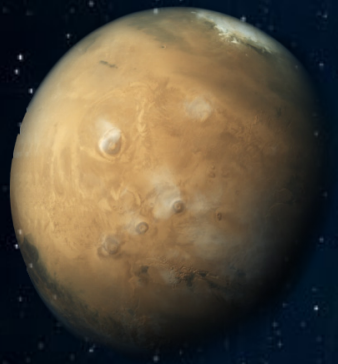
SPACE RESEARCH IN INDIA

(January 2016 – December 2017)



Presented to 42nd COSPAR Scientific Assembly Pasadena, California | July 14-22, 2018

Start

SCIENTIFIC REPORT

SPACE RESEARCH IN INDIA

(January 2016 – December 2017)

A Report of the

Indian National Committee for Space Research (INCOSPAR)
Indian National Science Academy (INSA)
Indian Space Research Organization (ISRO)

For the
42nd COSPAR Scientific Assembly
14 July – 22 July 2018
Pasadena
California, USA

INDIAN SPACE RESEARCH ORGANISATION
BENGALURU

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Cover Page Images:
Left: Global image of Mars taken on 8th Oct 2017
Right: Colour composite image of NGC 1851 - UVIT images of AstroSat

FOREWORD
PREFACE
COMPOSITION OF THE INDIAN NATIONAL COMMITTEE
CHAPTER-1 ORGANISATION AND FACILITIES
CHAPTER-2 PHYSICAL RESEARCH LABORATORY
CHAPTER-3 NATIONAL ATMOSPHERIC RESEARCH LABORATORY
CHAPTER-4 SPACE PHYSICS LABORATORY, VSSC
CHAPTER-5 SPACE ASTRONOMY GROUP, URSC
CHAPTER-6 U R RAO SATELLITE CENTRE
CHAPTER-7 SPACE APPLICATIONS CENTRE
CHAPTER-8 NATIONAL REMOTE SENSING CENTRE
CHAPTER-9 NORTH EASTERN SPACE APPLICATIONS CENTRE
CHAPTER-10 INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
CHAPTER-11 THUMBA EQUATORIAL ROCKET LAUNCHING STATION
CHAPTER-12 SEMI-CONDUCTOR LABORATORY
CHAPTER-13 INDIAN INSTITUTE OF REMOTE SENSING
CHAPTER-14 TATA INSTITUTE OF FUNDAMENTAL RESEARCH
CHAPTER-15 INDIAN INSTITUTE OF ASTROPHYSICS
CHAPTER-16 INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS
CHAPTER-17 RAMAN RESEARCH INSTITUTE
CHAPTER-18 ARYABHATTA RESEARCH INSTITUTE OF OBSERVATIONAL SCIENCES
CHAPTER-19 NATIONAL GEOPHYSICAL RESEARCH INSTITUTE
CHAPTER-20 INDIAN INSTITUTE OF GEOMAGNETISM
CHAPTER-21 INDIAN CENTRE FOR SPACE PHYSICS
CHAPTER-22 S N BOSE NATIONAL CENTRE FOR BASIC SCIENCES
CHAPTER-23 RESEARCH ACTIVITIES AT OTHER UNIVERSITIES AND CENTRES
23.1 Banaras Hindu University
23.2 Bangalore University
23.3 Dibrugarh University
23.4 Pune University
23.5 S.K. Mitra Centre, University of Calcutta

FOREWORD

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FOREWORD

It is my extreme privilege to present the INCOSPAR report to the 42nd COSPAR assembly to be held at California, USA during July 2018.

Every country needs effective usage of space assets for self reliance and development. In India, the primary responsibility of promoting the development of space science, technology and applications is entrusted to the Department of Space (DoS).

The last two year period has been remarkable for ISRO due to its achievements and advancements in almost all fields of space science, technology and applications. It gives me immense pleasure to mention few of the achievements.

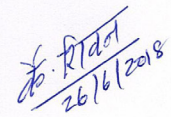
The successful launch of GSLV-MKIII D1, capable of placing 4 ton satellite into a Geosynchronous Transfer orbit was the most exciting milestone in 2017. It has placed first Indian high throughput satellite (HTS) in orbit. During February, 2017, Polar satellite launch vehicle (PSLV) successfully launched 104 satellites, including satellites from 6 countries. All satellites were separated successfully from the vehicle in a predetermined sequence and were placed in precise orbits. South Asia Satellite, a gift from India to neighboring countries was successfully launched during May, 2017, to establish smooth communication network amongst the South Asia nations in Ku Band. PSLV injected Cartosat-2 Series Satellite along with another 30 Satellites during June, 2017. The significant achievement in this mission was the restart of fourth stage twice in order to lower the orbit. This mission was aided with NavIC data as primary source of navigation for engine start phases.

Towards achieving self reliance in weather forecasting and monitoring, GSLV successfully launched INSAT-3DR during September, 2016. Another launch of PSLV carried SCATSAT-1, a unique scatterometer mission for weather forecasting and cyclone detection along with seven co-passengers, for the first time in two different orbits during September, 2016. Resourcesat-2A, a powerful three tier imaging system for natural resources survey was successfully launched by PSLV during December, 2016.The robustness of satellite design and the expertise in Mission Management is proved in terms of Mars Orbiter mission (MOM). A diligent orbit maneuver shortened the long eclipse duration from 480 minutes to 100 minutes. MOM has completed three years in orbit and is still providing high quality images/data.

In addition, ISRO is presently working on Chandrayaan-2 mission which aims for a precise landing on lunar surface and a Rover for in-situ measurements of lunar soil.

As part of advance launch vehicle technology initiatives, research and development got boosted through the successful testing of RLV-TD and SCRAMJET engine Technology Demonstrator in 2016. Critical technologies needed for human spaceflight were identified and being developed in the pre-project phase.

This report gives a summary of activities and achievements for the years 2016-17 at ISRO and various other institutions in India involved in Space Research. I sincerely hope that this information strengthens the existing cooperation and creates new ones among the global space community. I wish the 42nd COSPAR a very big success.



Bangalore
Date: June 26, 2018

(K.Sivan)

PREFACE

It is a pleasure to introduce the report on Space Research in India, prepared for the 42nd COSPAR Scientific Assembly, 14 July – 22July 2018, California, USA , by the Indian National Committee for Space Research (INCOSPAR), Indian National Science Academy (INSA), and Indian Space Research Organization (ISRO). The report gives an overview of the important achievements and research activities carried out in India in many areas of near- Earth's space, Sun and astrophysics during the years 2016 and 2017. It also reflects the major facilities for space research available in India and the important results coming out from the observations using these facilities. The report summarizes the contributions from various ISRO centers, national institutes laboratories, and universities.

The period spanning the years 2016 and 2017 witnessed noteworthy developments on many fronts along with significant growth in research, academic and technical activities.

It is heartening to note that in the Thirty Meter Telescope (TMT) project, the world's most advanced ground-based observatory in optical and mid-infrared wavelengths, the design configuration analysis was completed for the Wide Field Optical Spectrograph (WFOS).

Dual Polarimetric Doppler Weather Radar at Cherrapunjee, Meghalaya, developed indigenously by North East SAC(NESAC), ISTRAC, Bangalore and India Meteorological Department (IMD) to support operational services for disaster management, was inaugurated and dedicated to Nation on 27 May, 2016. The DWR is currently operated on 24 X 7 basis and data made available to researchers and operational forecasters in near real time.

The MST radar has been upgraded into a full-fledged active phased array system. Capability of the new system to probe different regions of the atmosphere has been successfully demonstrated.

In Space Sciences, the major mile stone has been India's Mars Orbiter Spacecraft launched by PSLV-C25, successfully completing 3 years in its orbit on 24th Sept 2017. For better utilization, a Planetary data analysis workshop in collaboration with NASA during Feb 2016 was conducted. Images of the full Martian disc with a single snap shot imaged the far side of Deimos for the first time. A study on the Mars Polar Ice cap was taken up. Nine images of the Northern Mars Polar Cap by Mars Colour Camera (MCC) on-board, were photometrically corrected and a complete mosaic of north polar ice cap of Mars was developed, super-imposed over topography data of Mars and a vertical distribution of ice over north polar region of Mars was generated. High resolution DEMs of the light toned mounds in Juventae Chasma, Mars generated using HiRISE and CTX images suggests that some of the light toned units are likely to have been deposited prior to the dark toned units in Juventae Chasma.

ISRO has launched MOM Announcement of Opportunity (AO) programmers for researchers in the country to use MOM data for R&D motivating the scientific community in a big way.

AstroSat, India's first multi-wavelength observatory, successfully completed two years in orbit on September 28, 2017. One of the unique features of AstroSat mission is that it enables the simultaneous multi-wavelength observations of various astronomical objects with a single satellite. An Announcement of Opportunity (AO) was made in June 2016 for Indian researchers to explore the universe using AstroSat data.

The Ultraviolet Imaging Telescope (UVIT) has imaged hot stars, evolved stars, planetary nebulae, star clusters, star-forming galaxies, active galactic nuclei, cluster of galaxies in the distant universe. Cadmium Zinc Telluride Imager (CZTI) has detected over 172 Gamma Ray Bursts (GRBs) demonstrating the capability to detect polarization in GRBs and Crab. Scanning Sky Monitor (SSM) has detected Aql X-1 a neutron star Low mass X-ray binary in its outburst on June 01, 2017. It has been reported as Atel # 10452.

The Astrosat satellite is being operated as an "Observatory", in which observing time is allotted based on the proposals received from interested researchers and scientists in the country, through ISRO's Announcements of Opportunity (AO). From October 2017, the observatory is open to Indian and International astronomy community.

Several interesting scientific outcomes have emerged from Chandrayaan 1: Discovery of endogenic/exogenic water on the Moon at Giordano Bruno crater from the Integrated analyses of Chandrayaan-1 Moon Mineralogy Mapper (M3) data and LRO Mini-RF data.

The Sub-keV Atom Reflecting Analyzer (SARA) with a neutral atom sensor CENA (Chandrayan-1 Energetic Neutrals Analyzer), and an ion mass analyzer, namely 'Solar Wind Monitor' (SWIM) have yielded several path breaking results on the solar wind interaction with the Moon, and on the lunar environment. The recent findings from the SARA experiment led to the discovery of a new population of Suprathermal protons around Moon and the first observation of Energetic Neutral Atoms from the Lunar Night side Surface. Compositional studies of Mare Moscoviense with New perspectives from Chandrayaan-1 VIS-NIR data indicates that the concentrations of orthopyroxene, olivine, and Mg-rich spinel, named as OOS rock family are widespread and dominant at the western and southern side of the middle ring of the basin with one isolated area found on the northern side of the peak ring.

Saraswati supercluster located in the Stripe-82 region of Sloan Digital Sky Survey (SDSS) is the first major discovery of its kind made in India by researchers based in IUCAA and in three Indian universities. This supercluster extends over an astonishingly large physical scale of ~ 200 Mpc, and contains a minimum mass of 2×10^{16} suns in at least 48 massive galaxy clusters and groups at the same redshift. This is possibly one of the most massive structures observed in the Universe so far, whose existence challenges the prevailing cosmological theories.

Several interesting studies to understand the Galactic structure in the solar neighborhood through parameters like scale height, solar displacement and local mass density, etc to probe the Galactic disk in the immediate solar neighborhood were taken up.

A new scenario of heliospheric plasma sheet impingement onto the magnetosphere giving rise to relativistic electron dropouts (REDs) due to their scattering by EMIC wave has been proposed. It has several important consequences for the climate change.

During the past two years, the Indian space community has been very active in carrying out investigations in many diverse areas related to Astronomy and Astrophysics, Solar Physics, Space and Atmospheric Sciences, Planetary Sciences, Geomagnetism and Geosciences. Observations have been made using various tools, like optical, radio, X-ray and gamma-ray telescopes, radars, Lidars, broadband seismometers, Satellite Meteorology and other Remote sensing techniques. The report describes highlights of the research outcome from the studies on Ionosphere, Magnetosphere, Solar Wind and Space Weather; Earthquake precursors, Oceanography, Atmospheric Structure and Dynamics; Cloud and Convective System; Aerosols, Radiation and Trace Gases, Weather and Climate Change, Sun and the solar system, stars, Galaxies, extragalactic astronomy and cosmology.

I would like to thank all the scientists who sent the inputs on the space research activities being carried out in their respective Institutes/Departments in time to prepare this report. I would like to acknowledge the hard work put in by Dr. S. Seetha, Advisor, Space Science Programme Office, ISRO HQ, Bangalore, and her team members for compiling and editing the report on behalf of INCOSPAR.

(Gurbax Singh Lakhina)

Chairman, INCOSPAR

COMPOSITION OF THE INDIAN NATIONAL COMMITTEE
FOR
SPACE RESEARCH (COSPAR), RADIO SCIENCE (URSI) AND SOLAR-TERRESTRIAL PHYSICS (SCOSTEP)

January 1, 2016 to December 31, 2019

Prof. G.S.Lakhina	---	Chairman
Dr. Anil Bhardwaj	---	Member
Dr. A. Patra	---	Member
Dr. S. Seetha	---	Member
Dr. D. Guha	---	Member
Prof. J. Padmanabhan	---	Member

January, 2012 – December, 2015

Prof. Archana Bhattacharyya	---	Chairman
Prof. S. Ananthakrishnan	---	Member
Prof. A. Jayaraman	---	Member
Prof. Animesh Maitra	---	Member
Prof. K. Niranjan	---	Member
Dr. Anil Bhardwaj	---	Member
Dr. P. Janardhan	---	Member
Dr. Ramesh Koul	---	Member

CHAPTER - 1
ORGANISATION AND FACILITIES

1. ORGANISATION OF SPACE RESEARCH

- **INDIAN NATIONAL COMMITTEE FOR SPACE RESEARCH (INCOSPAR)**

INCOSPAR is one of the committees of the Indian National Science Academy (INSA), which is the national adhering organisation to the International Council of Scientific Unions (ICSU), and a member of ICSU Council. Prof. G.S. Lakhina is the present Chairman of the Indian National Committee for Committee on Space Research (COSPAR) Solar-Terrestrial Physics (SCOSTEP). With respect to INCOSPAR, the committee has the following terms of reference:

i). To recommend and promote national activities and international co-operation in space exploration and space research.

ii). To provide necessary liaison with the COSPAR of ICSU, and encourage participation in international activities which contribute to the peaceful uses of outer space.

- **SPACE COMMISSION, DEPARTMENT OF SPACE AND INDIAN SPACE RESEARCH ORGANISATION**

The Space Commission and the Department of Space (DOS) were established by the Government of India in 1972 to promote development and application of space science and technology for identified national socio-economic objectives. The Space Commission lays down the framework of important space activities and advises the Government on major policies related to India's space programme. DOS functions directly under the Prime Minister of India. Dr. K. Sivan is the present Chairman of the Space Commission, Secretary to the Government of India in DOS and Chairman of the Indian Space Research Organisation (ISRO).

The Indian Space Programme is directed towards the goal of self-reliant use of space science and technology for national development, its main thrusts being:

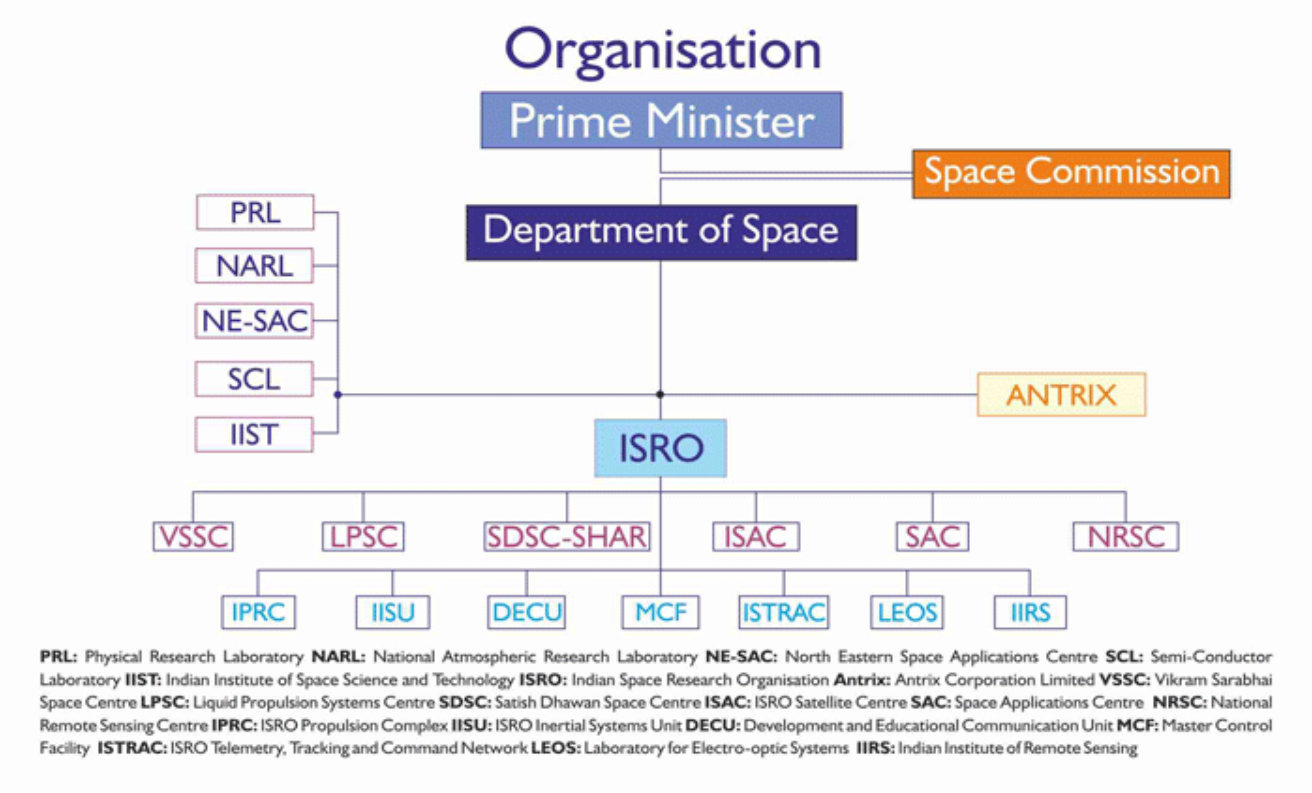
i). Satellite telecommunications, navigation, television and radio broadcasting

ii). Satellite remote sensing for resource survey and management, environmental monitoring and meteorological services.

iii). Development and operationalization of indigenous satellites and launch vehicles for providing these services.

DOS is responsible for carrying out space research and related activities in the country through ISRO's constituent units and major autonomous institutions. DOS is also the nodal department for implementation of the on-going National Natural Resources Management System (NNRMS).

The Organisation chart for Department of Space, ISRO and its major establishments are shown in Fig.1



Organisation chart of DOS/ISRO
Fig 1

PRL: Physical Research Laboratory, NARL: National Atmospheric Research Laboratory, NE-SAC: North Eastern Space Applications Centre, SCL: Semi-conductor Laboratory, IIST: Indian Institute of Space Science and Technology, ISRO: Indian Space Research Organisation, ANTRIX: Antrix Corporation Limited, VSSC: Vikram Sarabhai Space Centre, LPSC: Liquid Propulsions System Centre, SDSC: Satish Dhawan Space Centre, ISAC: ISRO Satellite Centre, SAC: Space Applications Centre, NRSC: National Remote Sensing Centre, IPRC: ISRO Propulsion Complex, IISU: ISRO Inertial Systems Unit, DECU: Development and Educational Communication Unit, MCF: Master Control Facility, ISTRAC: ISRO Telemetry, Tracking and Command Network, LEOS: Laboratory for Electro-Optics Systems, IIRS: Indian Institute of Remote Sensing.

