote sensing, the total signal received (in VIS-NIR) at the satellite altitude is dominated by radiance contribution through atmospheric scattering processes and only 8-10% of the signal corresponds to oceanic reflectance. Therefore, it becomes mandatory to correct for atmospheric effect before retrieving any useful information from space. The purpose of the atmospheric correction is to remove patterns in the image data sets, which are of atmospheric origin. The suspended sediment concentrations is derived using water-leaving radiance in band 490, 555 and 670 nm. The algorithm initially proposed by Tassan (1994), SAC Report (2003a) is used to compute suspended sediments from OCM data. It has the following mathematical form:

$$LogS = 1.83 + 1.26 LogX_s \quad for \quad 0.0 \le S \le 40.0 \qquad (1)$$

Where *S* is suspended sediment concentration in mg/l and X_s is the variable defined as

$$X_s = [Rrs(555) + Rrs(670)] \times \left[\frac{Rrs(490)}{Rrs(555)} \right]^{-0.5} \quad (2)$$

Where *Rrs (λ)* is the spectral remote sensing reflectance in respective wavelengths.
The retrieval accuracy of SSC from OCM data is within 15 % (SAC Report, 2003a).

Development of Site Specific Algorithms to retrieve Suspended Sediment Concentration : Pradhan et al., 2005 developed site specific algorithm to retrieve suspended sediment concentration for coastal waters of the northern Bay of Bengal (BOB). Data from six validation campaigns in the coastal waters of BOB were used to develop a regional SSC (Suspended Sediment Concentration) algorithm. The in situ data sets for this algorithm are composed of 60 stations with optical and 39 station with total SSC measurements, encompassing SSC concentrations between 13 and 189 mg/l, with most of the observations in shallow (Case 2; average depth ~45 m) waters and a limited number of observations in Case 1 waters. A simple statistical analysis was carried out to evaluate the SSC concentration variation with diffuse attenuation coefficient, Kd (555) at 555 nm in the BOB coastal waters. The linear regression to the fit has coefficient of determination, r^2 = 0.95 and a standard error of estimates $\sigma = 15$ mg/l. The algorithm relating K(555) to Lwn(443)/Lwn(670) was also evaluated through regression analysis of radiometric profiles in the BOB. However, the new SSC algorithm failed to explain the estimates in Case 1 waters, where a spectral reflectance ratio algorithm [Tassan 1994] appears to produce better results. An integration of both the approaches performs better in generating the routine IRS-P4 OCM (Ocean Colour Monitor) SSC mapped product.

Statistical analysis among various optical parameters and in-situ SSC values was carried out and following relationships were developed for coastal waters:

Kd(555) = 0.07+0.70029682*{Lwn 443/ Lwn 670}^{p}

where p = -0.871654 with r^2 = 0.87

SSC = 88. 3137 * Kd(555) + 14.731; with r^2 = 0.82
(for SSC values between 40 – 200 mg/l)

A methodology is developed to integrate the SSC values less than 40 mg/l (derived using Tassan's algorithm) and SSC values between 40-200 mg/l (derived from the above mentioned algorithm).

Sediment Dynamics by Integrating suspended sediments concentration derived from OCM data in existing sediment transport models:

A technique has been developed for integrating OCM derived SSC in MIKE-21 for simulating sediment transport in time series and has been demonstrated for the Gulf of Kachchh region (Fig. 1, SAC Report, 2013, Ratheesh and Rajawat , 2012), The simulation of suspended sediment transport is performed using Mud Transport module of MIKE-21. MIKE 21 developed by the Danish Hydraulic Institute, Denmark, is a software package containing a comprehensive modeling system for 2D free-surface flows which is applicable to the simulation of hydraulic phenomena in lakes, estuaries, bays, coastal areas and seas where stratification can be neglected. The hydrodynamic module simulates water level variations and flows in response to the forcing functions in lakes, estuaries and coastal regions. The mud transport module describes the erosion, transport and deposition of silt, mud and clay particles under the action of currents and waves. The governing equation is formulated in Cartesian coordinates. The depth averaged momentum equation in *x* and *y* directions and continuity equation used in the model for the hydrodynamic simulation are *x* momentum:

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left[\frac{p^2}{h}\right]+\frac{\partial}{\partial y}\left[\frac{pq}{h}\right]+gh\frac{\partial \eta}{\partial x}+\left[g\frac{\sqrt{\frac{p^2}{h^2}+\frac{q^2}{h^2}}\,\frac{p}{q}}{C^2}\right]-fVV_x-\frac{h}{\rho w}\frac{\partial P_a}{\partial x}-\Omega q-E=S_{ix}$$

y momentum:

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial x}\left[\frac{q^2}{h}\right]+\frac{\partial}{\partial y}\left[\frac{pq}{h}\right]+gh\frac{\partial \eta}{\partial y}+\left[g\frac{\sqrt{\frac{p^2}{h^2}+\frac{q^2}{h^2}}\,\frac{q}{h}}{C^2}\right]-fVV_y-\frac{h}{\rho w}\frac{\partial P_a}{\partial y}-\Omega q-E=S_i$$

the equation of continuity:

$$\frac{\partial \eta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=S-e$$

P and *q* are the flux in the *x* and *y* directions, respectively, *h* the water depth, *t* the time, P_a the atmospheric pressure, *ρw* the density of water, g the acceleration due to gravity, h the surface elevation, S the source magnitude, *e* the evaporation rate, *C* Chezy's coefficient, f the wind friction factor, V the Coriolis force, S_{ix} and S_{iy} the source impulse in *x* and *y* directions and *E* the eddy viscosity coefficient.

Suspended sediment transport in the Gulf of Kachchh (GoK) is simulated utilizing suspended sediment concentration (SSC) derived from Oceansat OCM imagery, as the initial condition in MIKE-21 Mud Transport model. The simulation is calibrated with erosion and depositional coefficients depending on the sediment size parameter distribution. Simulated SSC are compared with alternate OCM derived SSC (Fig. 2). The RMS error is found to be between 5.5 and 7.5 mg/l and the correlation coefficient obtained were in the range of 0.95 to 0.74 (SAC Report, 2013).

Sequential assimilation of OCM derived SSC has been done to improve the numerical simulation of sediment transport in GoK using ECOMSED 3D model. The simulation results are found to get improved while assimilating the sequential OCM derived SSC (Fig. 3). The mean SSC from the assimilated results are able to capture the general trend shown by satellite observed mean SSC.

A method has been developed to derive vertical profiles of suspended sediment concentrations for Gulf of Kachchh from OCM derived SSC which involves pixel by pixel information on bottom frictional velocity (obtained from numerical simulation), sediment size parameter (from in situ/published data) and attenuation depth (from OCM derived kd(490)). Bottom sediment concentrations and the total SSC along the entire water column has been estimated from the vertical sediment profiles (Ratheesh et al., 2013, Fig. 4).

Development of methodology to derive sea surface advective velocities: A technique has been developed for retrieving advective vectors using sediments as a tracer from the suspended sediment maps derived from the OCM data (Prasad et al., 2001). The method is based on matching Suspended Sediment dispersion patterns, in sequential two time lapsed images. The pattern matching is performed on a pair of atmospherically corrected and geo-referenced sequential images by Maximum Cross-Correlation (MCC) technique. The velocities retrieved are time-averaged velocities between the data sets used. This methodology retrieves velocities in terms of rate of transport of sediments. The retrieved velocities were validated using synchronous data collected along the east coast during a cruise (ST-133) onboard R.V. Samudra Kaustubh in January 2000. The method has been further improved (SAC Report, 2013) and the technique has been used to derived surface current vectors from sequential OCM derived SSC maps in Gulf of Kachchh. The insensitiveness of MCC technique towards the rotational motion of currents is overcome by implementing rotational registration method for pattern matching. The net simulated tidal currents between the sequential satellite images are compared with the MCC current (Fig. 5). The method finds useful applications in providing inputs to hydrodynamic modelling of coastal processes such as computation of alongshore transport, pollutants dispersion rates, siltation, etc.