2. MAJOR ACHIEVEMENTS OF THE ORGANISATION:

The Stellar achievements of ISRO/DOS during 2016, 2017 in Launch Vehicle/Satellite Programmes and Space Science Programmes are:

ACHIEVEMENTS IN LAUNCH VEHICLE PROGRAMMES

- **PSLV:** Launch of three Indian Regional Navigation Satellites IRNSS IE,IF and 1G into a sub-Geosynchronous Transfer Orbit (GTO) to provide accurate real time positioning and timing services, by PSLV C31,32,33 in Jan, March and April 2016 respectively.

  Launch of SCATSAT-1 with seven co-passenger satellites in two different orbits for the first time on September 26, 2016 by PSLV-C35.This was the longest of the PSLV missions conducted till date. After the successful separation of SCATSAT-1, the PSLV-C35 mission continued, carrying the seven co-passenger satellites, and with precise reignition and manouering of the fourth Stage of PSLV, the other co_passengers separated successfully in the predetermined sequence.

  Launch of 104 satellites by PSLV C37on February 15, 2017 ISRO, into a sunsynchronous polar orbit (SSPO), with all the 104 satellites successfully separating from the PSLV fourth Stage in the expected sequence.

- **GSLV:** Equipped with the indigenous Cryogenic Upper Stage (CUS), GSLV-F05 successfully launched the country's latest weather satellite, INSAT-3DR, on September 08, 2016. This mission further demonstrated the reliability of CUS engine and stage developed by ISRO.

  In may 2017, ISRO was also successful in launching GSLV-F09, that could successfully place the South Asia Satellite GSAT-9 into GTO, which is a gift from India to SAARC nations

- **GSLV-MkIII D1:** The successful launch of GSLV-MkIII , India's most powerful launch vehicle, was one of the important highlights during 2017. GSAT-19 is the heaviest satellite to be launched from the Indian soil so far.

- **Technology demonstrators:** On May 23, 2016, the first flight test of India's Reusable Launch Vehicle(RLV-TD) was successfully conducted. On August 28, 2016, ISRO's SCRAMJET engine technology demonstrator was successfully flight tested.

  Besides, developmental efforts on semi-cryogenic engine are also being pursued for further enhancing the country's launch capability. Development of critical technologies for undertaking human spaceflight has also made progress during the reporting period.

ACHIEVEMENTS IN SATELLITE PROGRAMMES

- **Indian Remote Sensing (IRS) satellite system**

Resourcesat-2A, a powerful three tier imaging system for resource survey, was successfully launched by PSLV-C36 on December 07, 2016 It is a follow on mission to Resourcesat-2,that provides data continuity to the user with improved frequency. Three Cartosat-2 series satellites were launched on June 22, 2016, February 15, 2017 & June 23, 2017 aboard PSLV-C34, PSLV-C37 & PSLV-C38 respectively. The imageries from Cartosat-2 series satellites are useful for cartographic applications, urban and rural applications, infrastructure planning, coastal land use and regulation, utility management like road network monitoring, water grids or distribution, creation of land use maps, precision study, change detection to bring out geographical and manmade features and various other Land Information System (LIS) and Geographical Information System (GIS) applications.Though, Cartosat-1, Cartosat-2, RISAT-2, Oceansat-2, satellites have completed their design mission life in orbit; these satellites continue to provide imaging services for the remote sensing user community. Various instruments onboard these satellites provide data in varied spatial, spectral and temporal resolutions to cater to different user requirements in the country.

- **Meteorology satellites**

INSAT-3DR was launched on September 08, 2016 by GSLV F-05 launch vehicle and for improved geolocation accuracy and enhanced band to band registration. The radiometric measurements have been also improved using Black Body calibration. SCATSAT-1, a unique scatterometer mission, with a focus on weather forecasting services was launched on September 26, 2016 by PSLV-C35 to provide wind vector data products for weather forecasting,cyclone detection and tracking services. The satellite carries Ku-band Scatterometer similar to the one flown onboard Oceansat-2.

The INSAT series ofsatellites, with meteorological payloads operating from geostationary orbit, provide data for generating various parameters, namely, cloud motion vectors, cloud top temperature, water vapour content, vertical profiles of temperature and humidity and facilitate weather forecasting, genesis of cyclones and their track prediction, etc. Currently, KALPANA-1, INSAT-3D, Scatsat and INSAT-3DR are providing meteorological data to the user community.

- **Communication satellites**

Indian National Satellite (INSAT) system, established in 1983, is the largest domestic communication satellite system in the Asia Pacific Region with several commercial communication satellites in operation such as INSAT-4A, INSAT-4B, INSAT-4CR, GSAT-8, GSAT-10, GSAT-12, GSAT-14, GSAT-16, GSAT-15, GSAT-17, GSAT-18 and GSAT-19. These satellites are operating over India with communication transponders in C-band, Extended C-band, Ku-band and S-band. These transponders support services like television broadcasting, Direct-to-Home, VSATs, telecommunication, radio networking, Strategic communication and societal applications. ISRO has supported programmes like Telemedicine, Tele-education, Village Resource Centre (VRC) and Disaster Management Support (DMS), which are solely development oriented with an aim to address specific requirements at different Strata of the society.

GSAT-9 (South Asia Satellite) was launched onboard GSLV-F09 on May 05, 2017 GSAT-9 is a Geostationary Communication satellite realised with the objective of providing various communication services in Ku-band with coverage over South Asian countries. It is configured around the ISRO's Standard I-2K bus.

GSAT-19 satellite was launched on June 05, 2017 with a lift-off mass of 3,136 kg ,configured around ISRO's I-3K bus. It carries Ka / Ku-band high throughput communication transponders.. It was launched onboard first developmental flight GSLV-MkIII-D1. GSAT 9, 19 were launched from SDSC, SHAR. GSAT-18 configured around I-3K extended bus was launched by Ariane-5 on October 06, 2016 from Kourou, French Guiana.

GSAT-17 was launched on June29, 2017 from Kourou, French Guiana with payloads in Normal C-band, Extended C-band and S-band to provide various communication services. It also carries payload for data relay and satellite based search and rescue services.The satellite also has transponders in Extended C-band that provide connectivity to Antarctica.

- **Navigation satellite system**

NavIC, the Indian Regional Navigation Satellite System (IRNSS)

The NavIC is an ISRO's initiative to build an independent satellite navigation system to provide precise position, velocity and time to users over the Indian region. The NavIC System is designed to provide position accuracy of better than 20 meters over Indian land mass and a region extending to about 1500 km around India for a dual frequency user. NavIC provides two types of services, namely, Standard Positioning Service (SPS) which is provided to all users and Restricted Service (RS), which is an encrypted service provided to authorized users.

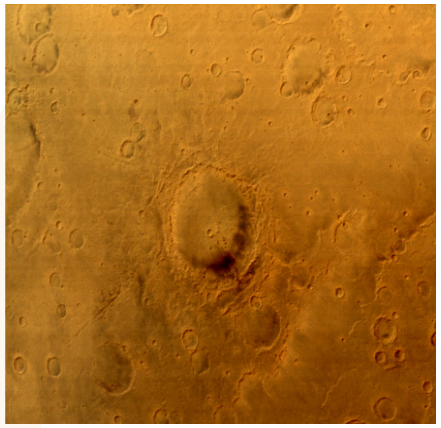
IRNSS constellation consists of seven satellites. While the first satellite of the constellation, IRNSS-1A was launched in July 2013, the constellation was completed in 2016. Ground Segment of the IRNSS is established for the maintenance and operation of the IRNSS constellation. The ground segment carries out satellite health monitoring, orbit corrections, uploading navigation data, etc activities round the clock.

ACHIEVEMENTS IN SPACE SCIENCE PROGRAMMES

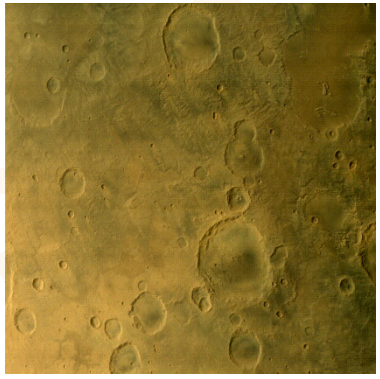
- **MARS ORBITER MISSION (MOM)**

Mars Orbiter Mission (MOM), the first interplanetary mission of ISRO, completed three years in its orbit on September 24, 2017 well beyond its designed mission life of six months. The health parameters of Mars Orbiter spacecraft are normal .The Mars Colour Camera (MCC) has produced 950+ images so far, one of which has appeared on the cover page of the November 2016 issue of the National Geographic Magazine. Some of the processed images taken by MCC are shown below in Fig 1.

Global image of Mars taken on 8th Oct 2017 at an altitude of 70157 km



Sabaeus quadrangle of Mars imaged on 27th May 2017 at an altitude of 4406 km.



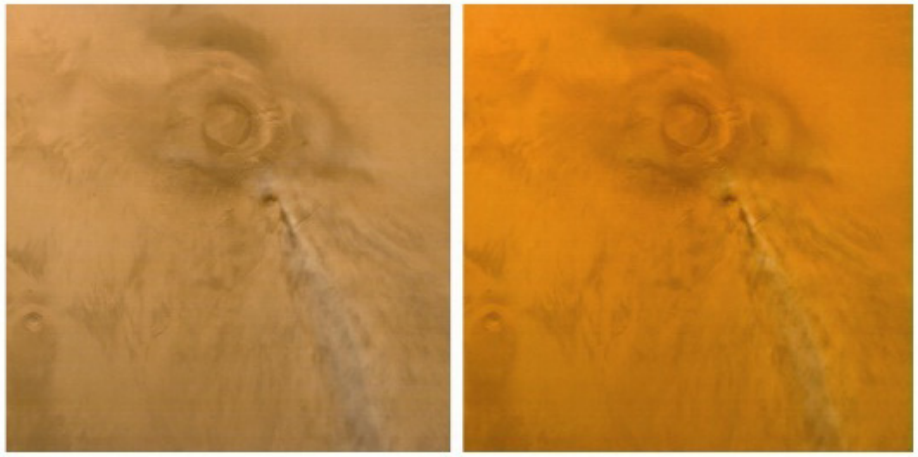
Eridania quadrangle of Mars image taken on 15th Mar, 2017 from an altitude of 3072 km

This picture of Margaritifer quadrangle of Mars was taken on 26th Dec 2016 at an altitude of 534 km

Fig 1

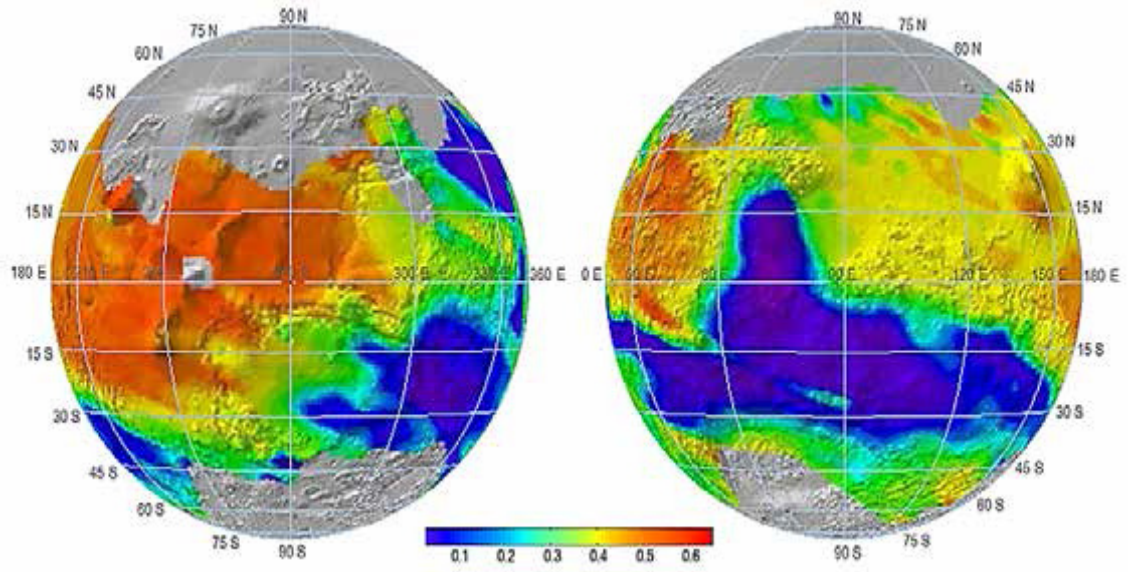
Mars Colour Camera (MCC) on-board the MOM makes use of a Bayer pattern detector. Spectral response of RGB (Red, Green and Blue) pixels of Bayer detector showed large overlap which reduced the spectral information content of the image. Scientists at ISRO developed a method to correct the MCC data for spectral overlap. It was shown that correction process significantly increased the spectral information content of the image

and enhanced the ability of the sensor to identify different target types like dust clouds and water ice clouds. The following figure 2 shows the image before and after overlap correction.



Composite image of Arsia Mons before and after overlap correction
Fig 2

Global apparent short wave infrared (SWIR 1.64 – 1.66µm) albedo mapping results from data from Methane Sensor for Mars (MSM) on-board MOM were prepared.



The one pixel per degree binned global MSM SWIR (1.65 m) albedo map over MOLA map.
Fig 3

The occurrence frequency of MSM apparent SWIR albedo showed a clear bimodal behaviour and is in good agreement with OMEGA NIR albedo distribution.

The outermost region of a planetary atmosphere, called the exosphere is the region being explored *in-situ* by theMars Exospheric Neutral Composition Analyser (MENCA) experiment onboard MOM. MENCA has discovered the presence of suprathermal Argon atoms. Neutral Gas and Ion Mass Spectrometer observations on the Mars Atmosphere and Volatile Evolution mission also indicate that such suprathermal atoms are present on certain days and significant wave-like perturbations are observed but only on certain days when suprathermal population is seen. The discovery has important implications in the context of understanding the energy deposition in the Martian upper atmosphere, and will help understand why the Martian atmospheric escape rates are higher than what was believed previously.

To avoid a long eclipse duration of 480 minutes, much higher than the battery's supporting capacity of 100 minutes, an orbit maneuver was carried out successfully on 17th January 2017 The MOM orbit was changed from 522 km x 70992 km to 465 km x 70866 km due to which, the total eclipse duration will not cross 90 minutes till 2021. MOM also successfully emerged out of second blackout (superior solar conjunction) in July 2017.

Science Meet of MOM

A 'MOM Science Meet' was conducted at ISRO HQ on 25th September 2017 on the occasion of three years completion of MOM in Martian orbit on 24th September 2017. During this occasion, the second year data of MOM (24th Sept 2015 to 23rd Sept 2016) was released to public through ISSDC website https://mrbrowse.issdc.gov.in/MOMLTA/

- ### ASTROSAT MISSION

  AstroSat, the first Indian Multi-wavelength space astronomy mission has completed two years in orbit on September 28, 2017. A unique feature of Astrosat mission is that it enables simultaneous multi-wavelength observations (optical, UV and X-rays) of various astronomical objects with a single satellite.

  An Announcement of Opportunity (AO) was made in June 2016 for Indian researchers to explore the universe using data from AstroSat. A one-day workshop was organised at Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune on September 2016, on the successful completion of one year, to highlight the technical and scientific achievements of this satellite.

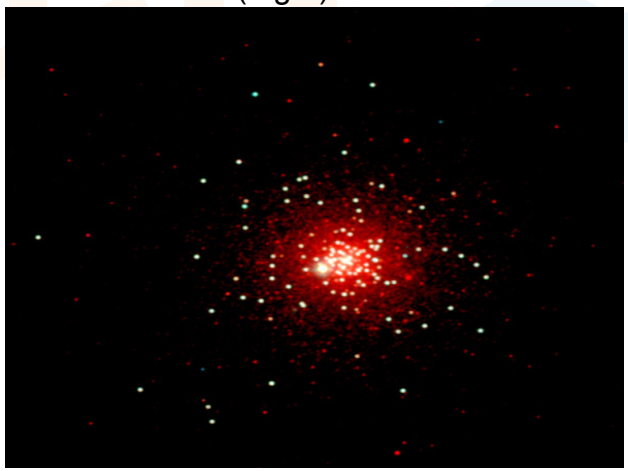
  The satellite is being operated as an "Observatory", in which observing time is allotted based on the proposals received from interested researchers and scientists in the country, through ISRO's Announcements of Opportunity (AO). From October 2017, the observatory is open to Indian and International astronomy community.

  The Ultraviolet Imaging Telescope (UVIT) imaged hot stars, evolved stars, planetary nebulae, star clusters, star-forming galaxies, active galactic nuclei, cluster of galaxies and Star formation history in the distant universe.

Wolf-Lundmark-Melotte, or WLM is a faint dwarf galaxy is located in the constellation Cetus which is 3 million light years away. Though it has low mass and less metallicity, WLM forms stars at a rate that is 12 times higher than our own Milky Way. The blue dots are the star clusters imaged in Far Ultra-Violet (130-180 nm) and the yellow dots are those imaged in Near Ultra-Violet (180-300 nm) Fig 4

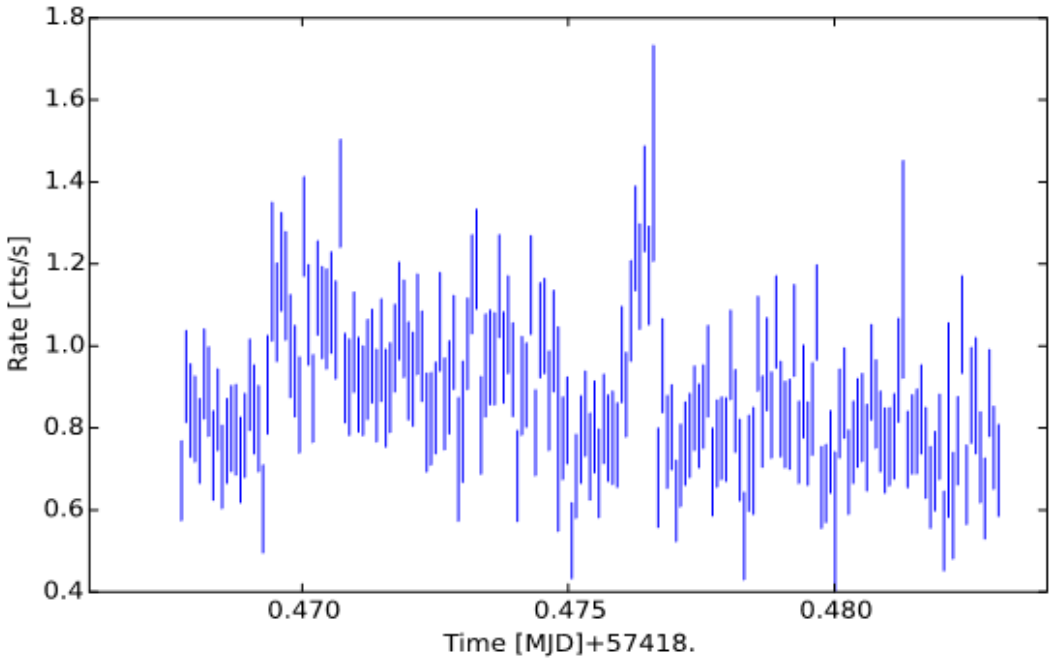
False colour composite image of WLM galaxy where FUV and NUV are displayed in blue and yellow colours respectively
Fig 4

NGC 1851 is a globular cluster located in the southern constellation of Columba. It appears to be surrounded by a diffuse stellar halo extending to radii of ~250 pc. 300 stars detected in FUV and 2300 stars in NUV. (Fig 5)



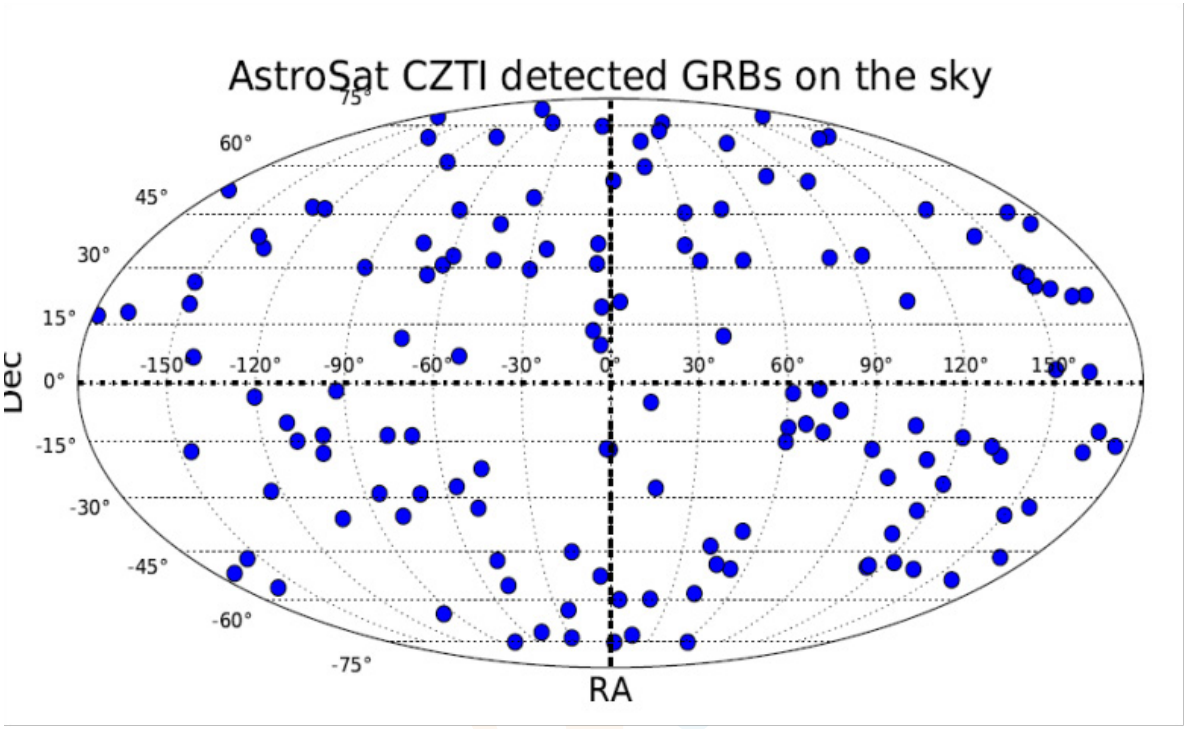
Colour composite image of NGC 1851 in which Blue and Red colors are UVIT images in FUV and NUV filters
Fig 5

Soft X-ray Telescope (SXT) has observed a variety of objects ranging from nearby active stars, X-ray binaries, supernova remnants to many types of distant active galaxies and clusters of galaxies. The X-ray light curve of a very rapidly rotating nearby active star known as AB Dor in the energy band 0.3 – 7.0 keV is shown below. A lot of flaring activity is observed which corresponds to the rapid rotation of the star. (Fig 6)



X-ray flaring activity of AB DOR
Fig 6

Large Area X-ray Proportional Counter (LAXPC) detected both kinds of milli-second variability i.e kHz Quasi-Periodic Oscillation (QPO) and Burst Oscillation (BO) in the low mass X-ray binary (LMXB) 4U 1728-34, from a single ~ 3 ksec observation, for the first time. **Cadmium Zinc Telluride Imager (CZTI)** has detected over 172 Gamma Ray Bursts (GRBs) (Fig 7). It has demonstrated capability to detect polarization in GRBs and Crab. One of the major results has been the observation of phase resolved polarisation of the Crab. CZTI team searched for X-ray counterparts to the third gravitational wave source GW170104. The speculated optical transient of this gravitational wave event was indeed identified to be corresponding to a GRB event GRB 170105A and not the gravitational wave event.



GRBs detected by CZTI
Fig 7

Scanning Sky Monitor (SSM) has detected Aql X-1 a neutron star Low mass X-ray binary in its outburst on June 01, 2017 at 08:55 UT. It has been reported as Atel # 10452.

A special section on AstroSat is published in the Journal of Astrophysics and Astronomy (June 2017) and in Current Science (August 2017).

- **CHANDRAYAAN-1, MOM DATA UTILISATION**

  In order to expand the planetary science community, projects using MOM data and Chandrayaan-1 data have been funded. ISRO has been supporting twenty eight MOM Announcement of Opportunity (AO) projects and nineteen Chandrayaan-1 AO projects centered at various academic institutes (IIT/NIT/Universities/other Institutes) since 2016. The main objective of supporting these projects is to expand and strengthen national scientific community which can have access and analyse the planetary/lunar data.

- **CHANDRAYAAN-2 MISSION**

The Indian space programme is gearing up for the next Lunar mission Chandrayaan-2 Chandrayaan-2, India's second mission to the Moon is a totally indigenous mission comprising of an Orbiter, Lander and Rover, which aims for a precise, soft and safe touchdown of the Lander on the Lunar surface The payloads will collect scientific information on lunar topography. mineralogy, elemental abundance, lunar exosphere and signatures of hydroxyl and water-ice.

To achieve a soft and safe landing, several advanced sensors are incorporated in the lander design. Engineering models of these sensors have been realized and tested during the Lander Sensor Performance Test (LSPT) phases-1 and 2. The first phase of the LSPT was completed in October 2016 & the second phase was completed in March 2017. All the sensors on LSPT were tested and their data was acquired for post processing.

The rover module will move on the lunar surface and will pick up soil or rock samples for in-situ chemical analysis. In order to test the rover on ground, a Lunar Terrain Test Facility similar to lunar soil has been established. Mobility tests to evaluate the Rover's wheel – soil interaction and the related constraints with respect to slope, boulder size etc have been verified.

- **ADITYA-L1 MISSION**

Aditya-L1 can provide observations on the solar corona the solar chromosphere using an UV payload and on the photosphere and flares using X-ray payloads. These payloads taken together are expected to provide a comprehensive understanding of how solar flares originate and propagate. In addition, the charged particle detectors and the magnetometer payloads can provide information on in-situ charged particles and the variations in magnetic field which arise due to eruptive events. To enable this, the Aditya-L1 spacecraft is to be placed in a halo orbit around the Sun-Earth Lagrangian point 1 (L1) which is about 1.5 million kilometre from the Earth.

Spacecraft configuration, thermal analysis, payload interfaces and mounting locations have been finalized. Payloads are under development.

- **X-ray Polarimeter Satellite (XPOSAT) MISSION**

The X-ray Polarimeter Satellite (XPoSat) mission is the dedicated mission for polarization studies. Polarimeter Instrument in X-rays (POLIX) payload will study the degree and angle of polarization of bright X-ray sources in the energy range 5-30 keV. The POLIX payload is being developed by Raman Research Institute (RRI), Bangalore.

3. SPACE SCIENCE RELATED ACTIVITIES/ PROMOTION SCHEMES AND PROGRAMMES

- **SPACE SCIENCE ACTIVITIES:**

► **Space Science research activities including balloon, rocket and satellite experiments, multi-agency sponsored projects** are all co-ordinated from ISRO HQ. ISRO's Advisory Committee for Space Science (ADCOS), represented by scientists of the country, recommends the conduct of various space science research activities and advises ISRO on the long term planning and promotion of space science research in the country. The detailed co-ordination and implementation of the space science programmes are carried out through the Space Science Programme Office (SSPO) at ISRO HQ.

► **Indian Space Science Data Center (ISSDC)**

The Indian Space Science Data Centre (ISSDC) is the state-of-the-art facility for hosting the data received from all space science missions of ISRO. Established ahead of the Chandrayaan-1 mission in 2008, ISSDC is known for its high-end servers and processing capabilities with enterprise-class data storage. ISSDC architecture is capable of supporting multiple missions in an automated and uninterrupted manner. This data centre, located at the Indian Deep Space Network (IDSN) campus in Bangalore, is responsible for the Ingest, Processing, Archive and Dissemination of the payload data and related ancillary data for Space Science missions. The primary users of this facility are the principal investigators of the science payloads. In addition to them, the data is made accessible to scientists from other institutions and also to the general public through registration, after the lock-in period.

Since its inception, ISSDC has served various missions and successfully caters the needs of project. During the year 2016 and 2017, the major upgradation and augmentation of data center activities were initiated to cater the requirements of existing and upcoming missions and refresh the ISSDC systems to avoid original equpment manufacturer (OEM) support issues. The entire data center upgradation has been carried out in well planned and phased manner which enables ISSDC to provide High End Computer systems, ~170 servers, High Performance Peta Scale storage Solution, SAN from 4G to 16G, LAN from 1G to 10G, Enterprise class tape library, High Bandwidth One Way Gateway (OGW), Up-to-date IT Security, Web Vulnerability Scanning (WVS) service, Multi-Homed Network for Internet Services, to name a few.

ISSDC has successfully supported all the require d payload operations/processing of Mars Orbiter Mission on a regular basis. Special events such as Deimos, Phobos imaging, stellar Imaging were also supported. Total of 2095 MOM Long Term Archive (LTA) products are hosted at ISSDC for general public using the web data portal: MRBrowse (https://mrbrowse.issdc.gov.in/MOMLTA/). The application has many user friendly features to help users to view, search and download data products.

ISSDC has configured the payload data ingestion, processing, storage& dissemination pipeline for AstroSat - a multi-wavelength space observatory, and successfully commissioned it for mission support. The complete proposal based operations of Astrosat was configured

during this period and implemented through different proposal cycles like Performance Validation (PV), Guaranteed Time (GT), Calibration (CAL), Announcement of Opportunity (AO) and Target of opportunity (ToO). Various new elements were introduced in order to handle last moment mission requirements and challenges like, cycle specific dissemination policy, case to case lock-in period definitions, common authentication to AstroSat applications, data tracking and monitoring, background data analysis, preliminary ToO data dissemination to public to name a few. A total of 7 TB of data comprising of more than 500 proposals and 900 observations has been disseminated to the proposers through Astro-Browse portal (https://astrobrowse.issdc.gov.in/astro_archive/archive/Home.jsp) hosted at ISSDC. ISSDC has continued its support for all the phases and observation cycles as per mission guidelines.

ISSDC has worked out the detailed payload data ingestion, processing & dissemination pipeline for CHANDRAYAAN2 and is in process of configuring the data center for the mission. Various new elements are incorporated like 3D Imaging System with 3D vision kit, High end processing - Decision Support Solution, 16-button TOPO Mouse. ISSDC is also an active member in Archive creation of Data, following international standards such as PDS3, PDS4 and is member of hosting planetary data in accordance with International Planetary Data Archive.

In addition to the aforementioned missions during this period, ISSDC has also carried out payload operations/processing/dissemination for on-going missions like Megha-Tropiques, Space-Based Automatic Identification System (AIS-SB) on-board ResourceSat-2 and SARAL.

ISSDC has re-designed its web architecture and hosted various mission specific Web applications for AstroSat, CH1Browse for Chandrayaan-1 data, MR1 Browse for Mars Orbiter Mission data, and Generalised Archival & Dissemination System for generalized multi-mission data sets. The AstroSat Payload Proposal System (APPS) is hosted at ISSDC for receiving proposals from Astronomy community for carrying out observations on various celestial sources by individual/all instruments of AstroSat. The end to end exchange of such information between the scientific community, review committees, mission & operations teams has been worked out and implemented for smooth & automatic exchange of such information among all. ISSDC has also updated the Chandrayaan-I data with 10m DEM data sets.

ISSDC has initiated the detailed requirements gathering activities for readiness of ISSDC to support Aditya-L1, and XPOSAT missions.

The higher level products generated by PIs at Payload Operation Centres (POCs) has to be returned to ISSDC for public dissemination after the lock-in period and peer review of data. Keeping this in view, ISSDC is in regular interaction with all the PIs/POCs for collection of the higher level products for all ongoing missions to conduct the peer review of data & subsequently host it for general public.

The facility is continuously getting enhanced with a motto of “providing Quality Data and Quick services” to future lunar, Planetary and space science missions of ISRO.

SPACE SCIENCE SCHEMES AND PROGRAMMES

ISRO-Space Science Promotion Scheme (ISRO-SSPS)

ISRO-SSPS is an initiative of ISRO's Advisory Committee for Space Science (ADCOS) to support and strengthen research in space sciences in the Universities, as a part of its Human Resource Developmental activities. The basic criterion for the selection of the Universities has been the heritage of research in space science and atmospheric physics. This scheme, approved in 2008, includes one-time grant for laboratory augmentation and recurring grant for a period of five years towards the augmentation of faculty positions, honorarium to visiting/guest faculty and fellowship to selected M.Sc / M.Tech students. Under phase-1 of the scheme, eight Universities were supported. On completion of the phase-1 activities, seven universities have been supported under Phase-II activities (five years duration) of the scheme.

Sponsored Research (RESPOND) Programme

The RESPOND Programme supports basic research and developmental projects, in the niche areas of Space Science, Space Technology and Space Applications which have linkages with the Indian Space Programme. The prime objective of the RESPOND programme is to establish strong links with academic institutions in the country to carry out research and developmental projects which are of relevance to space and to derive useful outputs of such R&D to support ISRO programmes and to develop quality scientific/technical human resources.

During this period, RESPOND has supported 106 new projects and renewed 95 ongoing projects from 64 Universities/colleges, 21 National Institutes and 10 Research Centres. During the period, 55 projects sponsored earlier under RESPOND have been successfully completed. A few high quality scientific publications have emerged out of these projects apart from fulfilling the objectives at project level.

In addition to the R&D Projects, ISRO has established research chairs to guide advanced research in niche areas of space at IIT Kharagpur, Indian Institute of Science (IISc), National Institute of Advanced studies (NIAS), University of Pune, and Bangalore University. During the year, ISRO has also supported 234 scientific activities, which included conferences, symposia, workshops, educational and promotional activities in space science, application and technology areas having relevance to the Indian Space Programme.

ISRO under RESPOND programme has also established Space Technology Cells at premier institutions like Indian Institute of Technologies (IITs) - Bombay, Kanpur, Kharagpur & Madras; Indian Institute of Science (IISc), Bangalore and with University of Pune (UoP) to carry out research activities in the areas of space technology and applications. During the period, 133 New Projects and 279 ongoing projects of Space Technology Cells have been supported and 104 projects sponsored earlier have been successfully completed.

- **ISRO Geosphere-Biosphere Programme (ISRO-GBP or IGBP)**

The major goal of IGBP is to study and understand the interactive physical, chemical and biological processes between Biosphere and Geosphere with particular reference to the potential impact of regional factors on climate system. It is important to understand the global interactions by studying the local and regional aspects such as impact of deforestations, aerosol loading in atmosphere and its radiative forcing and carbon sequestration in vegetation and soils.

The ongoing programmes include Climate Impact Assessment of Aerosols over India, Network of Observatories for Boundary Layer Experiments (NOBLE), National Carbon Project (NCP), Atmospheric Trace Gases Chemistry and Transport Modeling (ATCTM), Marine Carbon Nitrogen Cycles (MCNC) and Energy & Mass Exchange in Vegetative Systems. The participating ISRO/ DOS Centres are SPL, NRSC, IIRS and PRL. Around 70 partner institutions representing research centres and Universities across the country are also involved in these projects and contributing significantly towards ground based observations and data analysis.

National Carbon Project (NCP) is implemented under six inter-related sub-projects namely, (i) Spatial Assessment of Soil Carbon Dynamics (ii) Soil-Vegetation Atmosphere Fluxes studies in Forest Ecosystem (iii) Vegetation Carbon Pools and Dynamics (iv) Assessment of Carbon and Moisture Fluxes over Agro-ecosystem (v) Coastal Carbon and Hydro / Geo Chemical Fluxes (vi) Regional Carbon Cycle Modeling and Simulation, and (vii) Atmospheric $C0_2$ Retrieval and Monitoring.

The National Carbon Pool (NCP) envisages creation of remote sensing based spatial repository of terrestrial and oceanic Net Carbon balance estimates over India, its periodic assessment through an observational network and to provide support to Ministry of Environment & Forests communications to United Nations Framework Convention on Climate Change (UNFCCC) on carbon balance.The soil & vegetation-atmosphere fluxes (SVAF) has been envisaged to carry out terrestrial carbon flux measurements in different ecological regions of the country and to use this data to determine the source and sink strengths of different biomes in the country. A network of eddy covariance flux towers were established in Betul (teak mixed forests) Madhya Pradesh, Sundarbans (mangroves), West Bengal, and Kanha (Sal forests) Madhya Pradesh.

4. NATIONAL FACILITIES FOR SPACE SCIENCE RESEARCH

PHYSICAL RESEARCH LABORATORY (PRL)

PRL, a premier national research institute for basic researches under the aegis of Department of Space. The Laboratory has four campuses, located at Ahmedabad, Thaltej, Udaipur and Mt. Abu The main campus in Navrangpura, Ahmedabad houses most scientific activities of research and the programmes in Astronomy, Astrophysics and Planetary Science and Exploration are housed at the Thaltej campus. The other two campuses at Mt. Abu and Udaipur, house the Infrared (IR) and the Solar Observatory, respectively.

- **Udaipur Solar Observatory (USO):**

  The Multi-Application Solar Telescope (MAST) is a newly installed 50 cm aperture modern solar telescope at the island observatory of Udaipur, which is providing high spatial resolution solar images (around 250 km on the solar surface). It is aimed to provide regular measurements of the magnetic field on the solar atmosphere for understanding the origin and trigger mechanism of solar eruptions.

- **Mt. Abu Observatory at Gurushikar:**

  The PRL Mt. Abu Observatory, situated at the top of the Gurushikhar, peak of Aravali range, atan altitude of 1700 meters above mean sea level. The site is one of the best in the country and extremely good for near-IR wavelength observations up to 2.5 microns. Currently, the Observatory houses a 1.2 m Cassegrain focus f/13 telescope, optimized for infrared and optical observations. The PRL Advanced Radial-velocity All-sky Search (PARAS) to detect extrasolar planets using the radial velocity technique is operational since 2012. In the last two years a total of 77 papers have been published from observations using NICS, CCD imaging Polarimeter and PARAS.The Observatory is in the process of acquiring a larger 2.5 m telescope, which is expected to give a big boost to its scientific programs almost by a factor of 7 to 8, because of its larger aperture area and accurate precision tracking.