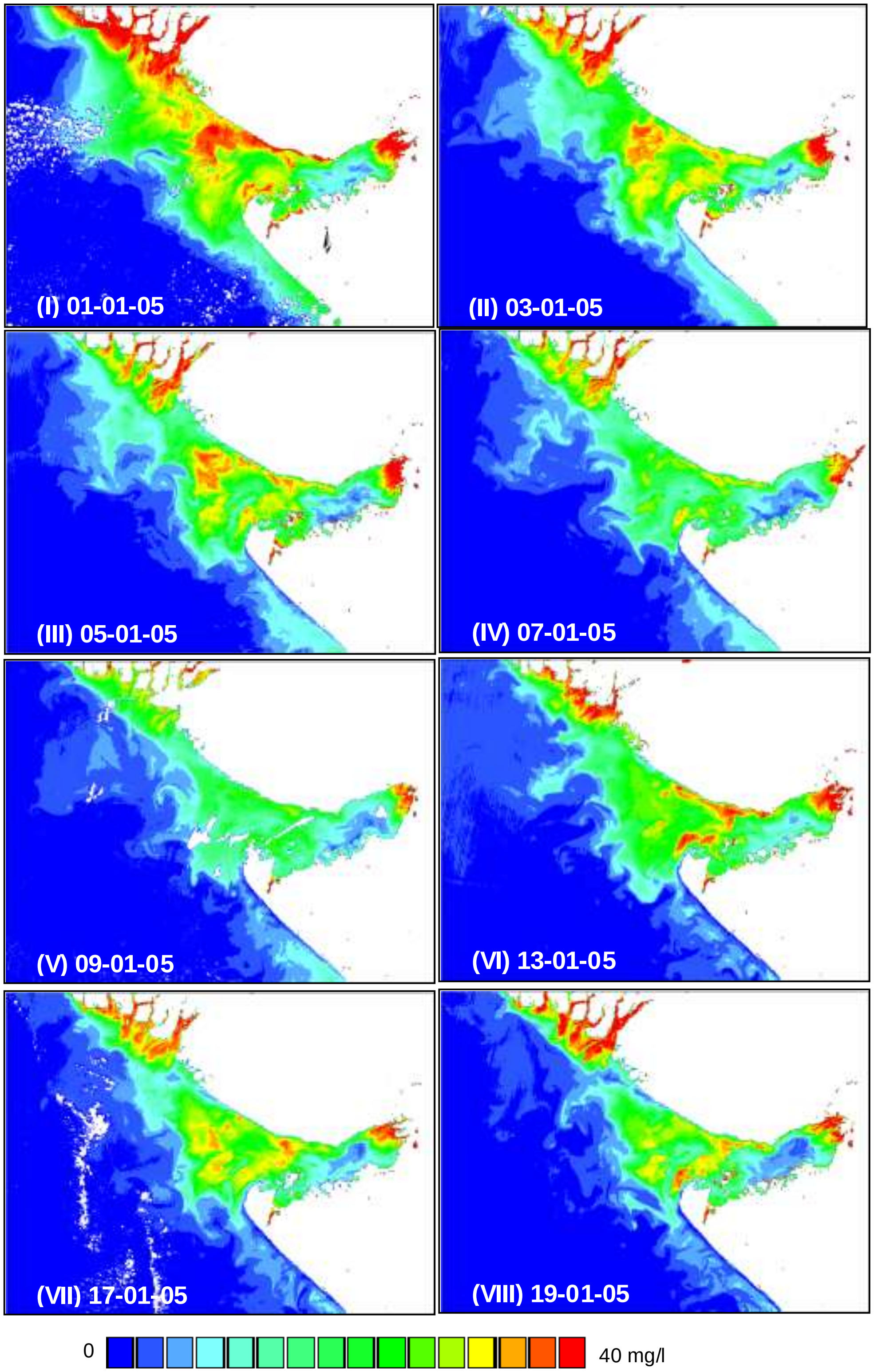

Fig.1: **OCM derived SSC (mg/l) for the Gulf of Kachchh region**

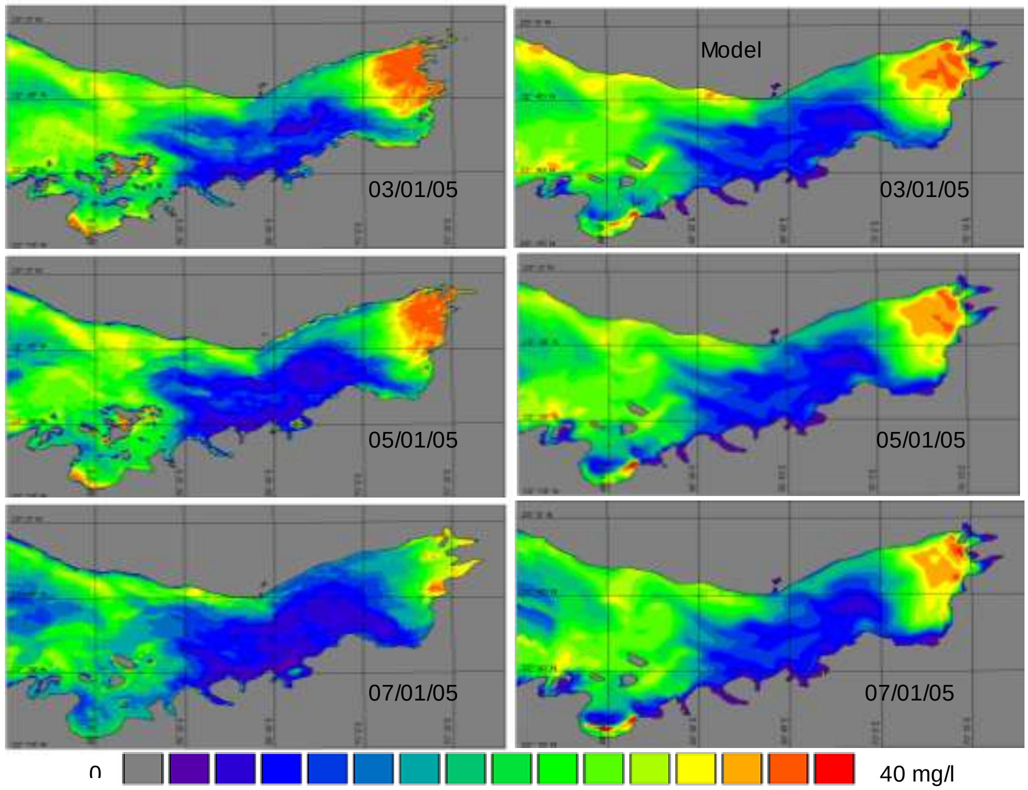

Fig. 2: Comparison of simulated SSC (mg/l) with OCM derived SSC in the Gulf of Kachchh.

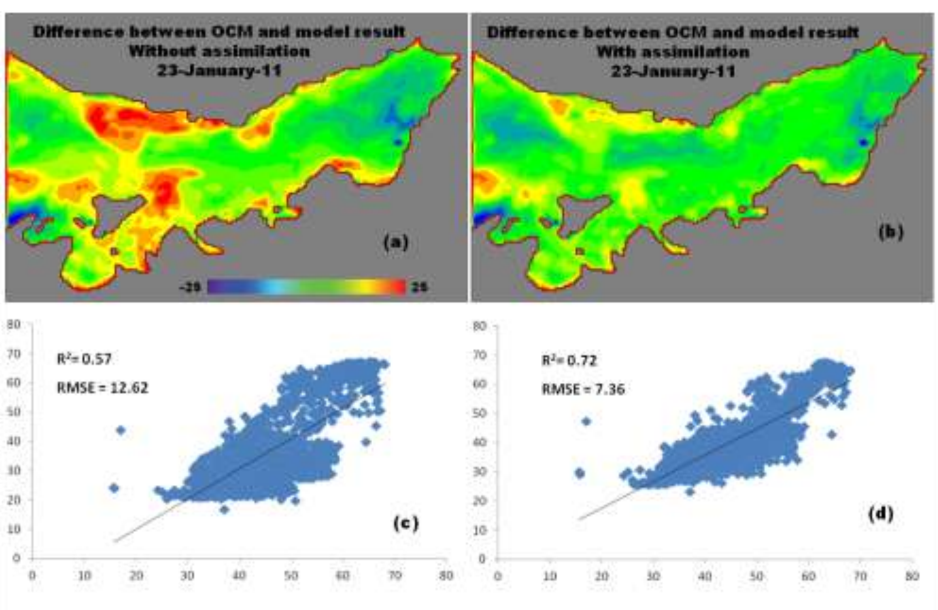

Fig. 3: Difference between OCM derived SSC and Simulated SSC for 23-January-2011 (a) without assimilation (b) with assimilation, Scatter plots of OCM derived SSC with model results (c) without assimilation (d) with assimilation

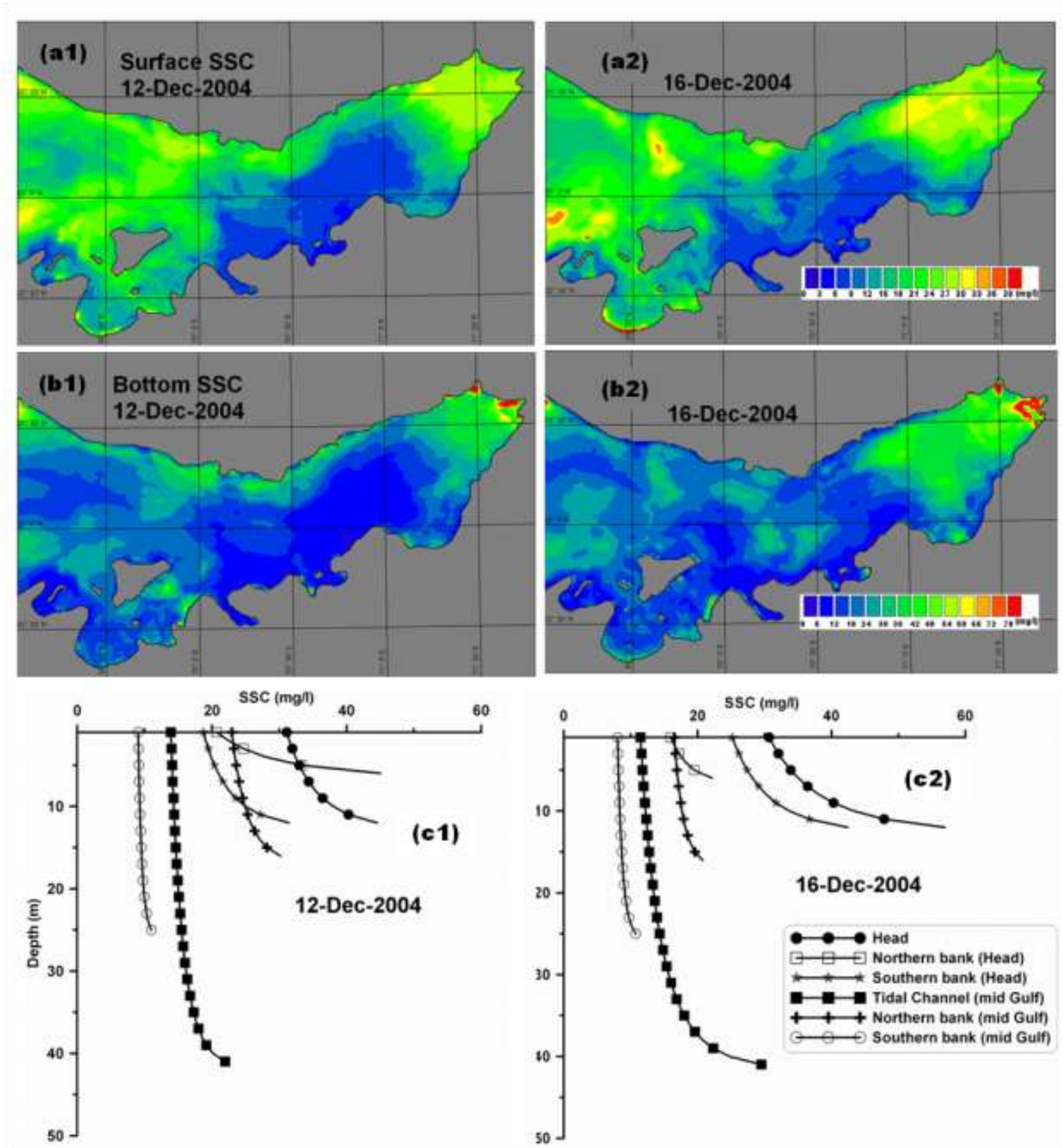

Fig. 4: (a) Surface SSC; (b) bottom SSC and (c) vertical SSC profiles derived from OCM scene

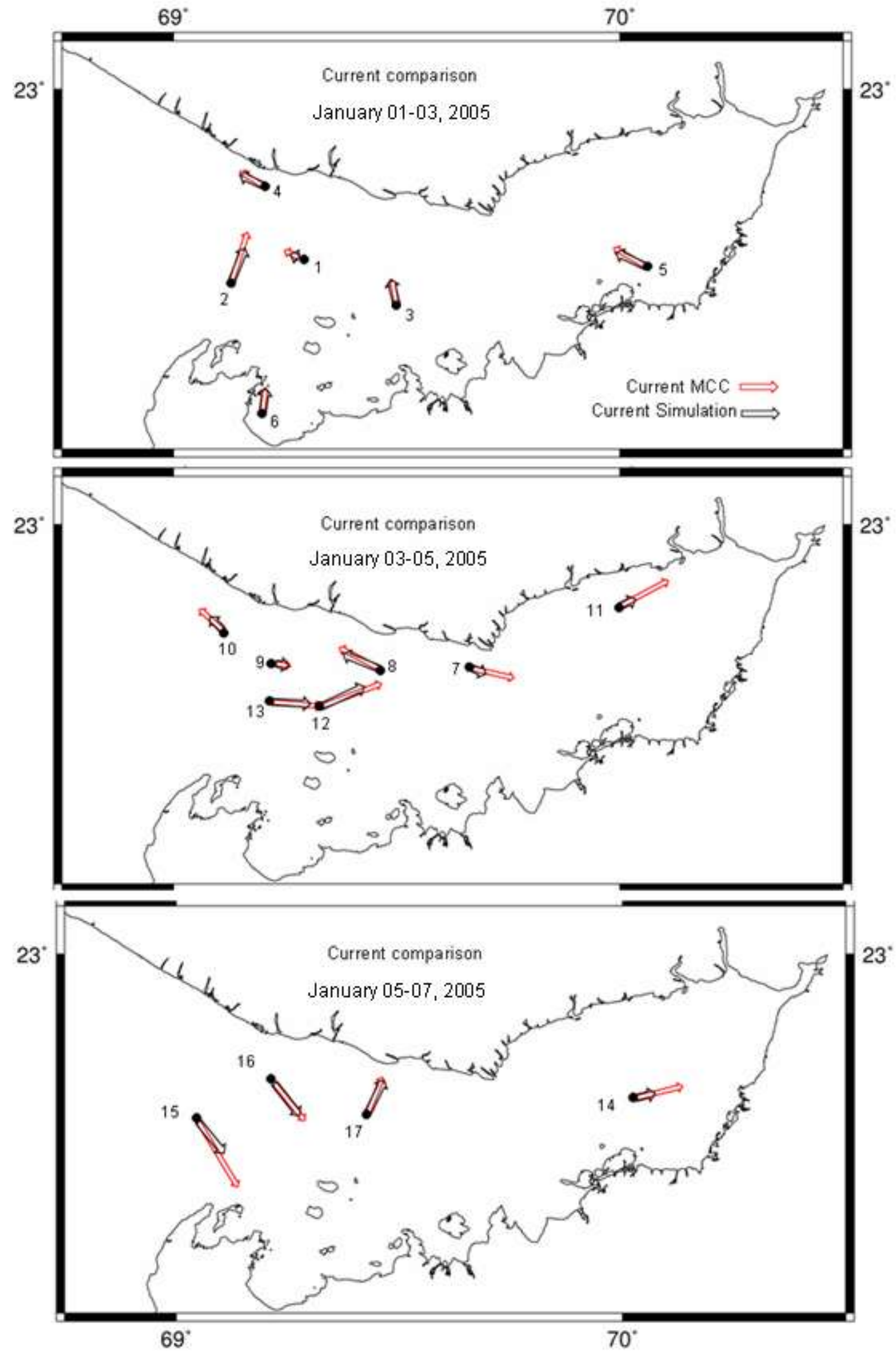

Fig. 5: Comparison of current vectors derived through modified MCC technique involving rotational registration of the search template and simulated current vectors

Future Work : It is well understood that coastal processes and sediment transport modeling requires use of ocean colour data related to regional sediment dynamics provided by sensors like Oceansat-1/2 OCM. Efforts are continuing to improve sediment transport models by collecting in-situ data, utilizing the in-situ data in calibrating and validating the models. It is planned to demonstrate applications of these models in some of the operational coastal engineering projects like development of ports/harbors, construction of shore protection structures like sea walls, breakwaters, jetties, groynes, quantification of dredging requirements and identification of suitable dumping sites etc. Work has been taken up under MOP-3 program for developing, models for coastal sediment budgeting and sediment cell identification and their applications in preparing sediment management plans.