  The research activities carried out by PRL during 2016, 2017 are summarized in chapter 2.

NATIONAL ATMOSPHERIC RESEARCH LABORATORY (NARL)

National Atmospheric Research Laboratory (NARL) at Gadanki near Tirupati, is a pioneer Atmospheric research laboratory with a vision to “Developing capability to predict the behaviour of the atmosphere through observation and modelling”. Currently more than 40 observational facilities are in regular operation at NARL, which includes MST radar, Rayleigh lidar, Rayleigh Doppler lidar, Mie lidar, L-band wind profilers, Ionosonde, Gadanki Ionospheric Radar Interferometer (GIRI), Airglow imager, Radiosonde, Weather station, and radiation, aerosol, trace gases measuring instruments along with a High Performance Computing (HPC) system.

The research and development activities at NARL are carried out by seven groups viz., Radar Applications and Development Group (RADG); Ionosphere and Space Physics Group (ISPG); Atmospheric structure and Dynamics Group (ASDG); Clouds and Convective System Group (CCSG); Aerosols Radiation and Trace gases Group (ARTG); Weather and Climate Research Group (WCRG); Computers and Data Management Group (CDMG).

During the period 2016 and 2017, MST radar was upgraded to an active phased array state of art technology with 1024 Tr/Receive modules. This facilitates efficient probing of the troposphere, stratosphere, mesosphere and ionosphere.A tethered balloon observation platform capable of hoisting 110 Kg flight module up to an altitude of 1 km has been established in 2016.

An emission model was developed to estimate the trace gases and particulate matter due to open burning of waste based on the Intergovernmental Panel on Climate Change (IPCC) guidelines The emissions from open waste burning were calculated for various constituents.

A climate model of Total Electron Content (TEC) was developed using data from 2 solar cycles 23 and 24 which provides perturbation amplitude in TEC for the first time with respect to the intensity of the geomagnetic storm.

Interesting studies have been undertaken during this period with respect to Martian ionosphere, like ionization bulges in regions of strong crustal magnetic fields, by analysing Mars Advance Radar for Subsurface and Ionospheric Sounding (MARSIS) data aboard the Mars Express spacecraft.

The research activities carried out by NARL during 2016, 2017 are summarized in Chapter 3 of this report.

SPACE PHYSICS LABORATORY (SPL)

Space physics Laboratory (SPL) is one of the premier research institutes in India carrying out front-line research in the realms of atmospheric, space and planetary sciences The motto of the laboratory is "*scientific understanding of the energetics, dynamics, and chemistry of the terrestrial and planetary environments, and implications to the society".*

SPL is also the lead laboratory for the regional atmospheric boundary layer and aerosol characterization, radiative forcing and quantifying atmospheric warming. It is also involved in investigating the terrestrial upper atmosphere in context of its energetics and dynamics vis-à-vis the vertical and lateral coupling this region has with the magnetosphere above and lower atmosphere below it.

SPL has been playing an active role in ISRO's planetary missions (including Mars Orbiter Mission, Chandrayaan-1 & 2 missions and Aditya-L1 mission) and also in planning future missions for planetary probing.

In the period 2016, 2017 some of the major research activities involves analysis of data from ISRO Planetary missions: from The Sub-keV Atom Reflecting Analyzer (SARA) experiment onboard Chandrayaan-1, analysis of Mare Moscoviense**,** a prominent mare-filled basin on the lunar far side**,** using the Moon Mineralogy Mapper (M^3) and Infrared Spectrometer-2 (SIR-2) data-sets. The research activities carried out by SPL during 2016-2017 are summarized in Chapter 4.

SPACE ASTRONOMY GROUP (SAG)

The Space Astronomy Team along with Space Science Instrumentation Facility (SSIF) at U R Rao Satellite Centre (URSC) is involved in scientific research and instrumentation, in the areas of astronomy and astrophysics, solar physics, planetary science, and space weather.

The primary responsibility of space astronomy team and SSIF is to analyse the scientific and technological requirements of identified proposals, converting the scientific requirement into instrumentation, help them developing the laboratory model of the payload, and oversee the realisation of associated Qualification and Flight payloads. Through these activities, space astronomy team provides domain expertise support for developing new scientific payload from laboratory model to the qualification and flight model. This involves simulation and modelling guidance, student training and establishing commonly required major test systems and science calibration facilities. To facilitate the external institutions, space astronomy team has the resources like simulation expertise, basic infrastructure and system design expertise.

In addition to this, this facility is setup to assist external colleges, universities and institutions in the design, development and realization of space-worthy science payloads.

The Space astronomy team has so far developed and flown various scientific payload experiments like Gamma Ray Burst (GRB) Experiment, Indian X-ray Astronomy Experiment (IXAE), Solar X-ray Spectrometer (SOXS), High Energy X-ray Spectrometer (HEX), Chandrayaan-1 Soft X-ray Spectrometer, Scanning Sky Monitor (SSM) and Geostationary RAdiation SPectrometer(GRASP) in various missions.

The team is currently involved in the realization of scientific payloads for the upcoming space missions. The research activities carried out by SPL during 2016-2017 are summarized in Chapter 5.

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY (IIST)

The Indian Institute of Space Science & Technology (IIST) is an autonomous institute under the Department of Space (DOS), and a deemed to be University. IIST has been offering undergraduate, post-graduate and doctoral education in the broad areas of space science and space technology. It is ranked 23rd for the year 2018 among all the engineering institutions in the country by the National Institutional Ranking Framework, set up by the Ministry of Human Resource Development (MHRD), Government of India. The MHRD ranking is based on a national survey that evaluated institutions on a wide set of parameters, including their excellence in teaching, quantity and quality of research output, interface with other institutions and the industry, laboratory and library resources, faculty-to-student ratio, gender equity, graduation placements etc.

The institute currently has seven departments, with nearly hundred faculty members holding Ph.D. Their expertise span the various fields of aerospace engineering, avionics, earth and space sciences, mathematics, chemistry, physics and humanities.

The institute offers four years B.Tech programmes in Aerospace Engineering and Avionics and a five year Dual Degree Programme leading to a B.Tech degree in Engineering Physics and Post Graduate Degree in any of the following specialization- (i) Master of Science (Astronomy & Astrophysics) (ii) Master of Technology (Earth System Science) (iii) Master of Science (Solid state Physics) and (iv) Master of Technology (Optical Engineering). The institute also offers stand alone post-graduate programmes in fifteen emerging and highly sought after specialisations. These two years post-graduate programmes are all research oriented, with one full year dedicated to supervised research work.

During the convocations held in 2016 and 2017, sixteen and eleven doctoral degrees have been awarded by the institute, with around one hundred and thirty peer-reviewed research journal publications appearing in science and engineering journals of global standing each year. Within a short span, the institute has also put together excellent and well equipped laboratories catering to its various researches and teaching needs.

The DOS/ISRO has established an endowment fellowship for the topper of B.Tech (Aerospace Engineering) student at the Graduate Aerospace Laboratories of the California Institute of Technology (GALCIT), California, USA in the honor of Dr. Satish Dhawan, the former Chairman of ISRO and an alumnus from CalTech. Since 2017, the above endowment fellowship has also been extended to the topper of B.Tech (Avionics). The above fellowship provides an excellent opportunity to the top ranking graduating student from B.Tech (Aerospace Engineering) and B.Tech (Avionics) student of IIST, to pursue Masters of Science programme at California Institute of Technology.The main activities are covered in chapter 10.

INDIAN INSTITUTE OF REMOTE SENSING (IIRS)

Indian Institute of Remote Sensing (IIRS) is a premier institute with a primary aim to build capacity in Remote Sensing and Geoinformatics and their applications through education and training programmes at postgraduate level. It is a constituent Unit of Indian Space Research Organisation (ISRO), Department of Space, Govt. of India. Formerly known as Indian Photo-Interpretation Institute (IPI), founded in 1966, the Institute is first of its kind in entire South-East Asia. While nurturing its primary endeavour to build capacity among the user community by training mid-career professionals since its founding in 1966, the Institute has enhanced its capability and evolved many training and education programmes that are tuned to meet the requirements of various stake-holders, ranging from fresh graduates to policy makers including academia, industry and NGOs. The major activities during 2016,2017 are covered in chapter 13.

TATA INSTITUTE OF FUNDAMENTAL RESEARCH

The Department of Astronomy and Astrophysics-TIFR is Located in the scenic Mumbai campus. The department carries out cutting edge research in theoretical and observational astrophysics with an active interest in instrumentation. The observations are carried out using ground based facilities as well as balloon-borne and satellite-borne instruments. This is supplemented by the work done in Radio Astronomy and High Energy Cosmic Rays by other groups in the Institute.The research activities carried out by TIFR Astronomy and Astrophysics during 2016-2017 is summarized in Chapter 14.1 of this report.

- **Giant Meter-wave Radio Telescope, Pune (National Centre for Radio Astrophysics)**

  The GMRT consists of thirty 45 m diameter antennas spread over a 28 km region. Twelve of the antennae are in a compact, quasi randomly distributed array with a diameter of about 1 km. The remaining antennas are distributed along 3 arms of length ~14 km in a Y-shaped configuration (NorthWest, NorthEast and South). The longest baseline is about 28 km and the shortest is about 100 m, without foreshortening. The telescope (with centre of the array at latitude=19.1 deg N, Longitude = 74.05 deg E) is located near Khodad village, which is about 80 km north of Pune.

The GMRT has been open to the international community of users since early 2002, via a proposal submission and approval scheme that presently runs two observing cycles in each year. Over the last 15 years of operations, the GMRT has produced several interesting new results and discoveries in different areas of astrophysics, and an average of more than 40 papers per year in international journals feature results from data obtained with the GMRT. The observatory has also been used as a sensitive ground station, for receiving signals from the Exomars mission in 2016, to track the descent of the lander module through the atmosphere of Mars.

The GMRT has just completed a major upgrade of its capabilities, which has increased its frequency range to have near seamless frequency coverage from 110 to 1500 MHz and a maximum bandwidth of 400 MHz, along with improved sensitivity receivers with better dynamic range. This has improved the sensitivity of the GMRT for continuum imaging by more than a factor of three, along with a similar benefit for pulsar observations, and has also widened the span of redshifts over which the line from neutral Hydrogen from different reaches of the Universe can be observed. The upgrade is also accompanied by installation of a revamped and modern servo system on all the antennas, a new generation monitor and control system, and various improvements in infrastructural and computational facilities. Major initiatives for mitigation of radio frequency interference have also been implemented for the upgraded observatory, such as automated detection and avoidance of interference from satellite signals, and real-time excision of interference signals from the signal chain for each antenna.

The upgraded GMRT has recently been released to the global user community and has already started producing exciting new results. On the basis of the new technology and science frontiers of radio astronomy that it probes, in 2016 the GMRT was accorded the status of a pathfinder facility for the international Square Kilometre Array (SKA) project.

- **Ooty Radio Telescope, Ooty (Tata Institute of Fundamental Research)**

The Ooty radio telescope (ORT) continues its program of long term monitoring of turbulence in the inner heliosphere. Over the last year, several solar wind and CME studies were carried out. In particular the fast CME associated with an intense flare was tracked. The results of this study was reported and was also used by the NASA space weather modelling and forecasting group. In addition to studies of the inner heliosphere, the ORT now has a new pulsar backend (PONDER)which is being used for a number of long term studies of pulsars. Over the last year the ORT has monitored pulsars for glitches, taken observations of several pulsars with the aim of doing pulsar timing and also observed the interstellar scattering for a number of pulsars.

- **National Balloon Facility (NBF), Hyderabad (Tata Institute of Fundamental Research)**

TIFR Balloon Facility is a facility of the Tata Institute of Fundamental Research located at Hyderabad, India for research in scientific high altitude ballooning. The research activities carried out by National Balloon facility, Hyderabad –TIFR during 2016-2017 are summarized in Chapter 14.2 of this report.

INDIAN INSTITUTE OF ASTROPHYSICS (IIA) BENGALURU

Indian Institute of Astrophysics (IIA) is India's premier research institution devoted to studies in astronomical sciences. Its main campus is located in Bengaluru.and the observational facilities are spread across the country, in four major field stations - Hanle (Ladakh, Jammu and Kashmir), Gauribidanur (Karnataka), and Kavalur and Kodaikanal (Tamilnadu). The Hosakote campus in the Bengaluru Rural District houses the Centre for Research and Education in Science and Technology (CREST). The Himalayan Chandra Telescope (HCT) in Hanle is remotely operated from this centre via a dedicated satellite link. IIA has its own optical, infrared, radio and high altitude gamma ray array facilities. IIA is partner in the International partnership for international research and education(PIRE) Collaboration for the study of transients, “Global Relay of Observatories Watching Transients Happen “(GROWTH)

Some of the major activities during the period cover: the Thirty Meter Telescope (TMT) project - the world’s most advanced ground-based observatory operating in optical and mid-infrared wavelengths, Visible Emission Line Coronograph (VELC) payload on Aditya-L1 space mission. and the upgradation of MGK Menon Laboratory facility .

The research activities carried out by IIA during 2016-2017 are summarized in Chapter 15 of this report.

THE RAMAN RESEARCH INSTITUTE (RRI)

The Raman Research Institute is an autonomous research institute engaged in research in basic sciences. RRI contributes to the understanding and scientific comprehension of natural phenomena right from the sub-atomic to mesoscopic to cosmological scales through experiments, theoretical modeling and an active combination of both. The highlights of the research activities carried out by RRI during 2016-2017 are summarized in Chapter 17.

- ### Gauribidanur Radio Observatory

  The Observatory has a variety of radio telescopes: a low frequency antenna array functioning at 34.5 MHz for observations of radio emission from Sun, pulsars and other galactic, extragalactic sources; a radio heliograph operating in the frequency range 40-120 MHz for imaging the solar corona in the height range of about 0.2-0.8 solar radii above the solar photosphere; a radio polarimeter for observations of circularly polarized emission in the above height range; a radio spectrograph for obtaining dynamic spectrum of the transient burst emission from the solar corona, again in the same height range. The aforementioned facilities at the Observatory are unique in their corresponding frequency range. This observatory is jointly operated by IIA and Raman Research Institute, Bangalore.

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS (IUCAA)

The Inter-University Centre for Astronomy and Astrophysics (IUCAA) is an autonomous institution set up by the University Grants Commission (UGC) of India to promote the nucleation and growth of active groups in astronomy and astrophysics at Indian universities. IUCAA aims to be a centre of excellence within the university sector for teaching, research and development in astronomy and astrophysics. IUCAA's computer facilities are accessible to the entire Indian University sector for astronomy domain applications.

The Radio Physics Laboratory setup in IUCAA, in collaboration with the National Centre for Radio Astrophysics (NCRA), Pune, continues its task to train motivated science and engineering students nationwide in the use of Radio Telescope, and introduce them to Radio Astronomy Science Education.

Besides conducting vigorous research programmes of its own, the Centre enables workers from Indian universities, teachers as well as students, to visit the Centre to use the facilities for various durations. Through the Associateship Programme which was started in 1990, the faculty members from Indian universities and colleges, along with their students may visit IUCAA and use the facilities for their research work. A visiting associate selected under this programme can visit maximum 365 days in a tenure of 3 years, as per their convenience.

Through the Public Outreach Programme, school and college students are invited to visit the Muktangan Vidnyan Shodhika (Science Exploratorium) in IUCAA campus, where they discover the joy of learning science by do-it-yourself. During summer vacation, school students are invited to do week-long projects with guidance from IUCAA members. Similar programmes have been conducted for the school students around the rural region of IUCAA Girawali Observatory. The research activities carried out by IUCAA during 2016-2017 are summarized in Chapter 16 of this report .

ARIES OPTICAL TELESCOPES, NAINITAL

ARYABHATTA RESEARCH INSTITUTE OF OBSERVATIONAL SCIENCES (ARIES), Nainital, one of the premier autonomous research Institute under the Department of Science and Technology (DST), Government of India, is engaged in carrying out front line research in the fields of Astronomy & Astrophysics, Solar Physics and Atmospheric Sciences. The Institute is also involved in developing state-of-the-art backend instruments. The main activities like installation of DevasthaL Optical Telescope (DOT) are covered in Chapter 18.

Remote Technical Activation of India's largest 3.6m Devasthal Optical Telescope by the Hon'ble Prime Minister of India Shri Narendra Modi and Hon'ble Prime Minister of Belgium Mr. Charles Michel from Brussels, Belgium on 30th of March, 2016.

Fig 8

CONFERENCES / SYMPOSIA

19th National Space Science Symposium (NSSS-2016)

The nineteenth National Space Science Symposium (NSSS-2016) was held at Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram, during 9-12 February 2016. The main aim of this symposium is to provide a scientific forum to present new results in the areas of atmospheric science, space science, planetary exploration and astronomy and astrophysics.

The broad areas covered during the symposium are Space and ground based astronomy and astrophysics, planetary science/ exploration, Sun and its interaction with the Earth and other planetary systems, Magnetosphere, ionosphere, thermosphere and middle atmosphere phenomena, space based oceanography, meteorology and tropospheric studies, climate changes and geosphere-biosphere interaction processes.

The symposium consisted of three Special Plenary Sessions (Future of Space Transportation; Evolution of atmosphere of Planets; New frontiers in Astronomy), a popular lecture on “History and Mysteries of the Universe”, three interdisciplinary lectures (Mystery of sunspot cycle; Observing clouds and precipitation from Ground and Space; Recent advances in understanding Earth and planetary magnetic fields) and five parallel sessions with contributory Oral and poster presentations.

The NSSS-2016 had a maximum number of delegates so far. Overall, about 250 oral presentations and 550 poster presentations were made with representation from almost all states in the country. More than 60% of the contributed papers were selected from researchers and scientists below 35 years of age. 27 Best paper awards for oral and poster presentations were given to young scientists. The award consisted of a certificate and cash prize.

Another unique aspect of the NSSS-2016 was that the delegates could witness a RH-200 launch live from TERLS, after their visit to space museum.

Space Research in India is carried out using the space and ground based facilities established and operated by ISRO as well as other institutions. The outcome of these research activities is presented in the following chapters on this report.

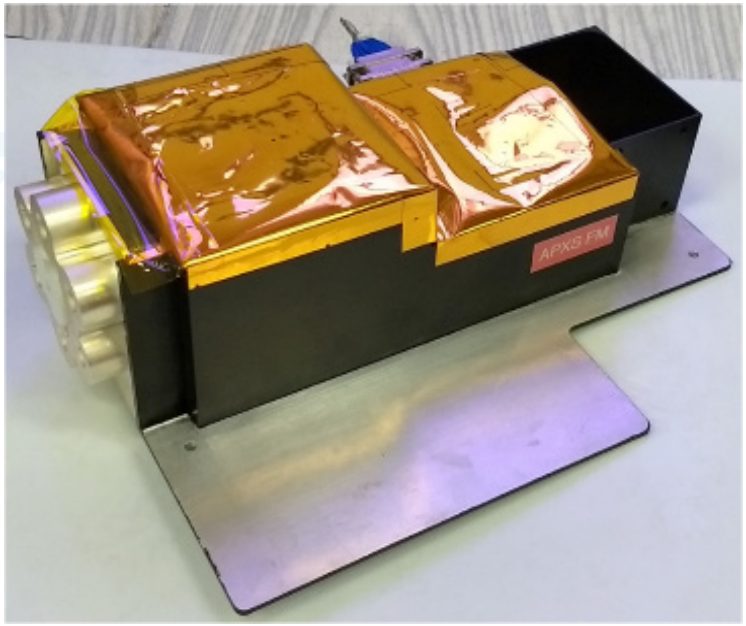
CHAPTER 2
PHYSICAL RESEARCH LABORATORY (PRL)
AHMEDABAD

Physical Research Laboratory (PRL) is a premier, national research institution, under the aegis of the Department of Space, Government of India. Founded in 1947 by Dr. Vikram Sarabhai, PRL has served as the “cradle of space sciences”. The laboratory is engaged in basic research in Theoretical Physics, Atomic, Molecular & Optical Physics, Astronomy, Astrophysics, Solar Physics and in Earth-, Planetary-, Atmospheric-, and Space- sciences. The research activities carried out by PRL during 2016-2017 are summarized in this chapter.

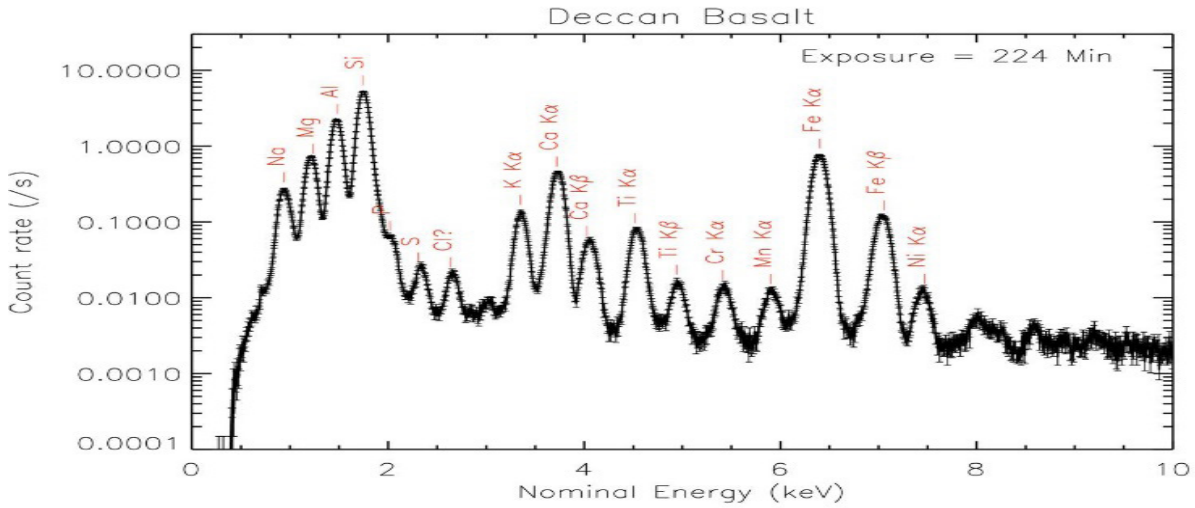
A. MAJOR INSTRUMENTATION DEVELOPED

• Alpha Particle X-ray Spectrometer (APXS)

The Alpha Particle X-ray Spectrometer (APXS) instrument is part of Chandrayaan-2 Rover and this instrument will determine the elemental composition (Na, Mg, Al, Si, K, Ca, Ti, Fe) of Lunar soil and rocks around the lunar landing site on the Moon. This is carried out by irradiating the sample surface on the Moon with Curium (^{244}Cm) alpha source (Alpha particles: 5.8 MeV and X-rays: 14.3 keV, 18.4 keV) and measuring the X-ray fluorescence spectra. From the measured spectra, one can determine the quantitative elemental composition of the Moon rocks and soil samples. The Flight Model of APXS payload has been fabricated and tested for all functional and scientific requirements. APXS instrument provides the energy resolution of ~140eV at 5.9 keV. The photographic view of the flight model version of the APXS payload is shown figure-1 and a spectrum acquired for a Basalt sample target is shown in figure-2.



Photographic view of Flight Model of APXS payload
Fig 1



Spectrum acquired from APXS payload for Basalt target
Fig 2

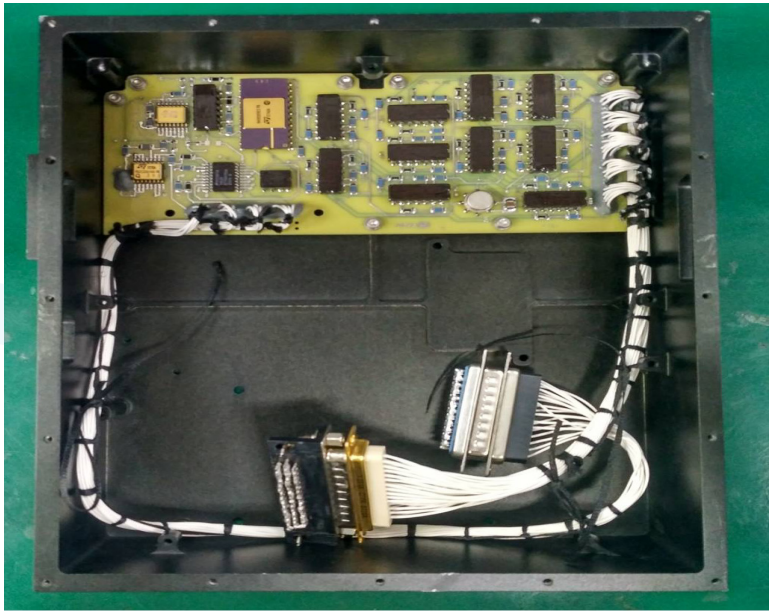
- **Solar X-ray Monitor (XSM)**

The Solar X-ray Monitor (XSM) instrument is an instrument developed for the Chandrayaan-2 orbiter. It will provide the incoming solar X-ray spectrum which is essential to interpret the quantitative global elemental composition of the Moon from the orbiting satellite by the companion instrument Chandra's Large Area Soft x-ray Spectrometer(CLASS). X-ray fluorescence from the Moon is critically dependant on the intensity of the Solar X-rays falling on the Moon. CLASS instrument will provide the global elemental composition of the Moon using the XSM data. XSM instrument has two packages namely XSM sensor package and XSM Processing Electronics package. The developed XSM instrument can provide Solar X-ray spectra every second, with very high energy resolution of ~180eV at 5.9 keV, and hence the data from XSM instrument can also be used for solar studies. The Flight Model of the instrument has been fabricated and characterized for various scientific parameters. The photographic view of Flight Model of the XSM instrument is shown in figure-3.

Photographic view of XSM payload Flight Model (Left - XSM Processing Electronics package, Right - XSM sensor package).
Fig 3

- **Chandra's Surface Thermophysical Experiment (ChastE)**

The objective of the instrument is to carry out in-situ measurements of temperature profile on the lunar surface to derive the vertical temperature gradient up to a depth of 100 mm near the polar region. This is carried out by means of inserting a probe with thermal sensors into the lunar regolith using a motor based mechanism. This instrument is being developed jointly by the Physical Research Laboratory (PRL), Ahmedabad and the Space Physics Laboratory (SPL), VSSC, Trivandrum. The Flight Model of the front-end electronics which is developed at PRL has been completed and tested for the performance requirement and has been delivered for further integrated tests. The photographic view of the front-end electronics is shown in figure-4.



Photographic view of the front-end electronics ChastE payload
Fig 4

B. SCIENCE RESULTS

1. ATMOSPHERE AND CLIMATE

- Black carbon (BC) aerosol loading produces a large radiative impact on climate. For the first time, using simultaneous measurements over a 2-year period, the spatial and temporal variability in BC mass concentration are investigated over two distinct locations in western India, namely, Ahmedabad (23.03^{o}N, 72.55^{o}E) (urban industrialized location, 55 m above mean sea level) and Gurushikhar (24.65^{o}N, 72.78^{o}E) (high altitude remote site, 1680 m above mean sea level). The observed BC mass concentrations at Ahmedabad are about a factor of 4-higher than Gurushikhar values. BC mass concentration exhibits distinct diurnal variability over the study locations. The BC maximum at Gurushikhar corresponds to the BC minimum observed at Ahmedabad, due to the significant effect of the diurnal evolution of atmospheric boundary layer. During the sunlit time the Earth's surface gets heated which increases the surface temperature resulting in the transport of pollutants from the foothills to the observational location which is in the free troposphere. Gurushikhar BC values can be considered as the representative of the regional background values for the western Indian region. The study highlights the significant role atmospheric dynamics plays in modulating the BC levels in different locations.

- Volatile organic compounds (VOCs) are important precursors of ozone (O_3) and secondary organic aerosols. Among many VOCs, measurement of biogenic-VOCs (BVOC) is one of our major research programs. In the tropics, sparse measurements of volatile organic compounds (VOCs) cause higher uncertainties in their emission estimates and atmospheric importance. Measurements of an important class of VOCs namely biogenic-VOCs (BVOCs) were made using a high resolution and high sensitivity proton-transfer-reaction time-of-flight mass spectrometer (PTR-TOF-MS) at an urban site of Ahmedabad during winter-to-summer transition period. Contributions of biogenic emissions from local vegetation to ambient levels of BVOCs during winter-to-summer transition period were estimated at a semi-arid urban site in India. From February to March, contributions of biogenic/secondary sources to oxygenated-VOCs and isoprene increased by 10-15%. But average contribution from local biogenic sources to monoterpenes increased from 31% in the first half of February to 67% in the second half of March. Overall, the combined effect of westerly winds and higher ambient temperatures in March provides favorable conditions for the local biogenic emissions and regional transport of BVOCs. The data set reported in this study is one of the best measurements available in India owing to high time- and mass- resolution of PTR-TOF-MS. We have also conducted field experiments to study the emissions of BVOCs in the Western Ghats (terrestrial forest biome) of India and Arabian Sea (oceanic ecosystem).

- Carbonaceous aerosols are mainly composed of organic carbon (OC) and black carbon (BC). Until recently, BC was the major known light absorbing species in the atmospheric aerosol. Recent studies have shown that a certain type of OC can also absorb light at near UV and visible region, and is termed as “Brown Carbon” (BrC). BrC immersed in cloud droplets can absorb light and facilitate evaporation/dispersion of clouds. It is shown to contribute ~35% of the direct radiative forcing warming by carbonaceous aerosols. To assess the role of BrC on regional/global level, it is important to understand their sources and characteristics on temporal and spatial scale. However, such studies are very limited in literature. Towards this, semi-continuous measurements of water-soluble organic carbon (WSOC) and BrC were performed using particle-into-liquid sampler coupled to liquid waveguide capillary cell and total carbon analyzer (PILS-LWCC-TOC) over Kanpur (26.5°N, 80.3°E), a site located in the middle of the Indo-Gangetic Plain (IGP). The IGP spread over northern India perennially receives large amount of primary particles and precursors of secondary particles from vehicles, industries, large-scale post-harvest biomass burning, and bio-fuel burning. Diurnal variability in the absorption coefficient of BrC at 365 nm (b_{abs_365}) showed higher values (35±21 Mm^{-1}) during late evening through early morning, and attributed to primary emissions from biomass burning and fossil fuel burning. The b_{abs_365} reduces by more than ~80% as day progresses, which is ascribed to photo bleaching/volatilization of BrC. Further, WSOC exhibited a strong correlation with b_{abs_365} (slope = 1.22±0.81, r^2 = 0.70, n =13265, intercept = -0.69 ± 0.17), suggesting the presence of significant but variable fraction of chromophores. Our observations suggest that BrC chromophores are a variable mixture of at least humic-like substances and nitrogen containing organic compounds over the study region.

- Global change in the weather patterns caused by natural and anthropogenic influence can result in climate change. The vital signs of global climate change could be extreme events such as frequent droughts or excessive rainfall. The climate change has significantly affected the Indian summer monsoon (ISM) intensities which has major impact on socio-economic conditions of Indian sub-continent. Various factors has played crucial role in controlling ISM intensity in the past which needs to be addressed to understand the present and the future trends.

  a) A sediment core retrieved from the western Arabian Sea (AS) demonstrated low (high) upwelling with ISM weakening (strengthening) during Glacial (Interglacial) periods causing low (high) productivity variations. Contrarily, the intermixing zone of the two distinct basins

near the equatorial region has shown contrasting paleo-productivity variations with high productivity and oxygen deficient conditions during glacial periods. Such contrasting behavior in the overhead productivity in western Arabian Sea and equatorial Indian Ocean can be deciphered from the southward migration of Intertropical Convergence Zone (ITCZ) during glacial periods causing ISM weakening and NE monsoon strengthening.

b) To delineate the recent changes in ISM and attributes of El Niño–Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) events, several drilled coral samples retrieved from the Northern Indian Ocean are being been studied which can provide clues to simultaneous change in the growth rates and its geochemical composition as a function of sea surface conditions like temperature, salinity and its variation with IOD and El Nino events. Additionally, the Δ^{14}C measurements for each growth band can provide high resolution climatic records of ambient environmental conditions during their growth. The radiocarbon measurement can be achieved with the help of 1 MeV Accelerator Mass Spectrometer (AMS) installed at PRL. The AMS has successfully demonstrated potential for ^{14}C, ^{26}Al and ^{10}Be isotopic measurements and the unit has been acronymed as PRL-AURiS (Accelerator Unit for Radioisotope studies). AMS can provide high resolution chronology and paleoclimatic signatures of climatic processes as registered in ocean archives along with ^{14}C of seawater to decipher air-sea CO_2 exchange rates. The PRL-AURiS would provide a major thrust to PRL research in the field of climate change, geochronology and applications in various earth and planetary science processes in future.

2. IONOSPHERE, MAGNETOSPHERE AND SOLAR-TERRESTRIAL RELATIONSHIP

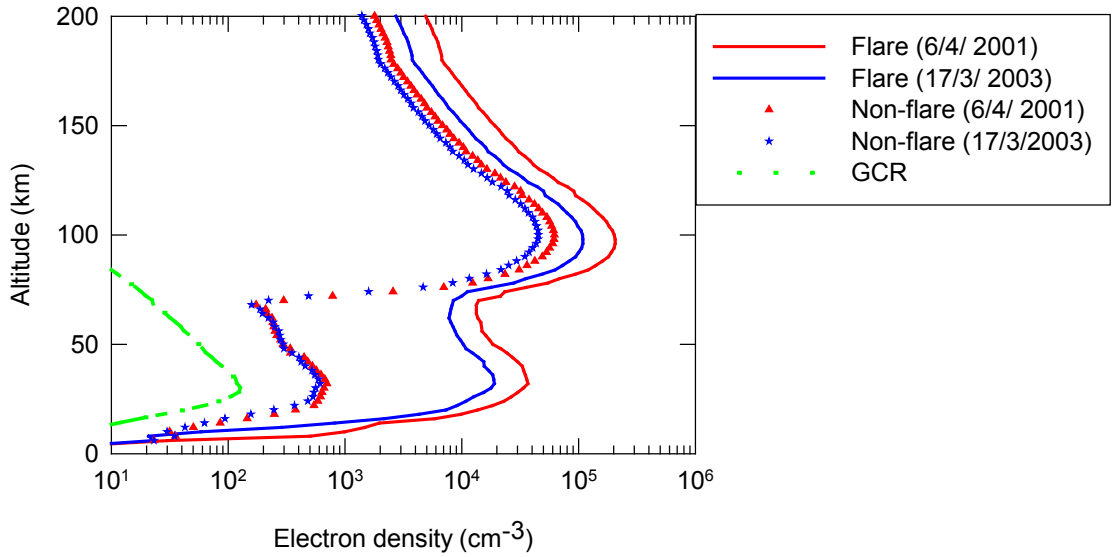
- First results on the three-dimensional wave characteristics in the daytime upper atmosphere have been derived using measurements of oxygen dayglow emissions at 557.7, 630.0, and 777.4 nm that originate at around 130, 230, and 300 km (peak of the F region). Such measurements were possible for night time conditions alone so far. The wave characteristics such as, the horizontal scale sizes of gravity waves, their time periods, phase propagation angles and phase speeds were derived. This technique opens up new possibilities in the investigations of daytime wave dynamics in three dimensions in the upper atmosphere. These results indicate that the scale sizes are smaller in the day as compared to the night time conditions.

- In addition to these, a couple of investigations have been carried out using the equatorial electrojet model (developed in PRL earlier) and data from rocket as well as ground-based measurements. These investigations confirm the existence of nighttime current in the equatorial E-region and bring out the inconsistencies between the drifts obtained from global empirical models and measurements conducted earlier from the Indian sector.

- A quasi-16-day wave found in the low latitude mesosphere and lower thermosphere (MLT) revealed broad spectral width which may indicate the existence of multiple modes of the 16-day wave. A potential coupling of the concerned wave with other short period planetary waves is evinced. Furthermore, an intermittent quasi-27-day oscillation is also observed. The solar radiation as well as lower atmospheric convective activity are found to excite the oscillation.

3. THE SOLAR SYSTEM BODIES INCLUDING PLANETARY SCIENCE

- Solar X-ray flare responses in E region of Mars' ionosphere were observed from Mars Global Surveyor (MGS) on 6 April, 2001 and 17 March, 2003. We have estimated Ionospheric Electron Content (IEC), flare and non-flare electron density profiles due to impact of X-rays (0.5-90 Å) and Galactic Cosmic Rays (GCR) in the Mars' ionosphere. In the non-flare profile D layer is produced at 25 km due to impact of GCR and hard X-rays (0.5-3 Å) with electron densities 1.0 x 10^2 cm^{-3} and 8 x 10^2 cm^{-3} respectively while E layer is produced at 110 km due to impact of soft X-rays (3-90 Å) with electron density ~ 4 x 10^4 cm^{-3}. The D layer peak density produced by hard X-rays is larger by about an order than that produced by GCR. The D and E flare peaks are produced for a short time at 30 km and 100 km with electron densities ~ 2- 4 x 10^4 cm^{-3} and ~ 1-2 x 10^5 cm^{-3} respectively. The predicted flare E-peak density is higher by factor of ~2 than the measurements carried out by MGS. The D peak density of flare profile is larger by 1-2 orders of magnitude than that produced for non-flare profiles.



First model results of complete electron density profiles of D and E region of Mars' ionosphere simultaneously
Fig 5

- High resolution DEMs of the light toned mounds in Juventae Chasma, Mars have been generated using HiRISE and CTX images. The nature of the contacts of the light toned materials with dark toned ones suggest that some of the light toned units are likely to have been deposited prior to the dark toned units in Juventae Chasma.

- The evolution of galaxies has been simulated by evolving the interstellar medium and the generation of stars within different annular rings. The thermal evolution and differentiation of Mercury has been investigated using a numerical model.