Further reading and references:

- Chauhan, O. S., Rajawat, A. S., Pradhan, Y., Suneethi, J., and Nayak, S. R., 2005, Weekly observations on dispersal and sink pathways of the terrigenous flux of the Ganga–Brahmaputra in the Bay of Bengal during NE monsoon; *Deep-Sea Research II,* 52: 2018–2030.
- IOCCG, 2000, Remote Sensing of Ocean Colour in Coastal, and Other Optically-Complex, Waters. Sathyendranath, S. (ed.), *Reports of the International Ocean Colour Coordinating Group*, No. 3, IOCCG, Dartmouth, Canada.
- Kunte, P.D., Zhao, C., Osawa, T. and Sugimori, Y., 2005, Sediment distribution study in the Gulf of Kachchh, India, from 3D hydrodynamic model simulation and satellite data, *J. Mar. Syst*. 55:139–153.
- Ratheesh R., Rajawat A.S and Chauhan O.S, 2013, Suspended Sediment Concentration Profiles from Synoptic Satellite Observations, *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.* (Under Print)
- Ratheesh R and Rajawat A.S , 2012, Simulation of suspended sediment transport initialized with satellite derived suspended sediment concentrations, *J. Earth Syst. Sci.* 121(5), 1201–1213
- Nayak, S.R., Sarangi, R.K. and Rajawat, A.S., 2001, Application of IRS-P4 OCM data to study the impact of cyclone on coastal environment of Orissa, *Current Science*, 80 (09), pp. 1209-1213.
- Pradhan, Y., Rajawat, A.S. and Shailesh Nayak, 2004, Application of IRS-P4 OCM data to study the impact of tidal propagation on sediment dynamics in the Gulf of Kachchh; *Indian Journal of Marine Sciences;* 33 (2): 129-137.
- Pradhan, Y., Thomaskutty, A. V., Rajawat, A. S., and Nayak, S. R., 2005, Improved regional algorithm to retrieve total suspended particulate matter using IRS-P4 Ocean Color Monitor data; *J. Opt. A: Pure Appl. Opt*., 7: 343–349.
- Prasad, J.S., Rajawat, A.S., Pradhan, Y., Chauhan, O.S., and Nayak, S.R., 2002. Retrieval of sea surface velocities using sequential ocean colour monitor (OCM) data, In *Proc. Indian Acad. Sci. (Earth Planet. Sci.)*, 111 (3), pp. 189-195.
- Rajawat, A.S., Gupta M., Pradhan, Y., Thomaskutty, A.V. and Shailesh Nayak, 2005, Coastal processes along the Indian coast – case studies based on synergistic use of IRS-P4 OCM and IRS-1C/1D data; *Indian Journal of Marine Sciences;* 34(4), 459-472.
- SAC Report, 2013, MOP-II Project Closure Report on Coastal Processes and coastal dynamics, SAC/EPSA/MPSG/GSD/MOP-II/SR/84/2013
- SAC Report, 2003 a, IRS-P4 OCM Utilisation/SATCORE Project Report, Volume 1: Atmospheric Corrections, Bio-optical algorithm development and validation of IRS-P4 OCM data, *SAC Scientific Report*, No. SATCORE/SAC/RESA/MWRG/SC/01/03.
- SAC Report, 2003 b, IRS-P4 OCM Utilisation/SATCORE Project Report, Volume 3: Coastal Processes, *SAC Scientific Report*, No. SATCORE/SAC/RESA/MWRG /SC/01/03.
- Tassan, S., 1994, Local algorithm using SeaWiFS data for retrieval of phytoplankton pigment, suspended sediments and yellow substance in coastal waters; *Applied Optics*, 12, pp. 2369-2378.

GEOPHYSICAL PRODUCTS RETRIEVAL FROM OCEANSAT-2 OCM

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Introduction: OCEANSAT-2 satellite was launched on 23 September 2009 carrying Ocean Colour Monitor (OCM) with a goal to provide continutity of ocean colour data for scientific analysis and management of the fishery resources and coastal zone management. Moreover, understanding the fate of fluvial nutrients and its possible effect on marine carbon budgets as well as to quantify ocean's role in the global carbon cycle and other biogeochemical cycles is another major area of concern for ocean colour scientists.

OCEANSAT-2 OCM Specifications: OCM sensor is solid state camera operating in push broom scanning mode using linear array of Charge Coupled Devices (CCDs) as detectors in a polar, sun synchronous orbit with 98.28° inclination at an altitude of 720 km with a high spatial resolution of 360m, swath of 1420 km and temporal resolution of two days. The sensor may be tilted forward or backward 20 degrees along the spacecraft orbital trajectory to minimize the effects of sun glint. OCM maps in two spatial resolutions: Local Area Coverage (LAC) of 360 m and Global Area Coverage (GAC) of 1 km. While LAC data is available either through direct broadcast and/or 'selective recording', Global Area Coverage (GAC) data is recorded onboard Solid State Recorder (SSR) and played back at the primary ground reception station at National Remote Sensing Agency (NRSA) at Hyderabad, India.

OCM consist of 8 bands covering the spectral range from 402 to 870nm. **Table 1** lists the bandwidth for each of the eight OCM bands, along with the primary use. Bands 1-6 are 20 nm wide, and bands 7 is 30 nm wide while band 8 is 40 nm wide. OCM-2 is almost identical to OCEANSAT-1 OCM but has a minor spectral shift for band 6 and 7 from OCEANSAT-I OCM configuration. The spectral band 6, which was located at 670-nm in OCEANSAT-I OCM has been shifted to 620-nm for better quantification of suspended sediments. The spectral band 7 which was located at 765 nm in OCEANSAT-1 OCM has been shifted to 740 nm in OCEANSAT-2 OCM to avoid oxygen absorption (Chauhan and Navalgund, 2010).

Table-1: Central wavelengths potential application of OCM

Bandwidth (nm)		Primary Applications
B1	404-424	Yellow Substance absorption
B2	431-451	Low Chlorophyll-*a* concentration, Vertical diffuse attenuation of the light (K_d)
B3	476-496	Mid Chlorophyll-*a* concentration
B4	500-520	High Chlorophyll-*a* concentration
B5	546-566	Chlorophyll-*a* reference
B6	610-630	Total suspended matter (TSM) estimation
B7	725-755	Atmospheric Correction, Aerosol radiance
B8	845-885	Atmospheric Correction, Aerosol radiance

Development of atmospheric correction and bio-geophysical algorithms: The backscattered sun light from ocean waters is ten times larger than the actual radiance scattered out of the sea water due to the contribution from air molecules scattering and aerosols Mie scattering. This contribution of air molecules and aerosols decreases with the increasing wavelength and hence affects the contribution of water-leaving reflectance to the top of the atmosphere (TOA) reflectance. Hence, it becomes mandatory to correct atmospheric effects to estimate the sea water reflectance just above its surface for further quantitative estimation of in-water bio-geophysical parameters from space. The last two spectral bands of OCM-2 i.e., 740 and 865 nm are used for atmospheric correction purpose. Figure 1 shows the details of the methodology adopted for estimating geophysical parameter from OCEANSAT-2 OCM imagery. The output of atmospheric correction algorithm is used for estimating the geophysical parameters using bio-optical algorithms. For the OCM-2 processing special features have been incorporated for doing the atmospheric correction for both LAC and GAC data. Many data quality flags such as for land, cloud, sun-glint masking, coastal waters and shallow turbid coastal water flags have been implemented. Global bathymetry data at 1 km resolution has been used for masking the land boundaries and this data is also used for shallow water bathymetry flag. New algorithm for total suspended matter (TSM) concentration are implemented for OCM-2, which makes use 620nm band for estimation of total suspended sediment concentration. More details about the atmospheric correction and bio-geo-physical parameters are provided in OCEANSAT-2 OCM geophysical ATBD document.

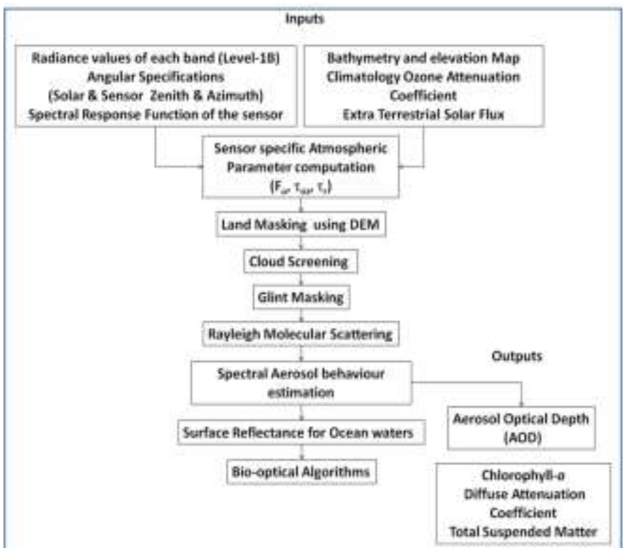

Figure 1: Elements of Geophysical Parameter Retrieval

A preliminary validation of geophysical parameters was carried out after re-calibration proposed by sensors group of Space Applications Centre, (ISRO), Ahemedabad for OCM radiance onboard OCEANSAT-2. Details of this validation exercise are documented in SAC Scientific Note.

Salient Illustration of OCEANSAT-2 OCM Estimated Geophysical Parameters: Retrieval yields four geophysical parameters namely Aerosol optical depth (AOD at 865nm), Chlorophyll-a concentration, Diffuse attenuation coefficient (K_d at 490nm) and Total suspended matter on operational basis. GAC data products for 21 March 2013 were processed using OCM Level 1B radiance product by using software developed at Space Applications Centre, Ahmedabad, to perform atmospheric correction of the OCM-2 data. The maximum band ratio (MBR) based Ocean chlorophyll-*a* algorithm (OC-2) was used for estimating chlorophyll-*a* concentration from OCM-2 data. Figure 2 shows the distribution of chlorophyll-*a* concentration retrieved from OCM-2 data around Yellow Sea and East China Sea. High concentrations of chlorophyll patches were observed near Yellow Sea region.

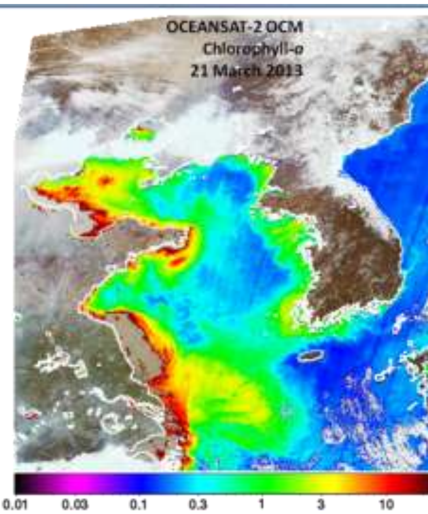

Figure 2: Distribution of Chlorophyll –*a* concentration around Yellow Sea and East China Sea.

The total suspended matter (TSM) concentration was estimated using the in-house developed bio-optical algorithm, which utilizes the nL_w values derived from 620nm spectral band as an input. Figure 3 shows the OCEANSAT-2 OCM generated total suspended matter concentration (mg / L) image for the turbid coastal waters of Yellow Sea using new 620nm spectral band. High sediment rich plume dispersal was observed from Yangtze River.

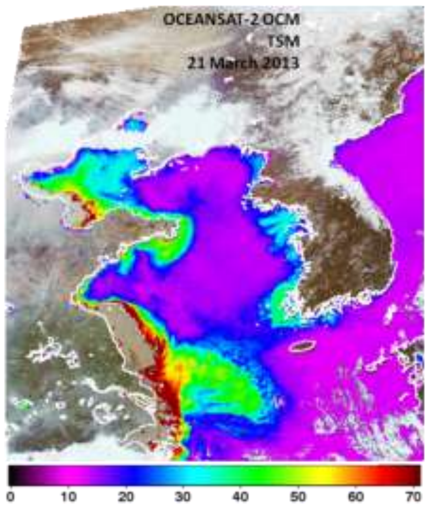

Figure 3: Sediment rich plume from Yangtze River empties into Yellow Sea around China.