- Relict olivine grains enclosed in the cosmic spherules were chosen in a study as they have survived the heating during atmospheric entry. Twelve cosmic spherules selected from ~1500 that contained Mg-rich relict grains were analysed for oxygen isotope variations using ion microprobe. The data lie close to the Carbonaceous Chondrite Anhydrous Mineral (CCAM) line and overlay oxygen isotopic compositions of chondrules from CV, CK, CR and CM carbonaceous chondrites which indicated that chondrules from carbonaceous chondrites are precursors of relict grains in cosmic spherules. Further, the chemical compositions of olivine were found to be comparable to olivines from chondrules of carbonaceous chondrites.

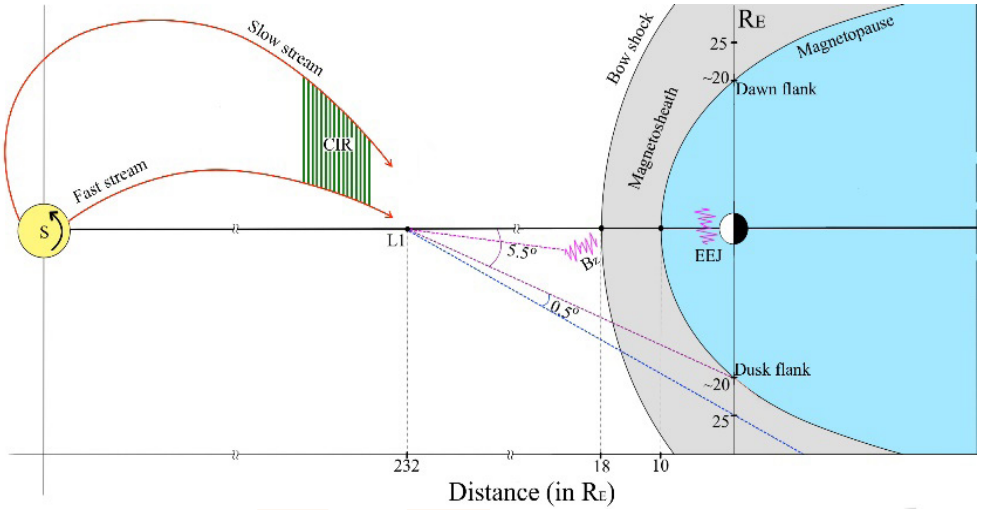
- The whistler mode waves in magnetosphere of Saturn have been investigated. Linear properties of ring velocity distribution function are used to derive dispersion relation for whistler mode waves in the ambient magnetic field of Saturn in extended plasma sheet of planet's magnetosphere. It has been shown that whistler mode waves have grown due to loss of perpendicular kinetic energy of ring electrons. Calculations have been performed at two radial distances in Saturn's magnetosphere, and the results are important in analyzing observed VLF emissions over wide spectrum of frequency range in Saturn's magnetosphere.

- Diffuse auroral intensities of OI 1356 A^{o} emission have been calculated, resulting from pitch angle diffusion of magnetospheric electrons by whistler mode waves. Intensities of the 1356 A^{o} emission was estimated from the precipitation of magnetospheric electrons observed near Ganymede, and are inadequate to account for the observational diffuse auroral intensities ≤ 100 R; an acceleration mechanism is suggested to energize the magnetospheric electrons.

- The magnetic field in the heliosphere continuously evolves in response to the solar photospheric field at its base. Together with the rotation of the Sun, this evolution drives space weather through the continually changing conditions of the solar wind and the magnetic field embedded within it. The aim of space weather studies has therefore been to try and predict the geo-effectiveness of solar wind streams interacting with the terrestrial magnetosphere and ionospheric system. In other words, space weather studies try to establish a causal relationship between solar wind events or disturbances taking place outside the terrestrial magnetosphere with events occurring within the terrestrial magnetosphere or the earth's ionosphere.

- Solar rotation coupled with the fact that solar wind streams can have different flow velocities will yield interaction regions, in the inner-heliosphere, where the different flow streams will interact. Such interaction regions are commonly referred to as co-rotating interaction regions (CIR) and are identified by rapid fluctuations in the z-component of the interplanetary magnetic field (Bz). A group of researchers from PRL have identified a large number of such CIR's at the L1 Lagrangian point of the sun-earth system and show that their geo-effectiveness is governed by their azimuthal or non-radial flow angle. Interestingly, only those CIR associated solar wind flows that deviate with respect to the radial direction by less than 6^{o} in the azimuthal plane are seen to be geo-effective and show a causal relationship between Bz and the equatorial electrojet (EEJ).

  These results thus, provide one an easy and quick method of predicting the geo-effectiveness of solar wind outflows by merely examining their degree of deviation from the radial direction.The schematic(Fig 6) represents the scenario described above. It is easy to see from the schematic that flows exceeding 6^{o} in the azimuthal plane will not interact with the terrestrial magnetosphere at all as they will pass by well beyond the flank of the terrestrial magnetosphere which is at a typical distance of 20 R_E, where 1 R_E is the Earth's radius.



Schematic (not to the scale; viewed from above the ecliptic plane) depicts the Co-rotating Interaction Region (CIR) caused by the different velocity outflows from the Sun which reveals the efficacy of geo-effectiveness of the solar wind flows caused by CIR. For azimuthal flow angle below 6°, measured at the first Lagrangian point (L1),with respect to the Sun-Earth line, the fluctuations in interplanetary magnetic field (Bz) and equatorial electrojet (EEJ) are causally connected.

Fig 6

4. ASTRONOMY AND ASTROPHYSICS

Hard X-ray polarization measurements with AstroSat-CZTI

AstroSat, the first Indian satellite dedicated for multi-wavelength astronomy has been successfully operating for more than two years. A unique capability of the AstroSat Cadmium Zinc Telluride Imager (CZTI) is the ability to measure polarization of the hard X-rays in the energy range of 100 – 380 keV, which was conceptualized, verified and experimentally tested by PRL team.

After the launch of AstroSat, we have thoroughly exploited all observations having total exposure of ~800 ks of the Crab nebula to successfully demonstrate this capability. This unique capability has resulted in the first, phase resolved polarization measurement for the Crab pulsar, which shows unexpected polarization variation within the off-pule period. This is an important observation, challenging all the present theoretical concepts of the pulsar radiation and thus are showcasing the true potential of the hard X-ray polarimetry. This result has been published in the prestigious journal Nature Astronomy.

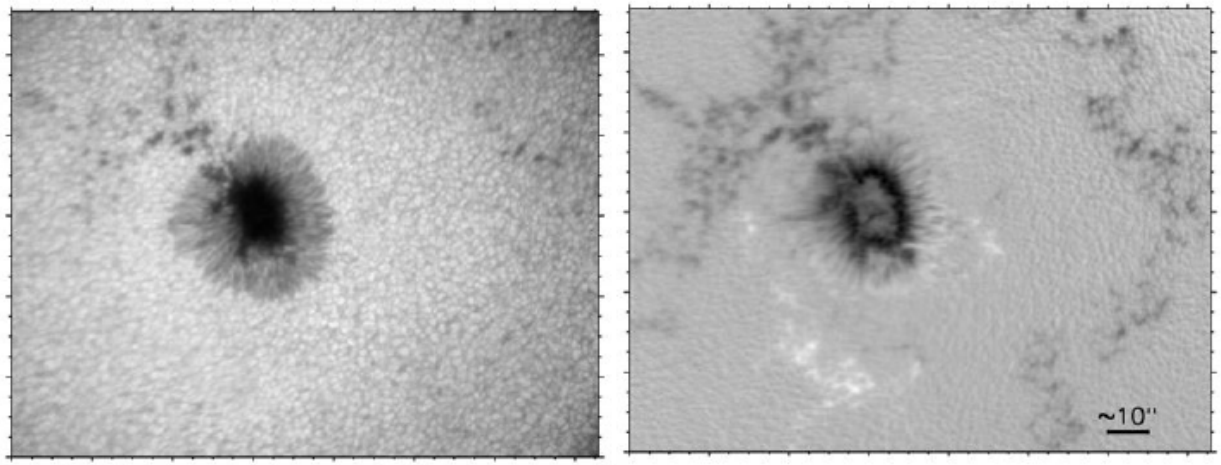
AstroSat CZTI has also another very important capability of detecting gamma-ray bursts (GRB) over large field of view. This, combined with hard X-ray polarization measurement capability, makes CZTI the only operational GRB polarimeter with high sensitivity. Within the first year of operation,

CZTI has doubled the sample of GRBs with polarization measurement from 10 (measured over 15 years before AstroSat launch) to 20 (additional 10 within one year by CZTI).

Spectro-polarimeter for Multi-Application Solar Telescope (MAST)

- Presence of magnetic field in the solar active regions or sunspots is responsible for the solar activities, such as flares and coronal mass ejections (CMEs). Measuring variations in the strength and configuration of the magnetic field is very important to understand and predict the solar activity. MAST is a newly installed 50 cm aperture modern solar telescope at the island observatory of Udaipur, Rajasthan, which is providing high spatial resolution solar images (around 250 km on the solar surface). It is aimed to provide regular measurements of the magnetic field on the solar atmosphere for understanding the origin and trigger mechanism of solar eruptions.

- A spectro-polarimeter (6173A, 8142 A) has been developed in-house as a back-end instrument for MAst which analyses the polarization property of the solar radiation (Zeeman effect) to infer the strength and configuration of the magnetic field. Two liquid crystal variable retarders (LCVR) along with a linear polarizer and a narrow band filter, provide polarization images of solar active regions which then can be converted into vector magnetic field maps using suitable computer programs. This facility for solar magnetic field measurements with high spatial and spectral resolution is the first in India. Continuous observations of magnetic fields of sunspots will help us to understand long term evolution of solar activity cycle and prediction of space weather.



The stokes I (left) and V (right) of a sunspot obtained using the MAST telescope

CHAPTER - 3
NATIONAL ATMOSPHERIC RESEARCH LABORATORY
GADANKI

National Atmospheric Research Laboratory (NARL), located at Gadanki near Tirupati, in Andhra Pradesh, is engaged in cutting edge research in atmospheric sciences with the vision of "Developing capability to predict the behavior of the earth's atmosphere through observations and modeling". Towards realizing this vision, NARL gives equal emphasis to technology development, observations, data archival, dissemination, data assimilation and modeling. Currently more than 40 observational facilities are in regular operation at NARL, which includes Mesosphere-stratosphere-Troposphere (MST) radar, Rayleigh lidar, Rayleigh Doppler lidar, Mie lidar, L-band wind profilers, Ionosonde, Gadanki Ionospheric Radar Interferometer (GIRI), Airglow imager, Radiosonde, Weather station, and radiation, aerosol, trace gases measuring instruments along with a High Performance Computing (HPC) system.

The research and development activities at NARL are carried out by seven groups viz., Radar Applications and Development Group (RADG); Ionosphere and Space Physics Group (ISPG); Atmospheric structure and Dynamics Group (ASDG); Clouds and Convective System Group (CCSG); Aerosols Radiation and Trace gases Group (ARTG); Weather and Climate Research Group (WCRG); Computers and Data Management Group (CDMG). There are also two independent projects viz., the Space-borne instrumentation development and LIDAR project.
During 2016-2017, NARL has published about 90 research papers in peer reviewed journals of international repute.

NARL also supports rocket launches from Satish Dhawan Space Centre (SDSC), SHAR by providing information on high altitude winds for wind biasing of launch vehicles. During 2016 and 2017, NARL has supported all the 12 rocket launches from SDSC and also designed and conducted special experiments tailored for the quantification of wind gust.

A. MAJOR FACILITIES / INSTRUMENTATION DEVELOPED DURING THIS PERIOD

One of the major developments at NARL during the above period is the upgradation of the MST radar into a full-fledged active phased array system having 1024 independent Transmit/Receive modules, and verification of their performance. This radar now facilitates conducting multi-receiver experiments for spaced antenna (SA) and radar interferometry/imaging of the neutral atmosphere and ionosphere. Capability of the new system to probe the troposphere, stratosphere, mesosphere and ionosphere, has been successfully demonstrated. Also, the system is so designed that it can be used to measure electron density, electric field, wind, composition and electron and ion temperatures in the ionosphere using incoherent scatter technique, which are not being measured elsewhere in India.

Tethered balloon observation platform has been established at NARL in 2016. The main components of this system are: 275 cu. m. balloon, tether, flight module, Wi-Fi communication link, electrical winch and hydrogen gas manifolds. This system is capable of hoisting 110 kg flight module up to an altitude of 1 km.

B. SCIENCE RESULTS

1. ATMOSPHERE AND CLIMATE

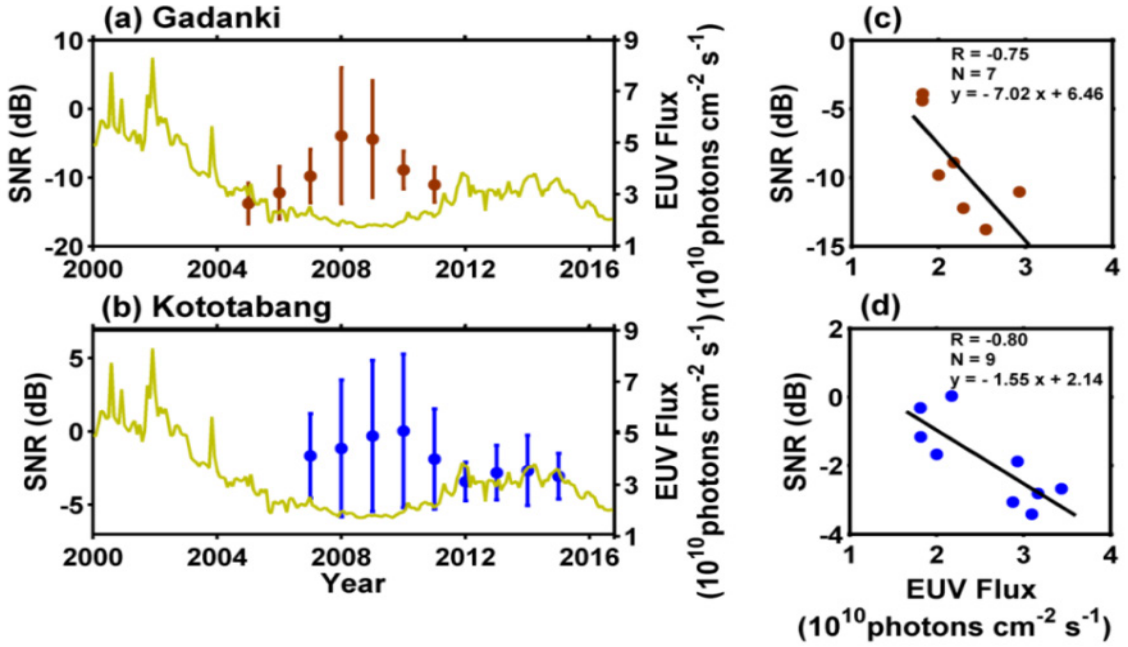
Recently an intense aerosol layer persisting at the tropical tropopause altitude (~16-17 km) over South Asia has been discovered in the satellite observations. At these altitudes, aerosols have a longer lifetime and thus can affect the Earth's energy budget, stratospheric ozone through heterogeneous chemistry, and the formation of cirrus clouds. They are perceived to be the result of increased pollutant gases and aerosols reaching these altitudes due to strong convective activity during the summer monsoon. A multi-instrumental intense field campaign - Balloon measurement campaigns of the Asian Tropopause Aerosol Layer – (BATAL) conducted to examine the composition of this layer has revealed that the layer is composed of small liquid volatile aerosol, primarily Nitrate, not dust. The BATAL project has been a successful partnership between institutes in the United states, Europe, India and Saudi Arabia.

The emissions of trace gases and particulate matter from open burning of waste are one of the sources of air pollution. An emission model has been developed based on the Intergovernmental Panel on Climate Change (IPCC) guidelines to estimate the district wise emissions of trace gases and particulate matter from open waste burning using the district wise data available for India.

Long-term trends and variability of the stratospheric ozone, water vapor and temperature over the Indian monsoon region are investigated using the long term data constructed from multiple satellites covering the period 1993–2015. Decreasing trend in ozone associated with NO_x chemistry in the lower stratosphere up to 24 km is found and the trend turned to positive above this altitude. The observed cooling trend in the stratosphere over Trivandrum and New Delhi is consistent with Gadanki Lidar observations. The water vapor shows increasing trend in the stratosphere matching with the observed increasing trend in the methane in the stratosphere. The trends in water vapor and temperature do not show much regional difference, but the ozone trend in the upper stratosphere is quite different between the stations.

2. IONOSPHERE, MAGNETOSPHERE AND SOLAR-TERRESTRIAL RELATIONSHIP

The discovery of the supra-thermal radar echoes from the daytime equatorial ionospheric F1 region, popularly known as '150-km echoes', have not only surprised the ionospheric scientists all over the world but remained the most puzzling and challenging field in the ionospheric plasma physics. Observations from Gadanki and Kototabang, Indonesia have revealed that the occurrence and intensity of the 150-km echoes have a clear inverse relationship with the extreme ultra voilet (EUV) flux (Figure 1), a result that is inconsistent with the latest theoretical premise. In addition, observations show important dynamical features providing new insight on the underlying physical processes including the complex role of atmospheric dynamics and solar photoionization process, which clearly support the potential role of ionospheric plasma instability manifesting these echoes. The new observational findings also open up the challenging unresolved science problem associated with the 150-km echoing riddle to the diverse scientific community.



Yearly mean SNR along with the standard deviation as a function of year observed at (a) Gadanki and (b) Kototabang. In both panels, the continuous line represents solar EUV flux Scatter plot of EUV fluxes and yearly mean SNR along with the best fit line for (c) Gadanki and (d) Kototabang, depicting the inverse relationship between the two parameters.

Fig 1

A severe geomagnetic storm, the largest till date in the solar cycle 24, occurred on 17 March 2015 with a minimum DSt index of -223 nT at 23 UT. This storm surprised many space weather specialists since it took place without any significant precursor X- or M-type solar flares. The most important finding obtained from the Gadanki Ionospheric Radar Interferometer (GIRI) observations is the confinement of plasma bubble and irregularities in a narrow longitude zone of 69°-98° E. Results also show reversal of zonal drift of the irregularities from ~120 m s^{-1} eastward drift to ~120 m s^{-1} westward drift in a time span of ~30 min. Both observations are shown to be linked with very special electro dynamical conditions induced by the magnetic storm related electric field in the dusk sector.

A climate model of Total Electron Content (TEC), representing latitudinal and local time variations, has been developed using data from 2 solar cycles 23 and 24. This model provides perturbation amplitude in TEC for the first time with respect to the intensity of the geomagnetic storm (minor, moderate or major). September equinoxes are found to bear maximum total, effective positive and negative storms; winters are found more prone to negative storms whereas summers have recorded minimum number of either of storms and minimum perturbation amplitudes. The results also highlight the lacuna in present observational facilities to understand the latitudinal and seasonal response of ionosphere during stormy conditions. Occurrence characteristics of day and night tropical (10°N–15°N, 60°E–90°E) mesospheric inversion layers (MILs) are studied by using TIMED

Sounding of the Atmosphere using Broadband Emission Radiometry satellite data products and chemical heating rates due to seven dominant exothermic reactions for the year 2011. It is found that the upper level height of daytime (nighttime) MIL descends (ascends) from ~88 km (~80 km) in winter to ~72 km (~90 km) in summer. The day and night inversion amplitudes are correlated with total chemical heating rates and CO_2 cooling rates, and they show semiannual variation with larger (smaller) values during equinoxes (solstices). The daytime (nighttime) inversion layers are predominantly due to the exothermic reaction, R_5: $O + O + M \rightarrow O_2 + M$ and R_6: $O + O_2 + M \rightarrow O_3 + M$ (R_3: $H + O_3 \rightarrow OH + O_2$). In addition, the CO_2 causes large cooling at the top and small heating at the bottom levels of both day and night MILs. In the absence of dynamical effects, the chemical heating and CO_2 cooling jointly contribute for the occurrence of day and night MILs.

Using the airglow CCD imager at NARL, diffraction of small wavelength scale (~20 km in horizontal) atmospheric gravity waves occurring around 97 km have been observed. Time series of images acquired during this event shows that the eddy parcel was almost localized stationary over NARL and lasted for about half an hour. Observations suggest that large-scale atmospheric eddy made up of pressure and temperature fluctuations with size of the order of 100 km width in the horizontal direction acted as an slit/obstacle to diffract an incoming large scale (>200 km wide) atmospheric gravity waves with wavelength of the order of 20 km.

It is well known that there are profound effects of solar cycle (SC) on the tropical deep convection and hence the atmospheric circulations. A detailed investigation of the effect of SC on the Hadley circulation (HC) reveals that the influence of SC is strong in southern hemisphere during the solar maximum.

3. THE SOLAR SYSTEM BODIES INCLUDING PLANETARY SCIENCE

Few aspects that cause horizontal inhomogeneity in the Martian ionosphere, like ionization bulges in regions of strong crustal magnetic fields, have been studied using data from the Mars Advance Radar for Subsurface and Ionospheric Sounding (MARSIS) instrument aboard the Mars Express spacecraft. It is found that the maximum density in the ionization bulges shows horizontal asymmetry. Some of the bulges, which appear as half-hyperbolas in radargrams, appear as full hyperbolas in maximum densitygrams. The apex of the hyperbola of the magnetically controlled density structures from the topside layer falls in the region of vertical magnetic fields, similar to those of the main layer. However, unlike the mainlayer, the recurrent occurrence of the topside layer at the same location is not common. More importantly, the oblique echoes from the topside layer are always associated with those from the main layer of the ionosphere, but not vice versa. The simultaneous observation of oblique echoes from the main and topside layers is explained by considering the formation of ionization bulges at the respective layer altitudes.

Using the electron density profiles measured by radio occultation experiment on the Mars Global Surveyor (MGS) spacecraft during 1998-2005, the variability of the topside Martian ionosphere has been studied. The variability of the topside ionosphere (occurrence and peak density) is found to be larger in the southern hemisphere than in the northern hemisphere. This variability is thought to be associated with the strength and variability of the crustal magnetic fields, which are larger in the southern hemisphere of Mars compared to the northern hemisphere.

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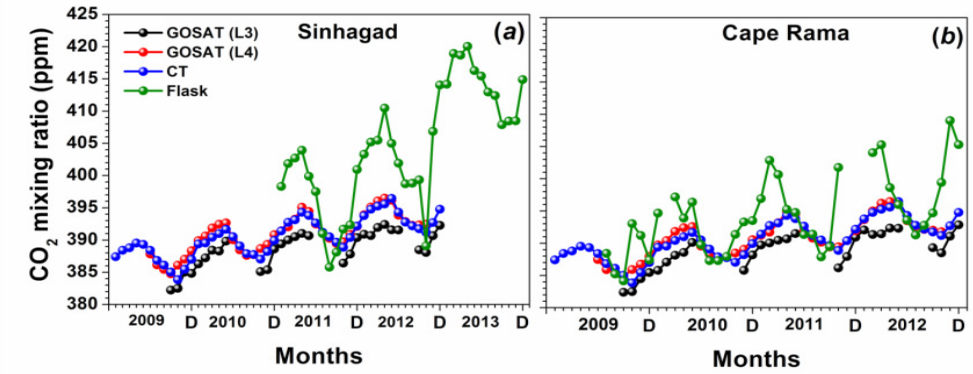
CHAPTER - 4
SPACE PHYSICS LABORATORY
THIRUVANANTHAPURAM

Space Physics Laboratory (SPL), Vikram Sarabhai Space Centre (VSSC) is committed for research in different disciplines of atmospheric sciences, space, and planetary sciences. It is involved in major space and atmospheric science programmes of India, such as Chandrayaan-1 & 2, Mars Mission, Youthsat, Megha-tropiques, ISRO-Geosphere Biosphere Programme, etc. SPL also co-ordinates major experimental campaigns, at national and international level, using balloons, air crafts, rockets, and research ship cruises. Highlights of some of the major scientific accomplishments during 2016-2017 are detailed in this report.

SCIENCE RESULTS:

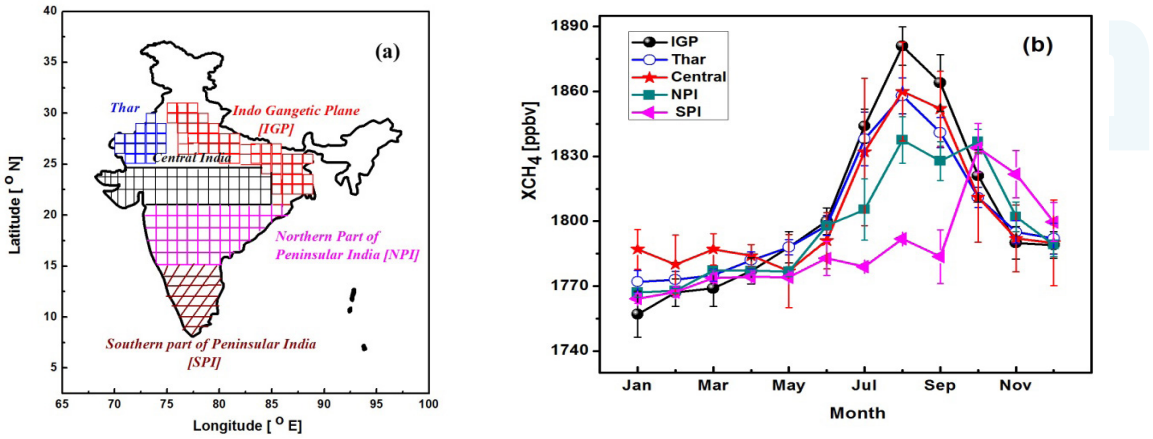
1. ATMOSPHERE AND CLIMATE

Satellite and ground-based measurements and model estimates of CO_2 over the Indian region - seasonal dependencies and spatial variability: Spatial distribution of carbon dioxide (CO_2) concentration over the Indian region and the surrounding oceanic regions during 2009-2012 was studied using measurements from satellite observations (GOSAT and AIRS), Carbon Tracker (CT) model simulations and flask measurements from two Indian stations Sinhagad (SNG) (73.7ºE 18.3ºN) and Cape Rama (CRI) (73.9ºE 15.1ºN). The concentration of CO_2 is observed to be maximum during pre-monsoon, with a decreasing phase during the post-monsoon season (Fig.1). On a regional scale, the Indo-Gangetic plain and northern India have relatively higher concentrations compared to the other regions. The comparison between the CO_2 flask measurements over SNG and CRI with respect to that of GOSAT and CT reveals that the differences in CO_2 are as high as 10 ppm between the ground and satellite based measurements. The Lagrangian model Flexible Particle (FLEXPART) has been utilized to understand the source-receptor relationship over CRI, SNG and the equatorial Indian Ocean. This shows that the source contributions from the northern and eastern continental regions of the Indian region are more influential over SNG compared to CRI. The equatorial Indian ocean has less influence from the continental source and therefore has a reduced seasonal variability compared to the land regions.



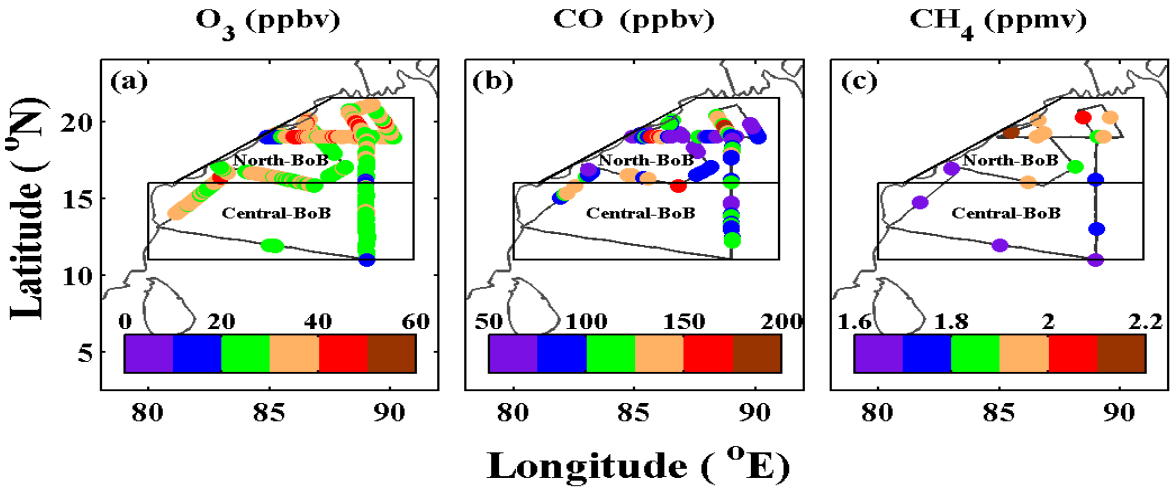
CO_2 concentration from GOSAT (L3A), GOSAT (L4B), CT, and Flask measurements over a) Sinhagad b) Cape Rama.
Fig 1

Satellite-observed seasonal pattern of methane over Indian region: The spatio-temporal variation of column averaged mixing ratio of methane (XCH_4) as obtained from satellite-borne payload SCIAMACHY over five distinct regions over the Indian landmass (Fig. 2(a)), namely Indo Gangetic Plains (IGP), Central India (CI), Thar, Northern part of Peninsular India (NPI) and the Southern part of Peninsular India (SPI). have been investigated and shown in Fig.2(b). The regional differences are attributed to the difference in emission from sources like livestock followed by rice cultivation, wetland, biomass burning and fossil fuel allied emission. The major sources inducing seasonality in CH_4 include, rice cultivation, wetland emission and biomass burning in addition to the meteorological conditions. Except for SPI, all other regions in India show an increasing trend in XCH_4 varying from 2.1 ppb to 3.5 ppb/year during 2003-2009.



(a) The study regions selected for the analysis: IGP, CI, Thar, NPI and SPI region and
(b) Monthly variation in Column averaged mixing ratio of CH4 (XCH_4) for the above regions
Fig 2

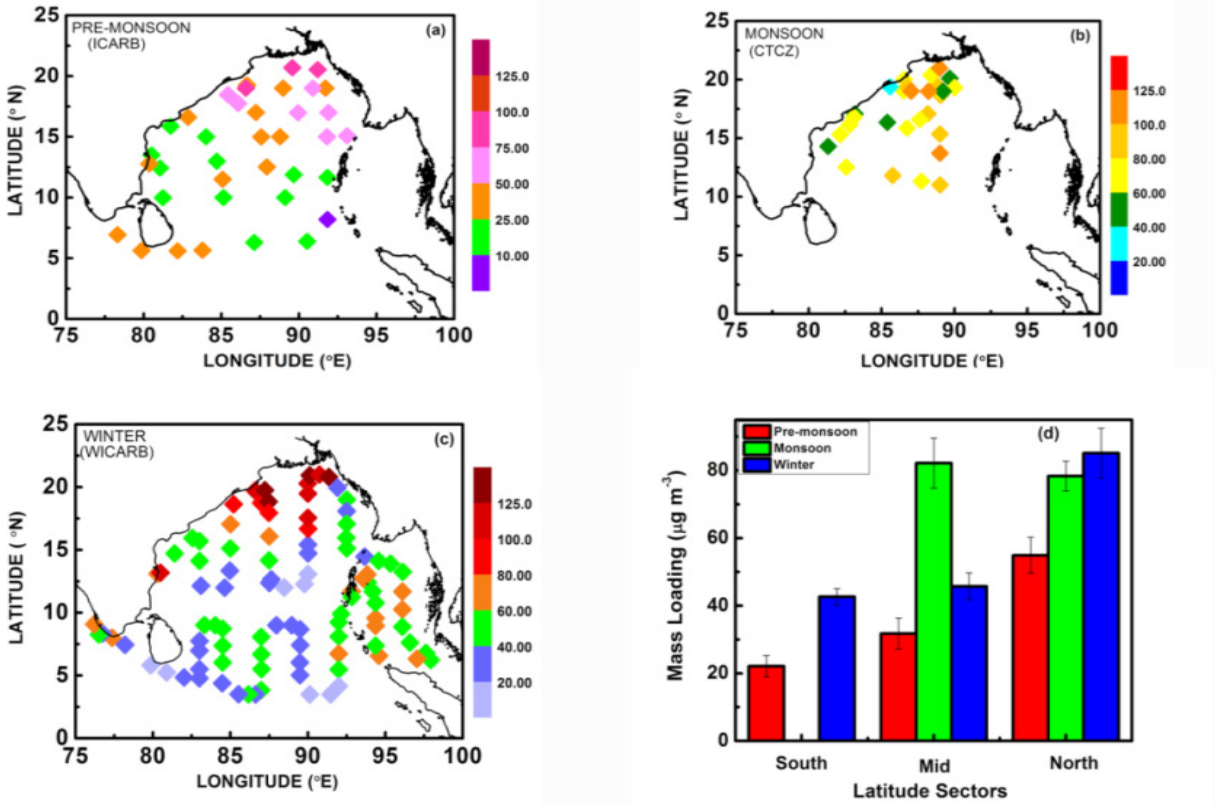
Variations in trace gases over the Bay of Bengal (BoB) during summer-monsoon: Spatio-temporal variations of O_3 and its residence time over continental India showed significantly correlated variability suggesting that transport from Indian subcontinent is the main controlling process for the observed variations (Fig.3). Model simulations using Weather Research and Forecasting model with Chemistry (WRF-Chem) captured the major observed variations in O_3 and CO over BoB during summer-monsoon. The observed reduction in O_3 that accompanied the onset of heavy rainfall, was associated with dynamics rather than wet scavenging.



Spatial variations of surface O_3 (a), CO (b) and CH_4 (c) mixing ratios along the cruise track during summer monsoon season. The solid lines mark two regions: central-BoB and north-BoB.

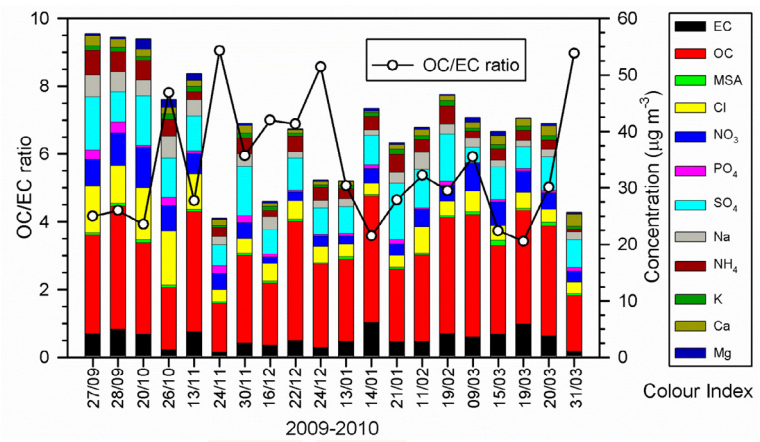
Fig 3

Seasonal changes in aerosol properties over the Bay of Bengal (BoB): A comprehensive study has been carried out on the near-surface and columnar properties of aerosols over the Bay of Bengal (BoB) addressing the physical, chemical and radiative aspects and their seasonal changes (Fig 4) based on (1) the ship-based in-situ measurement of near-surface aerosol properties, as part of two Integrated Campaign for Aerosols, gases and Radiation Budget (ICARB) campaigns and Continental Tropical Conversion Zone (CTCZ) campaign. The columnar characteristics of aerosols were retrieved from MODIS. The near-surface aerosol mass loading over BoB ranged from 10 to 100 μg m^{-3}, 41 to 117 μg m^{-3}, and 12 to 139 μg m^{-3} during pre-monsoon, summer monsoon and winter, respectively, with distinct seasonal patterns (Fig. 4). North BoB showed highest aerosol loading irrespective of the season with peak loading in winter. Continental influence is discernible during winter and pre-monsoon. The anthropogenic species (e.g., SO_4^{2-}, NO_3^-, NH_4^+ and BC) showed maximum levels in winter and minimum in summer monsoon with peak values over north BoB, and decreasing towards south, irrespective of season. The oceanic species Na^+ and Cl^- dominate during summer monsoon, with peak concentrations over mid BoB. Crustal species Fe and Al also peaked in north BoB in all seasons with peak loading in pre-monsoon, indicating long range transport of dust aerosols from western arid regions. The studies also reveal near surface aerosol loading has significant contribution to the columnar loading.



Spatial patterns of near-surface aerosol mass loading (M_L) over the Bay of Bengal during (a) pre-monsoon, (b) monsoon and (c) winter seasons. (d) Seasonal variation of aerosol mass loading for different latitude sectors of BoB.
Fig 4

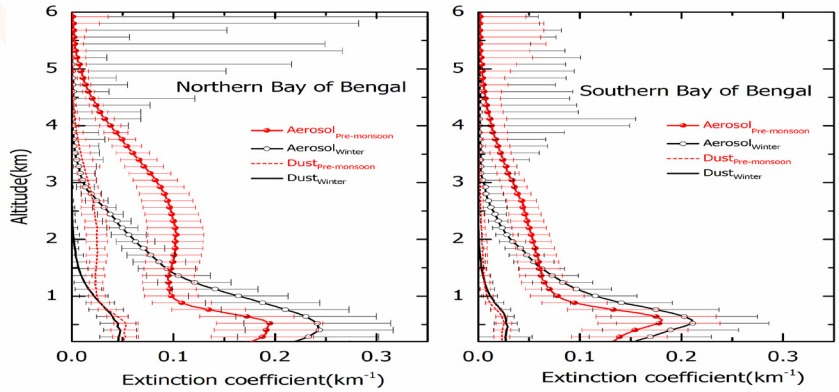
Carbonaceous and inorganic aerosols over a coastal and sub-urban site in peninsular India: At the coastal site Thumba (8.5°N, 76.9°E, 3 m asl), about ~20-70% of total suspended particulate matter is composed of carbonaceous matter comprising of organic carbon (OC) and elemental carbon (EC). Temporal variations of particulate chemical composition and the OC/EC ratio during the study period are shown in Fig.5. On average, water-soluble components (30 μg m^{-3}) account for about 33% of total aerosol mass (92 ± 35 μg m^{-3}). The Ca/Mg mass ratio centring around 3.6 ± 2.4 suggest that chemical composition of aerosols is dominated by calcareous dust transported form Arabian Desert region. In the aerosol samples collected from a sub-urban site in Coimbatore, the total carbonaceous aerosols and water soluble ionic species contributed to 31% and 45% of PM_{10} mass respectively. OC contributed to 17% while EC to 3% of PM_{10} mass. OC/EC exhibited an annual average of 5.7 ± 4.2. Large abundance of SO_4^{2-} and OC in PM_{10} along with good correlation of K^+ with OC, EC, POC, WSOC and SO_4^{2-} suggests biomass burning as a major source in this region.