The vertical diffuse attenuation coefficient (K_d-490) product was generated by using the normalized water leaving radiance ratio in 490 and 555nm as an input. Figure 4 shows the vertical diffuse attenuation coefficient image for Yellow Sea region using OCM-2 data. High values of K_d-490 were observed for the turbid sediment rich plume from Yangtze River and relatively lower values were observed over the nearby clear waters as per the expected range.

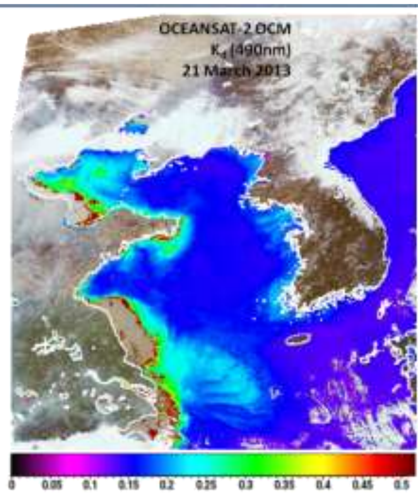

Figure 4: High Vertical attenuation coefficient (K_d-490nm) due to the sediment dispersal from Yangtze River in to the Yellow Sea.

AOD was estimated using 865nm spectral band of OCM-2. Figure 5 shows the distribution of atmospheric aerosols over the Yellow Sea. High AOD values are observed near around northern part of Yellow Sea relatively lower values are observed in the southern part Yellow Sea and eastern China Sea.

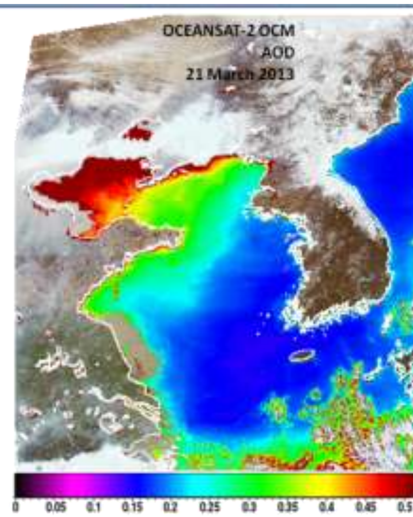

Figure 5: Distribution of atmospheric aerosols (AOD-865nm) around Yellow Sea.

Applications of OCM data : The OCM data is extremely useful for estimation of phytoplankton in oceanic /coastal waters, detection and monitoring of phytoplankton blooms, coastal upwelling, suspended sediment dynamics, location of fronts, identification of water mass boundaries and oil pollution. With additional input from other sensors such as winds from OCENASAT-2 scatterometer, sea surface height (SSH) from various altimeters, sea surface temperature (SST) from space, OCM data can provide detailed information on the coastal region owing to its increased spatial resolution. The information on pigments, in conjunction with sea surface temperature, will greatly assist in identification of potential fishery zones in coastal and oceanic waters. The potential end users of the OCM data products include fisheries management, marine industries, environmental management and studies related to the estimation of primary productivity in the oceanic basins. OCEANSAT -2 OCM, along with other ocean colour sensors such as MERIS and MODIS will assist the international ocean colour community in filling data gaps, and will also be used for the inter-sensor calibration of different ocean-colour sensors.

Conclusion: This article presents salient features of operational retrieval strategy for geophysical products with the illustration of GAC product over Yellow Sea.

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References:

- Chauhan P. and Navalgund R (2010). Ocean Colour Monitor (OCM) onboard OCEANSAT-2 mission, IOCCG website.
- Nagamani P.V. and Chauahan P., (2007). Algorithm Theoretical Basis Document for OCEANSAT-2 OCM, SAC/ISRO Scientific report no. : OCEANSAT-2-UP-3/SAC-2007.
- Sanwlani Nivedita and Chauhan Prakash, (2010). Preliminary Validation of geophysical parameters after re-calibration for Ocean Colour Monitor-2 (OCM-2) radiance onboard OCEANSAT-2. SAC/ISRO Scientific report no. : EPSA/MPSG/PMD/2010/01

OCEANOGRAPHY FROM SPACE USING SARAL/ALTIKA

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Introduction : SARAL, an ISRO-CNES collaborative altimeter mission, has been successfully launched and has already completed several revolutions in its orbit. It carries onboard an altimeter named AltiKa. As the name signifies, the primary goal of an altimeter mission is the measurement of the altitude of the sea surface from a reference ellipsoid. This is done by bouncing a radar beam at a particular microwave frequency and by measuring the two-way travel time of the radar pulse. Knowing the speed of the electromagnetic wave, and the precomputed height of the satellite above a reference ellipsoid, one can then easily compute the sea surface height (SSH). However, because of the slowing down of the radar pulse during its passage through ionosphere, atmosphere etc., several corrections have to be applied in order to do this. Apart from SSH, one can also compute another important characteristic of the sea surface, which is the significant wave height (SWH), related approximately inversely to the slope of the leading edge of the reflected pulse. Obtaining SWH of course requires sophisticated algorithms. The third quantity of interest is ocean surface wind speed, which is empirically related to the backscattered power.

Altimetry has a long history and several altimeters like Seasat, Geosat, Topex/Poseidon ,Envisat, Jason-1 and Jason-2 have already been flown over the years for the measurement of these three quantities. The unique feature of AltiKa is the use of Ka band frequency and this is the first such altimeter flown in space. Because of the use of higher frequency, the footprint size is relatively smaller, and consequently these data can be used for coastal studies. Below we provide the readers with a glimpse of the in house developed technique used to retrieve the abovementioned parameters from AltiKa data.

Mean Return Waveform: Radar return pulse, also known as the mean return waveform, is basically a time series W(t) of the return power. It is known to be a convolution of three terms, which are a) the flat sea surface response (FSSR), b) the sea surface elevation probability distribution (PDF), and c) the radar system point target response (PTR) (transmitted pulse as affected by the receiver bandwidth). The first term (a) includes the effects of antenna beam width and the off-nadir pointing angle. The mean return waveform thus can be written as :

$$W(t) = \mathrm{FSSR}(t) * \mathrm{PDF}(t) * \mathrm{PTR}(t) \qquad (1)$$

The first term is a series expansion involving Bessel functions and hence the convolution cannot be carried out analytically. However, under special circumstances, with the assumption that altimeter antenna mispointing angle is less than 0.3 degrees, the series expansion can be simplified and the convolution can be carried out analytically with the result:

$$W(t) = (A/2)\exp(-v)[1+erf(u)] \qquad (2)$$

where the auxiliary parameters u and v are related to two oceanic parameters of our interest (SSH and SWH), while the backscattered power can be obtained from amplitude using known scaling factors. It has to be once again borne in mind that the expression (2) is valid only for mispointing angle less than 0.3 degree. This is generally true for space-borne altimeters, which are continuously monitored for any possible deviation from nadir-looking view.

Retrieval Algorithms: Retrieval algorithms employed in this work are physical algorithms based on the analytical model (2) and are variants of maximum likelihood estimation (MLE) algorithms. In one of the variants, known as MLE3 method, one aims to find only the three oceanographic parameters, namely the amplitude, the epoch (the offset of the time origin in the return power), which is translated to range correction, used for calculating SSH, and σ_c (related to the echo rise time) used for calculating SWH. Since the analytical model needs an estimate of the off-nadir angle also, the same is obtained empirically beforehand from the trailing edge slope. As far as MLE4 algorithm is concerned, all the parameters (including the mispointing angle) are simultaneously estimated. These algorithms were earlier tested for Jason-2 waveforms in the Indian Ocean and in the present work these have been applied to the AltiKa waveforms.

Data Used: In this work we have made use of 1-Hz and 40 Hz data of SARAL/ AltiKa Sensor - Interim Geophysical Data Record (S-IGDR), which is level-2 data. Cycle 001 (March 14 to April 18) data has been used. In this data there are 1002 passes (both ascending and descending) all over the global oceanic region. Since we had at our disposal the dataset retrieved by operational algorithms from CNES, we could easily carry out inter-comparison of the three parameters, estimated by our algorithms (both MLE3 and MLE4).

Results: Although we have carried out analysis using 1 Hz as well as 40 Hz data, for the sake of brevity we report only the results using 40 Hz waveforms**.** In Fig. 1 we show a typical example of a 40 Hz waveform in the open ocean. One can notice noisy trailing edge in 40-Hz data over the open ocean while the same is quite smooth in 1-Hz waveform data (corresponding figure not shown). Unlike Jason-2 waveforms, AltiKa waveforms invariably have exponential trailing edges.

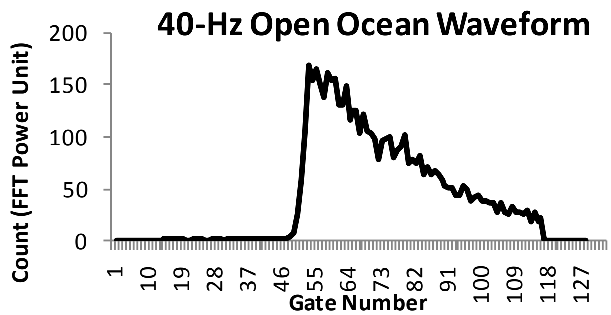

Fig. 1. A typical open-ocean 40 Hz waveform

Figure 2 shows the density scatter plot of range correction (dr) retrieved by the present algorithm vs operationally retrieved dr from 40-Hz waveforms. In this case MLE3 performed better and hence we show only this case.

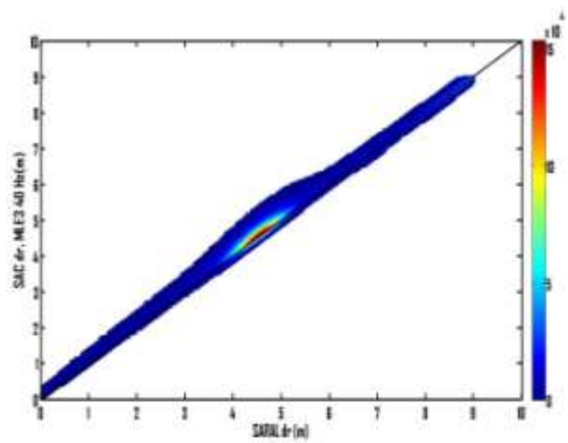

Fig. 2: Density Scatter plot of range correction, dr, retrieved by our algorithm (MLE3) against those retrieved by operational algorithm.

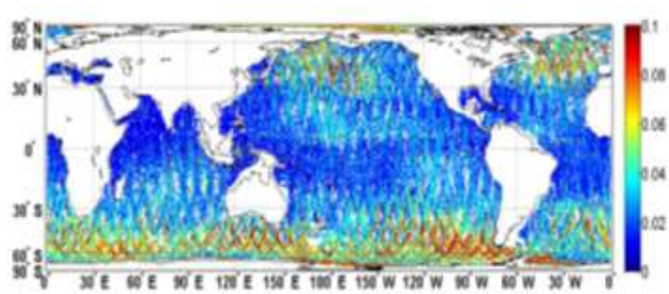

Fig. 3. Global distribution of the absolute difference between range corrections, dr, retrieved by the two algorithms (SAC algorithm is MLE3)

In Fig. 3 displaying absolute difference between the dr retrieved by the two algorithms, we note large differences at higher latitudes, while the differences are quite low (~ 2 cm or less) in the tropics, being well within the range of error budget of this particular parameter retrieved by a satellite altimeter.

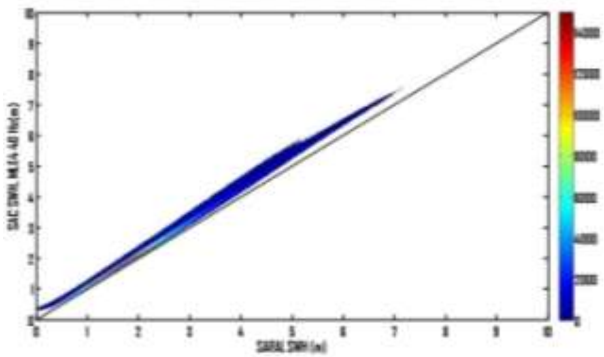

Fig. 4 : Density plot of Significant Wave Height retrieved by two algorithms. SAC algorithm uses the version MLE4.

In Fig. 4 we show a density scatter plot of SWH retrieved by the two algorithms. The agreement is good, with a slight positive bias in the case of in house algorithm. In the next figure (Fig. 5) we show the global distribution of the absolute difference between the two SWHs. It can be readily seen that the differences are within 0.5 m everywhere, being within the error budget of the mission for this parameter.

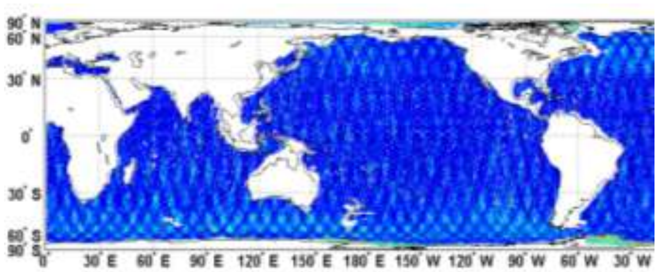

Fig. 5 : Global distribution of the absolute difference between SWH retrieved by two algorithms. SAC algorithm uses MLE4 version.

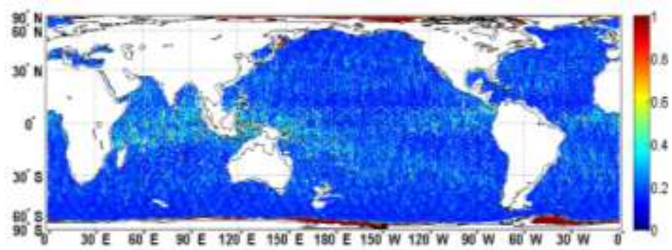

Fig. 6. Same as in Fig. 5 except for backscattering coefficient.

Finally, in Fig. 6 we show the global distribution of the difference between the retrieved backscattering coefficients. (We omit the corresponding density plot for the sake of brevity). It can be seen that the differences are less than 0. 4 db at most places.

Summary : Thus in this report we have outlined the results of applying MLE3 and MLE4 algorithms for retrieving three oceanographic parameters of interest from SARAl/AltiKa waveforms over global oceans (the open ocean region only). In majority of the cases the algorithm succeeds in providing reasonably accurate estimates of the oceanic parameters when compared with the standard operational products. However, the results are sensitive to the choice of a particular algorithm. For the retrieval of epochs or, range correction, it was found that MLE3 algorithm performs better, while for amplitude and SWH, the performance of MLE4 algorithm is better. Therefore it is proposed that for AltiKa, MLE3 should be used for deriving the epoch, while MLE4 should be used for amplitude and SWH derivation. These inferences are, however, somewhat preliminary, since they are based on the analysis of just one cycle of SARAL/AltiKa data. More definitive conclusion will require more rigorous analysis with many more cycles of data.

REMOTE SENSING OF OCEAN SUBSURFACE: A SOFT-COMPUTING APPROACH

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Abstract: Besides ocean surface data, information of subsurface parameters like profiles of temperature and sound speed, sonic layer depth, ocean heat content, are also critical for many of the ocean-atmospheric studies and for strategic applications. The present network of in situ measurements is not sufficient to resolve the mesoscale problems encountered by these studies. Though remote sensing techniques solve many of such problems dealing with ocean surface studies, analysis of subsurface data is still hampered as electromagnetic waves cannot penetrate deep into the ocean waters. Hence, alternate means of obtaining ocean subsurface information is required for which soft-computing technique is an alternative. In this article estimation of the ocean subsurface information using such a technique is demonstrated.

Introduction: A common man is well aware of the surface ocean parameters like sea surface temperature (SST), waves and currents. Besides these surface parameters, there are subsurface parameters, which are important in many strategic and atmospheric applications. For example, vertical profiles of sound speed and sonic layer depth are critical parameters for sub-marine operations. The amount of heat available in the upper layers of the oceans drives the air-sea interaction processes, which in turn controls cyclones and monsoons. Similarly, vertical profiles of temperature are required for many of the ocean studies. Till the advent of satellites we were depending upon the in situ measurements from ships or buoys, which are very limited both spatially and temporally. For example, if we wanted to measure ocean currents we had to stop the ship and calculate the current vector from the ship drift, or use the current meter. But, the altimeters onboard satellites are being used to compute the geostrophic currents with high temporal and spatial resolutions. These geostrophic currents can be approximated to actual currents on a temporal scales of two days and spatial scales of 2 degrees. However, remote sensing technology has a limitation of being able to observe only the surface of the ocean. For example, the Ekman Spiral (change of current direction and speed with depth) cannot be directly estimated from altimeters. Similarly, temperature profiles cannot be obtained from satellite sensors since electromagnetic waves do not penetrate ocean water columns.

Hence, alternate means of obtaining ocean subsurface information is required. This is a two-way step: In the first step we get surface parameters from the remote sensing sensors mostly using statistical methods like Multiple Regression Technique (MRT) and in the second step we use many surface parameters estimated from remote sensing platforms, and which control the profile to be estimated, to get the subsurface information. Using soft computing techniques like Genetic Algorithm or Artificial Neural Network (ANN) to obtain the subsurface information are such alternatives. Advantage of these techniques, say ANN, over MRT is that ANN can estimate the profiles of a parameter - it is capable of providing multiple outputs (here values at different depths) with a single or many input parameters. On the contrary, MRT can give only one output, ie it cannot provide profiles.

The ANN Approach: An ANN is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. ANN models learn through examples that can be designed for the specific applications like pattern recognition, data classification or parameter prediction, through a training (learning) process. Performing an ANN analysis requires three sets of data under the categories training, verification (testing) and prediction (validation). The data set marked for training is used to train the neural network. Verification cases are used to check the model during training so that the model does not over-fit. Once the ANN model is trained with good amount of in situ data covering as wide oceanographic regimes/conditions as possible, the output can be predicted with input parameters alone without any regional/seasonal constraints. If we have data for many years, a few years could be used for training and the other for validation. However, if the data is only for one-year, training for a few months and testing for the remaining months is not feasible, as the training of the model needs a good coverage of the entire seasonal conditions. Hence, we use the data randomly for training testing and validation so that the entire annual cycle is covered in the three data sets. A random selection is most suited for an ANN analysis for such a dataset [Haykin, 2002; Ripley, 1997]. Richaume et al. [2000], Pozzi et al. [2000], Schroder et al. [2003], and Bourras and Liu [2003] used random selection technique for the prediction of various parameters. Random selection also eliminates the periodicity/bias that may creep in while using a systematic selection of data for the network training and validation, which is desirable. Here, we discuss a few applications of ANN in obtaining ocean subsurface information.

Estimation of Sound Speed Profiles: The sound speed in the ocean determines the characteristics of the sound transmission that has civil and military applications. The locations and the extent of shadow zones and the sound channels depend on the sound speed structure. The vertical gradients of sound speed in most of the regions of the ocean are about a thousand times the horizontal ones, except in areas of convergence of cold and warm currents, where even horizontal gradients are also significant. In the absence of the preferred measurements from velocimeter, sound speed profiles (SSPs) can be estimated from the vertical profiles of temperature, salinity, and pressure. Due to the limited availability of *in situ* measurements of these profiles, studying temporal variations of the three-dimensional structure of the sound speed is difficult to achieve. Hence, it is of importance to find suitable methods of estimating the SSP from surface parameters alone that are available from remote sensing platforms. However, several attempts have been made to infer temperature profiles from surface observations through models and other techniques.

Jain and Ali [2006] used hourly surface and subsurface observations from the central Arabian Sea mooring located at 15.5°N and 61.5°E deployed by the Woods Hole Oceanographic Institution during October 16, 1994 to October 22, 1995. This is the only data set of hourly time series for one-year with meteorological and oceanographic observations in the Indian Ocean. Hence, they selected this data set for the study. The parameters used in this study are net surface heat flux (NSHF), net radiation, sea surface wind stress (SSWS), dynamic height (DH), and vertical profiles of temperature and salinity.

The ANN-predicted SSPs compare well with those obtained from *in situ* profiles with an overall root-mean-square (rms) error of 1.16 m/s with a coefficient of determination (R^2), a measure of the total variance in a dependent parameter, of 0.98 and a slope of 44.7° (Figure 1). About 76% estimations lie within +/- 1 m/s, and 93% estimations lie within +/- 2 m/s of the SSP estimations obtained from the mooring. Monthly rms differences between the ANN-predicted and the *in situ* estimated SSPs are more in the 40–125m depth range. This could be due to the fluctuations caused by the internal waves and/or to the large MLD variations in this range.

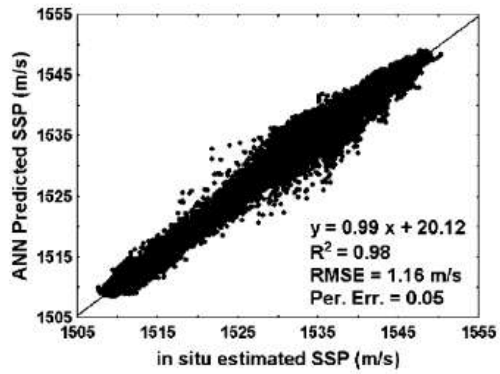

Figure 1: Scatter of in situ estimated and ANN-predicted SSP for validation data set.

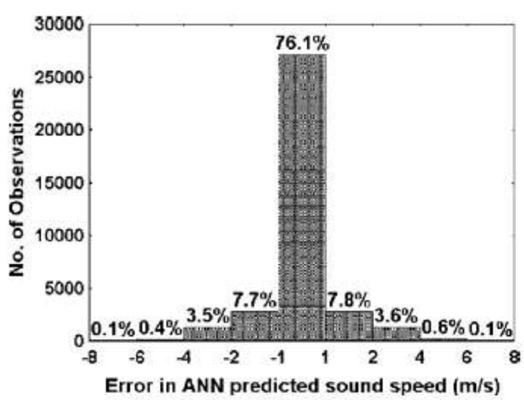

Figure 2: Histogram of residuals in ANN-predicted SSP for validation data set.

Estimation of temperature profiles: The capability of the ANN approach to synthesize the ocean subsurface temperature structure (OSTS) from surface parameters like net surface heat flux, net radiation, SST, wind stress, and dynamic height is demonstrated by Ali et al. [2004]. The observations of the same Arabian Sea mooring have been used for this analysis. The model estimated profiles were compared with the actual in situ profiles. They agree quite well with the corresponding observed (in situ) profiles (Figure 3). About 50% of the estimated profiles lie within an error limit of ±0.5° C and 95% of the estimations, within ±1° C. 1–2° C errors account for only 5% of the total data set. The average RMS error of the model estimated profiles is 0.584° C, with a depth-wise average R value of 0.92.

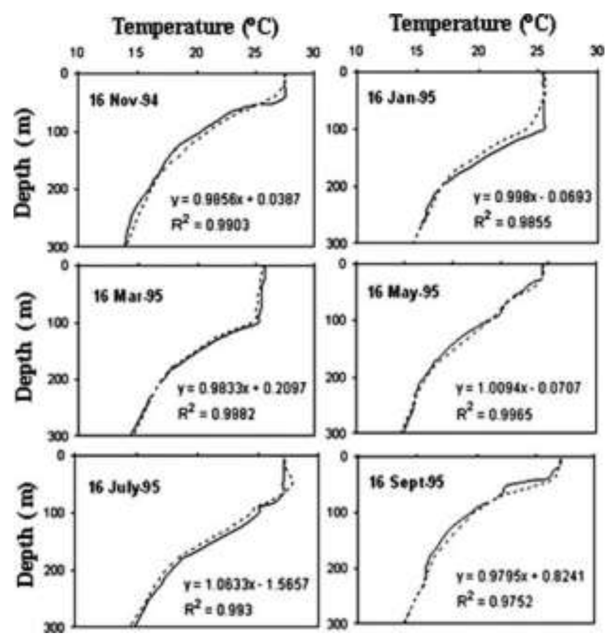

Figure 3: Comparison of in situ and predicted temperature profiles at different depths. Solid lines represent the in situ temperatures and dashed lines represent the estimated temperatures

Estimation of Sonic layer depth (SLD): Water is an efficient medium for the transmission of sound. Sound travels more rapidly and with much less attenuation of energy through water than air. This characteristic resulted in development of submarine acoustic methods having tremendous value in navigation. SLD, an important parameter in underwater acoustics, is the near surface depth of first maxima of the sound speed in the ocean. The lack of direct observations of vertical profiles of velocimeters or temperature and salinity, from which sound speed and SLD can be calculated, hampers the investigation of SLD. Jain et al. [2007] demonstrate SLD estimation using ANN approach from surface measurements that can be replaced with satellite observations later. Surface and subsurface measurements from the central Arabian Sea mooring are used for this purpose. The estimated SLD had a root mean square error (correlation coefficient) of 11.83 m (0.84). Approximately 76% (91%) of estimations lie within ±10 m (±20 m). SLD has also been estimated from surface parameters using multiple regression technique (MRT). ANN proved its superiority over MRT in estimating SLD from surface parameters.

Estimation of Tropical Cyclone Heat Potential: Energy from the oceans is one of the critical factors influencing the intensification of tropical cyclones (TCs). After the sudden intensification of Hurricane Opal when passing over a warm oceanic feature [Shay et al. 2000], the role played by the upper ocean thermal structure has taken prominence in cyclone intensification studies. In addition to SST, tropical cyclone heat potential (TCHP), which is defined as the heat content of the ocean integrated from surface to the 26^o C isotherm [Leipper and Volgenau, 1972], has been studied in regard to its possible relations with TC intensity [Goni and Trinanes, 2003; Wada and Usui, 2007; Lin et al. 2005, 2008, 2009] and storm surge prediction [Lin et al. 2012].

Given the importance of TCHP in the intensification of Indian Ocean cyclones, it is necessary to improve the accuracy of its estimations to assist CI forecast and analysis [Lin et al. 2009; Goni and Knaff 2009]. The spatially and temporally limited availability of *in situ* hydrographic observations constrains the estimation and monitoring of TCHP on a regular basis, particularly over regions of TC activity. Since the sea surface height anomaly (SSHA) is strongly correlated with the thermal structure of the upper ocean, TCHP can be estimated from this parameter over finer spatial and temporal scales. Details of the estimation of TCHP from climatologically temperature profiles, SST, and SSHA observations using a two-layer reduced gravity model are given in Shay et al. [2000], Goni and Trinanes, [2003], Wills et al. [2004] and Jain and Ali, [2005]. In addition to this model, artificial neural network (ANN) is another possible method to derive TCHP based on altimeter observations.

Ali et al. [2012] developed an ANN technique to estimate TCHP using about 25000 *in situ* temperature profiles, climatologically depth of 26^o C isotherm (*D*26*c*), and the collocated SST and SSHA observations over the North Indian Ocean spanning 10^o S–25^o N latitude and 40^o E–100^o E longitude. SSHA represents the subsurface thermal structure, whereas SST represents the heat energy at the surface. *D*26*c* provides the climatologically background over which changes take place. They estimated TCHP by 1) an ANN technique, 2) a two-layer reduced gravity model, and 3) a multiple regression technique and compared the estimations with the *in situ* observations. Out of the three methods, the ANN approach has given the best result. These results suggest the utility of the ANN technique in estimating TCHP with better accuracy in the North Indian Ocean that certainly, in turn, helps in improving the cyclone track and intensity predictions.

Conclusions: The ANN approach was found to be successful in estimating ocean subsurface temperature and sound speed profiles, sonic layer depth and TCHP from surface observations. To further strengthen and apply this model globally, it is necessary to test the validity of such an approach with widely varied sets of data from different regions and with better networks (models with more/optimum number of hidden layers and better training algorithms). This method may also be used in the estimation of salinity/density and current profiles, provided, more in situ measurements are available. Once accurate predictions of OSTS/SSP have been made, over a larger area, the estimated profiles can be used for the practical applications of acoustic propagation and MLD estimations. Though the approach to estimate OSTS, SSP and SLD is demonstrated using in situ observations, remote sensing data can be conveniently used to estimate these products. TCHP estimated from remote sensing observations is being hosted at the NRSC Bhuvan site on near real time basis. Ocean heat content is also estimated from remote sensing data using the ANN technique. This product will also be hosted in Bhuvan very shortly.

References:

- Wada and N. Usui, "Importance of tropical cyclone heat potential for tropical cyclone intensity and intensification in the western North Pacific," *J.Oceanogr.*, vol. 63, no. 3, pp. 427–447, Jun. 2007.
- D. Ripley, *Pattern Recognition and Neural Networks*. Cambridge, U.K.: Cambridge Univ. Press, 1997.
- Bourras and W. T. Liu, "Evaluation of latent heat flux fields from satellites and models during SEMAPHORE," *J. Appl. Meteorol.*, vol. 42, no. 2, pp. 227–239, Feb. 2003.
- D. F. Leipper and D. Volgenau, "Hurricane heat potential of the Gulf of Mexico," *J. Phys. Oceanogr.*, vol. 2, no. 3, pp. 218–224, Jul. 1972.
- G. Goni, S. Kamholz, S. Garzoli, and D. Olson, "Dynamics of the Brazil–Malvinas Confluence based on inverted echo sounders and altimetry," *J. Geophy. Res*, vol. 101, pp. 16 273–16 289, 1996.
- G. J. Goni and J. A. Trinanes, "Ocean thermal structure monitoring could aid in the intensity forecast of tropical cyclones," *EOS Trans. AGU*, vol. 84, no. 51, p. 573, 2003.
- G. J. Goni and J. Knaff, "Tropical Cyclone Heat Potential ['In State of the Climate in 2008']," *Bull. Amer. Meteor. Soc.*, vol. 90, no. 8, pp. S54–S56, 2009.
- G. J. Goni, M. DeMaria, J. Knaff, C. Sampson, I. Ginis, F. Bringas, A. Mavume, C. Lauer, I.-I. Lin, M. M. Ali, P. Sandery, S. Ramos-Buarque, K. Kang, A. Mehra, E. Chassignet, and G. Halliwell, "Applications of satellite-derived ocean measurements to tropical cyclone intensity forecasting," *Oceanography*, vol. 22, no. 3, pp. 176–183, 2009.
- I. Lin, C. C. Wu, and I.-F. Pun, "Upper ocean thermal structure and the western North Pacific category-5 typhoons—Part I: Ocean features and category-5 typhoons," *Mon. Weather Rev.*, vol. 136, no. 9, pp. 3288–3306, Sep. 2008.
- I. Lin, C. C.Wu, K. A. Emanuel, I. H. Lee, C. R.Wu, and I. F. Pun, "The interaction of supertyphoon Maemi (2003) with a warm ocean eddy," *Mon. Weather Rev.*, vol. 133, no. 9, pp. 2635–2649, 2005.
- I. Lin, C.-H. Chen, I.-F. Pun, W. T. Liu, and C.-C. Wu, "Warm ocean anomaly, air sea fluxes, and the rapid intensification of tropical cyclone Nargis," *Geophys. Res. Lett.*, vol. 36, p. L03 817, Feb. 2009.
- Lin, I.-F. Pun and C.-C. Wu, "Upper ocean thermal structure and the western North Pacific category-5 typhoons Part II: Dependence on translation speed," *Mon. Weather Rev.*, vol. 137, no. .11, pp. 3744–3757, 2009.
- J. K. Willis, D. Roemmich, and B. Cornuelle, "Interannual variability in upper-ocean heat

content, temperature and thermosteric expansion on global scales," *J. Geophys. Res.*, vol. 109, p. C12 036, Dec. 2004.

- Jain, S. and Ali, M. M. (2006). Estimation of sound speed profiles using artificial neural networks, IEEE Geoscience and Remote Sensing Letters, Vol. 3, No. 4, pp 467-470.

- L. K. Shay, G. J. Goni, and P. G. Black, "Effects of a warm oceanic feature on Hurricane Opal," *Mon. Weather Rev.*, vol. 128, no. 5, pp. 1366–1383, May 2000.
- Lin, I-I, G. J. Goni, J. Knaff, C. Forbes and M. M. Ali (2012). Ocean Heat Content for Tropical Cyclone Intensity Forecasting and Its Impact on Storm Surge, Natural Hazards, DOI: 10.1007/s11069-012-0214-5
- M. M. Ali, P S V Jagadeesh, I-I Lin, and Je-Yuan Hsu (2012). A Neural Network Approach to Estimate Tropical Cyclone Heat Potential in the Indian Ocean, IEEE Geoscience and Remote Sensing Letters, Vol. 9, pp 1114 – 1117, DOI No: 10.1109/LGRS.2012.2190491
- M. M. Ali, Swain, D and Weller, R (2004). Estimation of ocean sub-surface thermal structure from surface parameters: A neural network approach, Geophysical Research Letters, Vol. 31, 120308, doi 10.1029/2004GL021192,2004.
- M. Pozzi, B. A. Malmgren, and S. Monechi, "Sea surface temperature and isotopic reconstructions from nannoplankton data using artificial neural networks," *Palaeontologia Electronica*, vol. 3, no. 2, pp. 4–14, 2000.
- P. Richaume, F. Badran, M. Crepon, C. Mejía, H. Roquet, and S. Thiria, "Neural network wind retrieval from ERS-1 scatterometer data," *J. Geophys. Res.*, vol. 105, no. C4, pp. 8737–8751, Apr. 2000.
- S. Haykin, *Neural Networks: A Comprehensive Foundation*, 2nd ed. Singapore: Pearson Education Asia, 2002.
- S. Jain, MM Ali and PN Sen (2007). Estimation of Sonic Layer Depth from Surface Parameters, Geophys. Res. Lett. Vol. 34, Doi: 10.1029/2007GL030577
- T. Schroder, J. Fischer, M. Schaale, and F. Fell, "Artificial neural network based atmospheric correction algorithm: Application to MERIS data," in *Proc. SPIE*, Hangzhou, China, 2002, vol. 4892, pp. 1–9.

ARTICLES IN HINDI

चौदवीं का चान्द हो।

योगदीप देसाई, बी कार्तिकेयन

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मानव हमेशा से ही चन्द्रमा के प्रति आकर्शित रहा है। इंसान का चान्द से यह लगाव हर एक उम्र में और कई क्षेत्रों में भिन्न भिन्न स्वरूप में प्रदर्शित होता है। बचपन में माँ चन्दामामा की लोरियाँ सुना कर सुलाती हैं तो यही चान्द, बच्चे को बडे हो कर, किसी चेहरे में नज़र आता है। कविओं को तो चान्द ने अनगिनत कविताएँ लिखने को प्रोत्साहित किया है। चान्द ने जब वैग्यानिको के दिल से उपर ऊठकर बुध्धिमत्ता को प्रभावित किया तब 'एपोलो' जैसे कई मिशन चन्द्र की सैर कर आये।

चान्द की रोशनी को हमेशा से ही एक 'सन्दर्भ' माना गया है---जैसे चेहरे की सुन्दरता की तुलना के लिये। पर यहाँ चन्द्रमा की चर्चा एक 'सन्दर्भ विकिरणमितीय स्त्रोत' के रूप में कि गयी है क्युंकि चन्द्रमा के स्थायी विकिरणमितीय गुण के उपरांत चन्द्रमा और संवेदक के बीच मे वातावरण कि अनुपस्थिति संलग्न अनिश्चितता को कम कर देती है। चन्द्रमा की परावर्तकता मे प्रति वर्ष 10^{8} से भी कम परिवर्तन पाया गया है ।

चन्द्रमा के इसी गुण को अंतरिक्ष वैग्यानिकों द्वारा अपने अवकाशी कैमरे के अंशांकन के लिये उपयोग में लाया जा रहा है। चन्द्रमा की रोशनी को 'सन्दर्भ' मानकर किये जानेवाले अवकाशी कैमरेके अंशांकन को **चन्द्रमा-अंशांकन** कहते है। चन्द्र-अंशांकन की पध्धति, भूस्थिर और सूर्य तुल्यकालि, दोनो ही प्रकार के प्रकाशिक संवेदक के लिये प्रयोग में लायी जा सकती है।

विश्व की कई अंतरिक्ष संस्थाओं ने अपने अवकाशी-कैमरे के अंशांकन में ईस पध्धति का प्रयोग किया है। अमरीका के सँयुक्त राज्य भूवैग्यानिक सर्वेक्षण (यु.एस.जी.एस) ने अपने चन्द्रमा-अंशांकन कार्यक्रम के तहत 'रोबोटिक ल्युनार ओब्सरवेटरी', जिसे सँक्षिप्त में 'रोलो' कहा जाता है, की स्थापना कि है।

चन्द्रमा के स्थायी विकिरणमितीय गुण को ध्यान में रखते हुए भारतीय अंतरिक्ष अनुसन्धान संगठन ने भी 'ओशन कलर मोनिटर-2' से चन्द्र अंशांकन कार्यक्रम ko को प्रचालित किया है।

चन्द्र-अंशांकन प्रक्रिया में दो समूह सम्मिलित है अ) रोलो-समूह और ब) संवेदक-अंशांकन-समूह जो नीचे दिये गये सोपान को अनुगमन करता है:-

1) संवेदक द्वारा चन्द्रमा का प्रतिबिम्बन । संवेदक द्वारा चन्द्रमा का प्रतिबिम्बन 7 अंश की कला पर होना जरुरी है जो पूर्णिमा या चौदवीं के चान्द के बराबर होगा।

2) चन्द्रांकित्-चित्रांश् को पहचानना।

3) चन्द्र-बिम्ब-डाटा से तिमिर-संख्या को हटाना ।

4) बिम्ब-संख्या को विकिरणता मे परिवर्तित करना ।

5) चन्द्रांकित्-चित्रांश् के विकिरणता का योग करना ।

6) संवर्धित विकिरणता को किरणता मे परिवर्तित करना ।

संवेदक-अंशांकन-समूह द्वारा गणित स्पेकट्रमि-किरणता-मान को रोलो-समूह को भेजा जाता है ।

चित्र- 1 चन्द्र की कलाएँ

चन्द्र की विकिरणता ऊसकी ज्यामिति और कला पर निर्भर करती है (चित्र:1) और निम्नलिखित घटको के लिये प्रसामान्यीकरण करना आवश्यक है:-

1) सूर्य-चन्द्र मे अंतर

2) संवेदक-चन्द्र मे अंतर

3) चन्द्रकला कोण

4) अति प्रतिचयन घटक

'ओशन कलर मोनिटर-2' ने अपने प्रमोचन से लेकर साल 2012 के बीच तीन बार चन्द्र अंशांकन के किये चन्द्र को प्रतिबिम्बित किया (सारणी-1)।

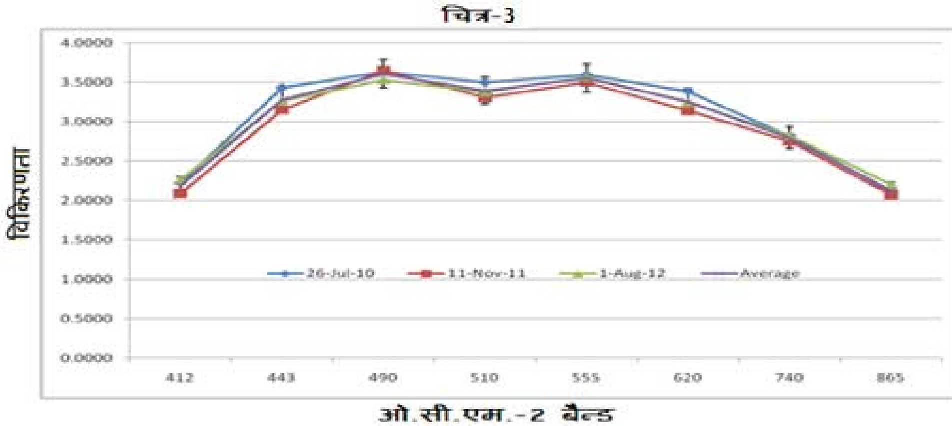
सारणी-1	
क्रमांक	तारिख्
1	26 जुला. 2010
2	11 नवे. 2011
3	01 ओग. 2012

26जुलाई2010 को लिये गये चन्द्र के बिम्ब को चित्र 2 द्वारा दिखाया गया है।

चित्र-2
ओ-सी-एम-2 द्वारा बिम्बित चन्द्र-बिम्ब

उपरोक्त वर्णन के अनुसार किये गये विश्लेषण से यह प्रमाणित होता है की 'ओशन कलर मोनिटर-2' का आचरण स्थायी रहा है । आलेख में दी गयी त्रुटि रेखा (चित्र-3) दर्शाति है कि 'ओशन कलर मोनिटर 2' के तीन वर्ष के कार्यकाल के दौरान स्पेकट्रमि किरणता का विचरण +/- 5% के भीतर ही रहा है, जो एक उल्लेखनीय परिणाम है।

चित्र-3



सुदूर संवेदी उपग्रहों द्वारा पृथ्वी के संसाधनो का छायांकन

विवेक शर्मा,

आंकड़ा संसाधन विभाग/ सिग्नल एवं प्रतिबिम्ब संसाधन एरिया / सेक

ईमेल: विवेक@सेक.इसरो.गव.इन {vivek@sac.isro.gov.in}

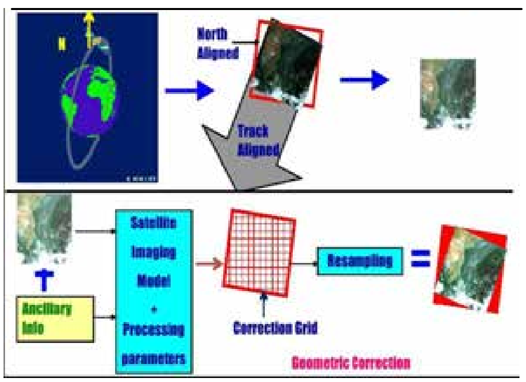
उपग्रह तकनीक में हासिल महारत ने मानव प्रजाति की उन्नति को नए आयाम तक पहुचाने में अहम भूमिका निभायी है| आज उपलब्ध अद्यतन संचार माध्यम और पृथ्वी के संसाधनों का नए तरीके से अध्ययन इत्यादि इसी वजह से संभव हो पाए हैं| सभी मानव निर्मित उपग्रह इलेक्ट्रो-मैग्नेटिक(विद्युत चुम्बकीय) विकिरणों के अलग अलग क्षेत्रों में कार्य करते हैं| इन उपग्रहों को भू स्थिर, सुदूर संवेदी, संचार इत्यादि प्रकार में बांटा जा सकता है| यहाँ हम सुदूर संवेदी उपग्रहों की चर्चा करेंगे|

सुदूर संवेदी उपग्रह पृथ्वी के संसाधनो को नियमित अंतराल पर छायांकित करने की विशिष्ट सुविधा प्रदान करते हैं| सुदूर संवेदी उपग्रह राडार, दृश्य(ऑप्टिकल) अथवा भू स्थिर उपग्रह हो सकते हैं| इनमे से कुछ (जैसे रडार) सक्रिय संवेदक होते हैं जो स्वतः विद्युत चुम्बकीय विकिरणों को प्रेषित और वस्तुओं द्वारा परावर्तन के बाद अवशोषित करते हैं| सक्रिय संवेदक रात के समय भी चित्रण की सुविधा प्रदान करते हैं, ऑप्टिकल सुदूर संवेदक सूर्य की रौशनी का प्रयोग करते हैं इसलिए रात में प्रतिबिंबिन नहीं करते| ऐसे संवेदक रात के समय आंकड़ा प्रेषित कर सकते है, इसलिए ओ.बी.एस.एस.आर (ऑनबोर्ड ठोस अवस्था रिकार्डिंग और डंप) व्यवस्था के तहत कार्य करते हैं| इसमें भू एंटीना की दृश्य सीमा से बाहर चित्रण करके ऑनबोर्ड मेमोरी में स्टोर कर उसे बाद में भूकेंद्र पर प्रेषित करते हैं|

पृथ्वी के पदार्थ अपनी बनावट व प्रकृति के अनुसार अपने ऊपर आने वाले विकिरणों को परावर्तित, अवशोषित, पुंनः परावर्तित अथवा पुनःप्रेषित करते हैं | हर पदार्थ के द्वारा प्रेषित सिग्नल का अपना एक खास हस्थाक्षर होता है, जिसे (signature) सिग्नेचर कहते हैं, इससे उस पदार्थ को उपग्रह प्रतिबिम्ब में पहचानने और उसके अध्ययन में सहायता मिलती है| उपग्रह पर मौजूद संवेदक इन परावर्तित विद्युत चुम्बकीय विकिरणो को अवशोषित कर चित्रण के दौरान इन सिग्नल्स को डिजिटल बिट्स में परिवर्तित कर ऑनबोर्ड मेमोरी में स्टोर कर देता है अथवा तुरंत प्रेषित कर देता है| उपग्रह पर मौजूद संवेदक (केमरा) चित्रण के लिए एक सुव्यवस्थित व्यवस्था पर काम करता हैं (जैसे पुश ब्रूम जिसमे कई डिटेक्टर एक रेखीय चित्रण करते है)| ऑप्टिकल संवेदको के चित्रण का परिणाम इलेक्ट्रिकल सिग्नल्स की तरह होता है जिसका सीधा सम्बन्ध चित्रित पदार्थ की विशिष्टताओं से होता है|

वास्तविक समय के आँकड़ा स्थानांतरण में भूकेंद्र पर स्थित एंटेना उपग्रह के अवलोकन/ट्रेसिंग परिधि में आने पर, भूकेंद्र पर स्थित आँकड़ा अधिग्रहण व्यवस्था से प्रेषित सिग्नल को आंकड़ा के रूप में टेप्स पर अथवा डिस्क सिस्टम्स पर स्टोर कर देते है! इसके लिए आँकड़ा अधिग्रहण व्यवस्था द्वारा सर्वप्रथम प्रेषित सिग्नल को बिट सिरियालिजर द्वारा संसाधित करके

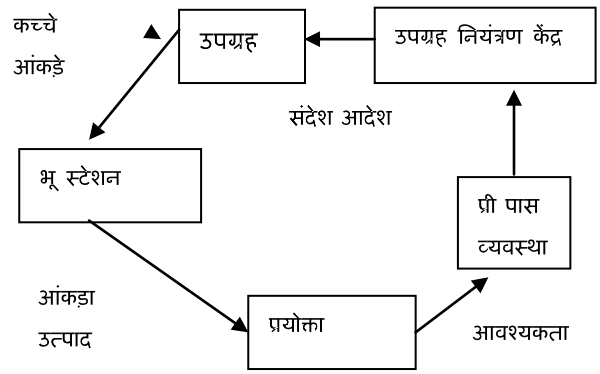
सीरिज इनपुट लेकर फ्रेम्स में परिवर्तित करते हैं और ग्राउंड सेगमेंट कंप्यूटर इन फ्रेमड बिट्स को फ्रेम डिटेक्शन,सेपरेशन व डिकम्प्रेशन करके संवेदक के अनुसार स्टोर करते है| इसके बाद आंकडा प्री-प्रोसेसिंग प्रारंभ होती है, जिसमे कंप्यूटर सॉफ्टवेर द्वारा इन आकडों से समय, उपग्रह की स्थिति, छायाँकन के समय, गति ओर उपग्रह स्थित संवेदक का ज्ञान प्राप्त



चित्र १: आकड़ा प्रेषण, अभिग्रहण और उत्पाद जनन श्रृंखला

सर्वप्रथम कार्यादेश से उपयुक्त पैरामीटर और कच्चे आंकड़ों के साथ दृश्य रूप से सही आंकड़े तैयार किए जाते हैं। चित्र पर स्थित पिक्सल को भो भू स्थित वस्तु से संबद्ध करने के साथ ही उसके अक्षांश/देशांश/समय/ऊँचाई ज्ञात करने के लिए गणितीय सिद्धांतों द्वारा उपयुक्त गणना कर के चित्र को भू लिन्क(मैपिंग अथवा भू स्पेस में चित्र जनन) किया जाता है| किसी भी प्रयोक्ता द्वारा चाहे गए उत्पाद को एक कार्यादेश में विश्लेषित किया जाने के बाद "संसाधन और उत्पाद जनन श्रृखंला" की पूर्व निर्धारित प्रक्रिया से उत्पाद बनाते है , जिसे पूर्व निश्चित उत्पाद फार्मेट (पदक्रम आंकड़ा फार्मेट-HDF या GEOTIFF), में आंतरिक फार्मेटिंग के बाद CD/DVD पर उपभोक्ता को दिया जाता है। इन उत्पादों का उपयोग मेप इत्यादि बनाने, संसाधन आकलन, शहर/मौसम-अनुमान,

करते हैं| इसमें एन्सिलरी आंकड़ों को अलग करके उनके द्वारा आंकड़ा जांच और गुणवत्ता मूल्यांकन होता है! इस तरह संचित आकडों को उपग्रह के चित्रण सिधांत के अनुसार चित्रण की परिकल्पना का प्रयोग कर चित्रों में बांटा जाता हैं | चित्र १ में उपग्रह के चित्रण और आंकडा संसाधन के बारे में बताया गया है|



चित्र २: उपग्रह, उत्पाद, भू-व्यवस्था और प्रयोक्ता श्रृंखला

समुद्रिक क्रियाकलापों की निगरानी, नैसर्गिक संसाधनो की मेपिंग, आकलन और गणना इत्यादी में होता हैं|

उपग्रह की भू व्यवस्था की प्रक्रिया को चित्र २ में बताया गया है| उपग्रह नियंत्रण केंद्र उपग्रह के रख रखाव, सुचारू व्यवस्था और आदेश-संदेश का नियंत्रण करता है| उपभोक्ता को अनुप्रयोगों हेतु प्रतिबिंबित आंकड़े उत्पाद उपलब्ध कराने हेतु भू केंद्र प्री पास अनुमान और उपग्रह नियंत्रण केंद्र द्वारा अपेक्षित स्थान के आकडा अर्जन की सुविधा देता है, इसमें आवश्कता पड़ने पर तात्कालिक अर्जन भी संभव है| अंतरिक्ष उपयोग में उपग्रहों के द्वारा प्रेषित आंकड़ों के अभिग्रहण, सुलभ प्रस्तुतिकरण और शीघ्र वितरण मे इस व्यवस्था का अपना अलग स्थान है|

ISRS-AC Activities

World Environment Day (WED) Celebration

This year, the World Environment Day (5th June) was celebrated by ISRS-AC on 16th June. The events were organized at a place called, 'The Serenity Library' which is situated on Koteshwar-Bhat road, which is about 5 Km from the Ahmedabad airport. At the midst of a beautifully landscaped botanical garden the nature library is like an oasis located far from the madding crowd of the city. The purpose of the library is to imbibe and educate school children about their rich natural heritage. The program was attended by around 70 school children.

The WED events started with a walk through the lush green fields. The participants were shown a variety of trees and birds.

The nature walk was followed by drawing/painting competition amongst the school children, categorized into three different groups. Children of SAC members, and NGOs like Shreyas foundation, Kavita foundation, and also the under privileged children from Ramdevnagar area actively participated in this event. Their colourful paintings depicted ideas for saving the natural resources for the development of a better world in the years to come.

Shri Jagat Kingkhabwala, the expert environmentalist, delivered an interesting talk and presented a video on 'Agri-waste management, kitchen waste management and water conservation'.

The talk evoked significant response from the little participants. The wholehearted involvement of the children of SAC employees along with the under privileged children from different NGOs of Ahmedabad, made the event a great success. It ended with the prize distribution ceremony.

Celebrating One year of RISAT-1

ISRS-AC jointly celebrated one year of RISAT-1 with Faculty of Geomatics and Space Applications, CEPT University and other professional Societies at Faculty of Geomatics and Space Applications, on April 27th 2013. A brain storming session was organized on 'RISAT-1, Professional Societies and Academia'. 37 professionals participated in the programme, with more than half participation from different academic institutes like Nirma University, M G Science institute, PDPU, Gandhinagar etc.

Dr Parul Patel informed the gathering regarding background and the purpose of organizing such a brainstorming session. Shri R P Dubey and Shri D R M Samudraiah gave their guidelines on how to increase the interaction between the academia and the professional societies which would enhance research activities. Prof. Nagendra Gajjar, expressed his happiness for initiative taken by the professional societies in this direction. Dr. Dhaval Pujara talked about the need of such interactions.
In his opening remarks, Shri Tapan Misra took the gathering through a journey of 'Making of RISAT'. Shri Nilesh Desai emphasized on furthering academia involvement in research activities.

Academia participants informed about various research activities taken up by them and their views on enhancing the participation of academia in advanced research. Shri Kirti Padia clarified a number of queries from participants regarding the RISAT-1 SAR data availability and about free data available on NRSC website and Bhuvan.

The programme exceeded its scheduled time limit as the participants were too engrossed in discussing how best to increase the interaction to notice the time. Every participant welcomed the brain storming session and expressed that it is a good step as a beginning towards the same. The gathering ended on a note that professional societies can provide a bridge between the professionals working in advanced research areas, and the academia.

The programme ended with the cutting of 'Birthday' cake on the occasion of one year completion of RISAT-1.

ISRS-AC National Remote Sensing Day celebrations

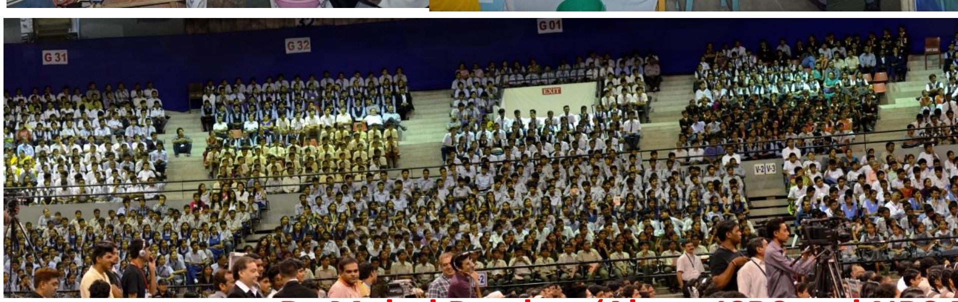
ISRS-AC celebrated "National Remote Sensing Day" (NRS Day) on August 09, 2013, Friday (on the eve of birthday of father of Space Science in India, Eminent Scientist and Educationist Dr. Vikram Sarabhai) jointly with St. Xavier's High School, Surat, which is also celebrating its Golden Jubilee. As part of the NRS day celebrations, Drawing, Essay and Science project competitions for secondary and higher secondary students along with Vikram Sarabhai Space Exhibition and screening of video programmes on space technology and its applications etc. were organised. Dr. Mehul Pandya explained about ISRS and NRS Day. The NRS Day celebration was a grand success with Hon'ble Former President of India, Dr. A P J Abdul Kalam inaugurating the exhibition. He

also delivered the Xavier's Golden Jubilee Commemorative Lecture on "Ignited Minds: The Power of the Nation-India" during the event. Shri D Subrahmanyam briefed about the relevance of the programme. Dr Parul Patel delivered a popular talk in Gujarati on “સુદર સંવેદન અને તેના ઉપયોગો” . More than 5000 students from 58 schools, including schools from rural areas, and more than 50 ISRS-AC members participated in the event. Prizes to the winners of three competitions were given by ISRS-AC members. Shri K M Rana presented the Vote of Thanks. Following gives glimpses of the event.

Inauguration of the exhibition by Hon'ble Former President of India Dr A P J Abdul Kalam

Winner drawings of competition on "My clean and green planet earth"

Students' Science Project Competition



Dr Mehul Pandya: 'About ISRS and NRS Day'


Hon'ble Former President of India
Dr APJ Abdul Kalam: *Ignited Minds: The Power of the Nation-India*
Shri D Subrahmanyam on Relevance of the programme
Popular talk by Dr Parul Patel
Vote of Thanks by Shri K M Rana
Presenting Memento to School
Prize distribution to the winners of NRS Day competitions

ISRS-AC and St. Xavier's Team

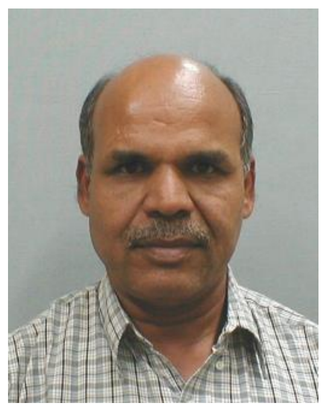
Enjoying the journey and tea break on bank of the Narmada river

FEEDBACK

Name: ***S. M. Bhandari***   **Feedback:** Thank you for mailing me PDF file of the Signatures Jan.- Mar. 2013 Sp. issue. It looks highly impressive. I am sure you must be planning to print a limited number of copies, as has been the tradition. As an author of one of the invited articles, I would request and very much appreciate if a Printed Copy of the issue is made available to me as reference.
Name: ***G. Raju***   **Feedback:** Climate Change is a vast subject, but you have brought out the central theme in a good collection of papers in nearly 100 + pages. Once again my compliments to you and the team for the quick publication of a very important publication on one of the most current topics. With this good beginning, it should be indeed possible for you to bring out a more comprehensive issue addressing instrumentation aspects, Geo-physical parameters, the products, retrievals, modelling and applications in weather-forecasting and climate studies in general.
Name: ***C. Prabhakar***   **Feedback:** Thanks Arundhati for the beautiful newsletter.

SUPERANNUATION

Shri D R M Samudraiah
April 2013



Shri N. S. Mehta
March 2013

Upcoming Events

The National Symposium on "*REMOTE SENSING AND GIS FOR ENVIRONMENT With Special Emphasis on Marine and Coastal Dynamics*" and Annual Conventions of ISRS and ISG will be organized jointly by ISG and ISRS during December 4-6, 2013 at Visakhapatnam.

A two-day workshop on "Innovative Learning Tools 2013 with specific emphasis on Earth Resources Management" will be held at CEPT University during 20-21 December, 2013. Details are available at www.isprs2013-cept.in

An international conference on "Geospatial Momentum for Society and Environment: AGSE2013" will be hosted by CEPT University in collaboration with Institute of Technology, Stuttgart University, Germany during 16-20 December, 2013. The details are available at www.agse2013-cept.in

AWARDS

RAFI AHMED KIDWAI AWARD

Dr Jai Singh Parihar, Deputy Director, EPSA, SAC, was awarded the Rafi Ahmed Kidwai Award for Outstanding Research in Agriculural Sciences 2012 by the Indian Council of Agricultural Research

ISRO AWARDS – 2010 & 2011

Name	Award
Dr. J. S. Parihar	Performance Excellence Award-2010
Shri Arup Roy Chowdhury	Merit Award – 2010
Shri Nilesh M. Desai	Merit Award – 2010
Shri Santanu Chowdhury	Merit Award – 2011
Dr.(Mrs) Sushma Panigrahy	Merit Award – 2011
Shri Pankaj Kanti Nath	Young Scientist Merit Award - 2010
Shri Ritesh Kumar Sharma	Young Scientist Merit Award - 2010
Shri Vishnukumar D. Patel	Young Scientist Merit Award - 2010

From The Editor's Desk

" Shoot for the moon. Even if you miss, you'll land among the stars."

Les Brown

I would like to remind our esteemed readers of ISRS-AC, that during the last one year three volumes of the Signatures with theme based articles have come out. The feedback from some of our readers have been quite encouraging, in this regard. We have tried our best, to keep interesting and informative themes as far as possible. This special issue will be panning through some of the interesting topics in the fields of Data Processing and Retrieval Algorithms.

We have taken a special interview of one of the eminent scientists in the field of Systems and Data Processing, Dr V Jayraman, Senior Advisor (Space Applications) & Satish Dhawan Professor at ISRO Headquarters, Bangalore. and former Director, EOS, and NRSC. We are extremely grateful to him, for sparing his valuable time and responding to our queries. I am sure this will enable our readers to connect to the vision and contributions of such a great scientist and a leader.

I would like to extend my heartiest congratulations to the editorial team for their enthusiasm and efforts. I am also thankful to the Guest Editor, Dr R Ramakrishnan, who took a keen interest in this special issue and for providing all the help needed for making this 'Signatures' a reality. We are extremely thankful to Sri D Subrahmanyam, Chairman ISRS-AC, Sri D R M Samudraiah, Vice-President, ISRS, and Dr Parul Patel, Secretary, ISRS-AC for their constant help and guidance in bringing out this issue.

We are also including the feedbacks from our readers about the past issue, and on some of the events organised by ISRS-AC.

It will be our utmost pleasure, to get more feedback from our readers, which will help us in improving the quality of the forthcoming 'Signatures' .
Best wishes and happy reading.

Arundhati Misra(Ray)
Editor, ISRS_AC

Signatures

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Ahmedabad Chapter
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ISRS-Ahmedabad Chapter

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The cover page was designed by **Indranil Misra**