Temporal variations of particulate chemical composition and the organic carbon/elemental carbon (OC/EC) ratio over Thumba

Fig 5

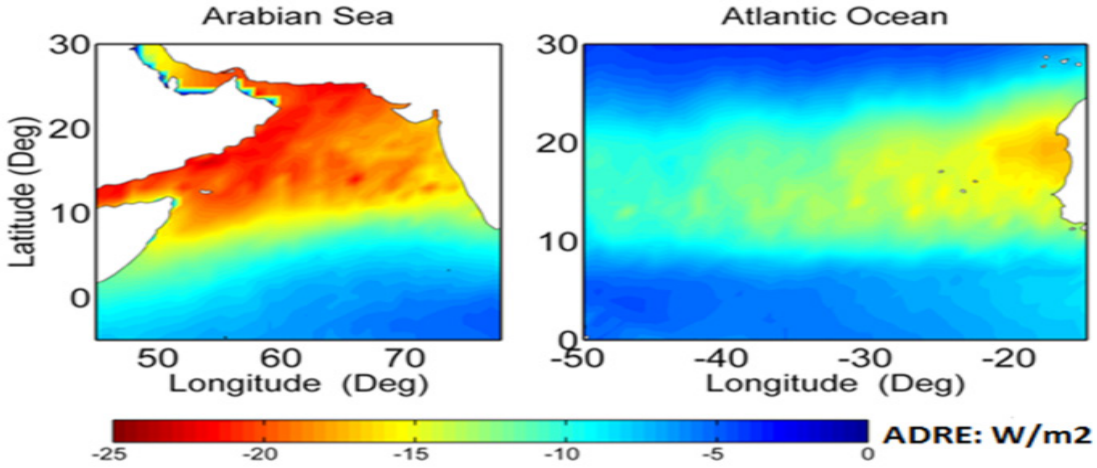
Vertical Structure of aerosols and mineral dust over the Bay of Bengal from multi-satellite observations: The vertical distribution of aerosol and dust extinction coefficient over the Bay of Bengal is examined using multi-satellite observations Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP) and Moderate Resolution Imaging Spectroradiometer (MODIS)) during 2006 to 2017 (Fig 6). An enhancement of 24% in the aerosol extinction is observed above 1 km from winter (December, January and February) to pre-monsoon (March, April, and May). Significant contribution of mineral dust is observed over the northern Bay of Bengal during pre-monsoon season where 22% of the total aerosol extinction is contributed by dust aerosols transported from the nearby continental regions. During winter, dust transport is found to be less significant with fractional contribution of ~10% to 13% to the total aerosol optical depth over the Bay of Bengal. MODIS derived dust fraction (fine-mode based) shows an overestimation up to 2 fold compared to CALIOP dust fraction (depolarization based) whereas the GOCART (chemical transport model) simulated dust fraction underestimates the dust fraction over BoB.



Altitude profiles of total aerosol extinction coefficient and dust aerosol extinction coefficient over Bay of Bengal derived from the combination of data from space-borne LIDAR (CALIPSO) and MODIS.

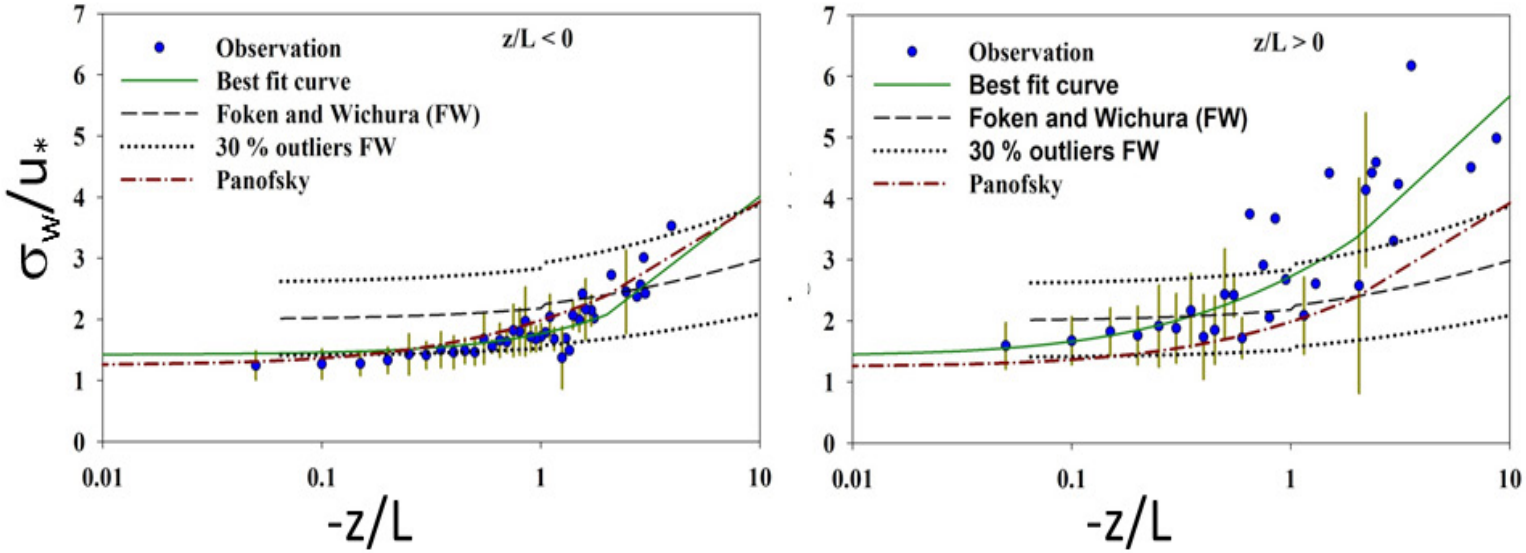
Fig 6

Megha-Tropiques ScaRaB observations of aerosol radiative effect over the mineral dust dominated Arabian Sea and the Atlantic Ocean: During the Asian summer monsoon season (June – September), the Arabian Sea is covered by large-scale mineral dust plumes transported from the west Asian deserts. In contrast, the Atlantic Ocean experiences large-scale mineral dust transport from the Saharan region throughout the year. Direct observations of the radiative effect of these mineral dust plumes and their diurnal variations during summer over the Arabian Sea are very limited. Direct observations of the diurnal variation of the instantaneous aerosol direct radiative effect (IADREE), diurnal mean aerosol direct radiative effect (ADREE) and diurnal mean aerosol direct radiative effect at top-of-atmosphere (TOA) over the Arabian Sea during the Asian summer monsoon season were carried out and compared these with the corresponding parameters at the mineral dust dominated northern equatorial Atlantic Ocean during the same period.(Fig 7) This was achieved by utilizing the uniqueness of the low-inclination Megha-Tropiques-ScaRaB satellite observations, which cover all local times over all regions in the tropics during the 51-day precession cycle of the satellite. Estimates of the IADREE are carried out using the collocated observations of shortwave radiative fluxes at TOA under cloud-free conditions using MT-ScaRaB and aerosol optical depth (AOD) derived from MODIS data. The estimates of the IADREE made using the MT-ScaRaB data at 13:30 local time are found to be in agreement with those derived from the CERES data at this local time, at which the latter observations are carried out. The IADREE derived from the MT-ScaRaB shows diurnal peak value of -53 ±10 $Wm^{-2}\tau_{550}^{-1}$ and -40 ± 3 $Wm^{-2}\tau_{550}^{-1}$ at solar zenith angle of ~ 40° over the Arabian Sea and the Atlantic Ocean respectively. Diurnal mean aerosol direct radiative effect efficiency at TOA during June-September is -22 ±4.5 $Wm^{-2}\tau_{550}^{-1}$ over the Arabian Sea and -18 ±3.6 $Wm^{-2}\tau_{550}^{-1}$ over the Atlantic Ocean.



Spatial variations of seasonal mean ADRE over the Arabian Sea and the tropical Atlantic Ocean based on the seasonal mean AOD during June-September of 2000-2014.
Fig 7

First experimental evidence for the applicability of Monin-Obukhov Similarity Relationships over complex terrains of Central Himalayas: In principle, the scaling methods and similarity relationships for turbulence variables observed over flat homogeneous terrains are not applicable as such to complex mountain terrains because of orography and slope winds. For the first time, the applicability of Monin-Obukhov Similarity Theory (MOST, which is conventionally applicable at flat terrains) over complex mountain terrains of the Central Himalayas have been investigated based on the micrometeorological observations carried out using fast-response (25 Hz) sonic anemometer (mounted at 10 and 27 m height levels) at ARIES, Nainital (29.4°N, 79.5°E, altitude 1926 m). Tilt corrections are applied to the sonic anemometer data using planar fit method (PFM) for converting the observed variations into terrain-following coordinate system. The variations of standard deviations of vertical wind normalized with friction velocity (σ_w/u_*) and standard deviations of temperature normalized with scaling temperature (σ_θ/T_*) as a function of stability parameter (z/L) are then used to assess the applicability of MOST (Fig. 8). During neutral conditions, the value of σ_w/u_* is found to be ~1.2. Variations of σ_w/u_* and σ_θ/T_* as a function of z/L indicate that they follow a power law variation during unstable conditions, with an index of 1/3 for the former and -1/3 for the latter. The coefficients defining the above variations are found to be in agreement with those derived over flat terrains when MOST is applicable.

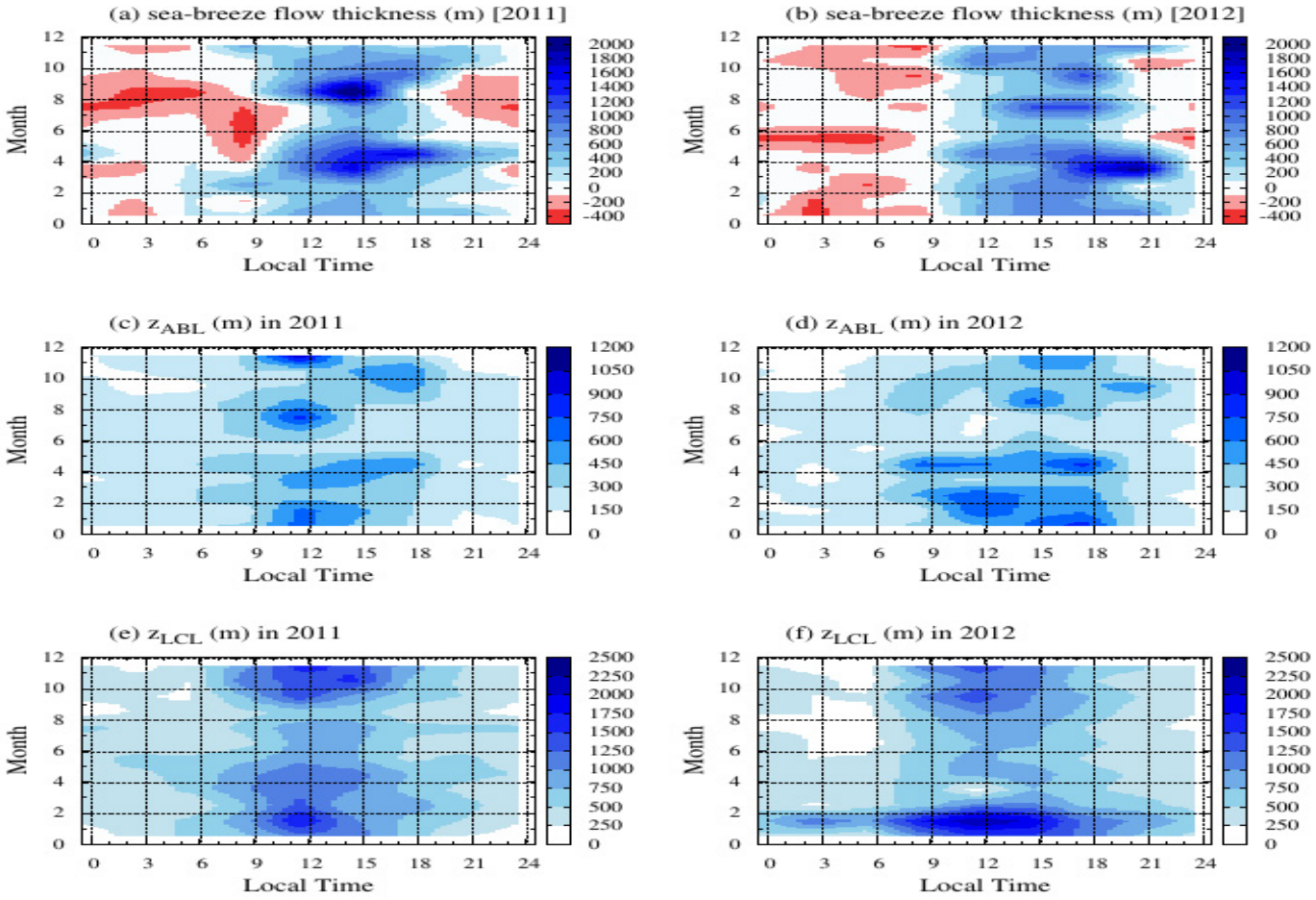


Variations of σ_w/u_* with z/L for unstable (z/L < 0) and stable (z/L > 0) conditions at Nainital. The solid line represents the curve fitted using the present observations. The dashed line represents the variation derived by Foken and Wichura (1996) (FW96). The dotted line represents the values 30% lower or larger than FW96.

Fig 8

Multi-Year morphology on the vertical Structure of coastal ABL over Thumba: Diurnal evolution of the vertical thickness of sea breeze flow (ZSBF) and thickness of ABL (ZABL) in association with the altitudes of lifting condensation level (ZLCL) over Thumba are investigated using radiosonde observations. The monthly patterns in the diurnal variations of coastal ABL in terms of ZSBF and ZLCL for two consecutive annual

cycles of 2011 and 2012 is depicted in Fig 9. The thickness of sea breeze flow is inferred from the vertical profiles of sea breeze component (SBC), and the altitude corresponding to the first reversal in the magnitudes of SBC from positive to negative is marked as the top of the sea breeze flow. (For accommodating the land-breeze flow together with the sea breeze flow, the land-breeze flow thickness is assigned negative sign). The thickness of land-breeze flow is lower (< 450 m) than the daytime sea breeze flow. The ZSBF peaks in April-May and September-October period. After attaining a maximum depth of the sea breeze flow typically by 15 LT, the flow sustains for a few more hours and gradually collapses after 20 to 21 LT through the intrusion of the land-breeze flow. In a broad sense, after the sunrise at about 06 LT, as the turbulence activities grow in magnitudes, the ABL unstable and its vertical thickness quantified as ZABL also attains a peak.



Monthly mean variations in the (a) sea breeze flow thickness (in m); (c) z_{ABL} (in m); and (e) z_{LCL} (in m) as a function of local time for the year 2011; (b), (d) and (f): same as (a,c,e), but for 2012.

Fig 9

Changes in La Nina Teleconnection to the Indian summer monsoon during the recent period: The Indian summer monsoon (ISM) season receives above normal rainfall during most of the La Nina years. The above normal ISM rainfall events have considerably decreased during post-1980 La Nina events. In intra-seasonal scale, the average number monsoon active days during La Nina years after 1980 reduced to 11.6 from 16.5 of pre-1980 La Nina years. The formation of weather systems (depressions and above) over the Bay of Bengal during the summer monsoon season are also considerably reduced during post-1980 La Nina years.

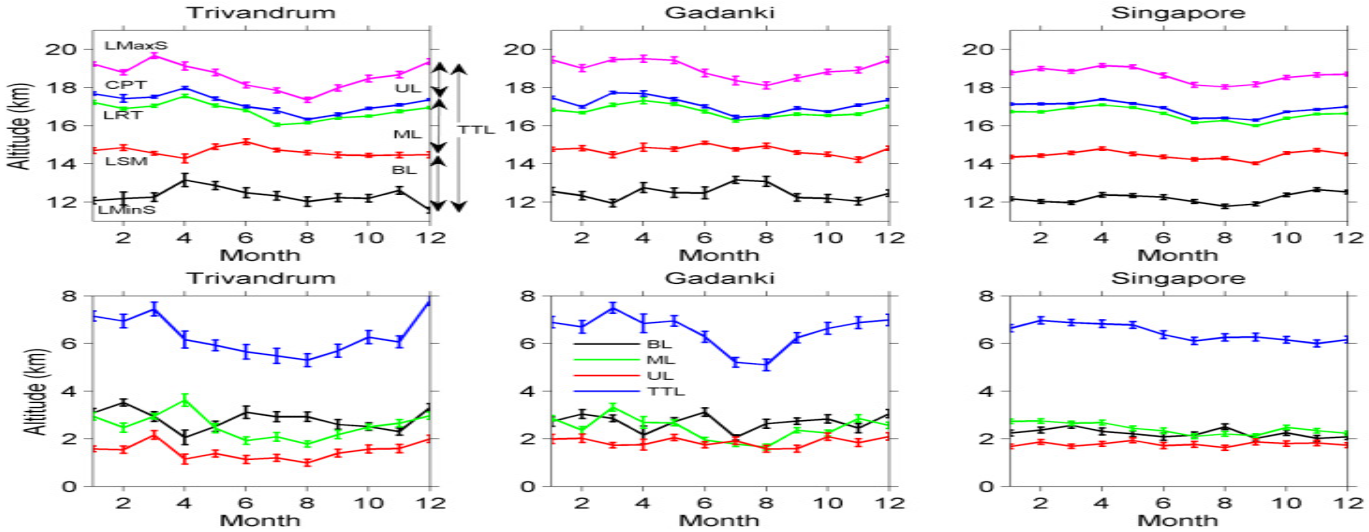
Microwave remote sensing of tropical convection: Using the water vapor channels of the Megha-Tropiques- Sounder for Atmospheric Profiling of Humidity in the Inter-tropical Regions (SAPHIR), a methodology has been developed to detect convective cloud cores with different vertical extents. The methodology has been validated by comparing with CloudSat radar measurements of deep convective and overshooting cloud systems and utilized to study the seasonal mean deep convective cloud characteristics over the entire tropics.

Diurnal variability of relative humidity using Megha-Tropiques SAPHIR: Global diurnal variability of relative humidity (RH) from August 2012 to May 2014 has been derived from SAPHIR, a microwave humidity sounder onboard Megha-Tropiques. A distinct diurnal variation is obtained over continental and oceanic regions at all the layers. The magnitude in the lower tropospheric humidity (LTH), middle tropospheric humidity (MTH) and the upper tropospheric humidity (UTH) show a large variability over the continental regions compared to the oceans. Afternoon peaks dominate in the LTH over land. The MTH is found to vary between evening and early morning hours over different geographical regions and not as consistent as that of the LTH. The UTH maximum magnitude is generally observed during the early morning hours, over the continents. Similar variations are found over oceanic regions. The diurnal amplitude was found to be maximum over the continents as compared to oceans. The Indian sub-continent showed maximum diurnal amplitude during October to March, and negligible amplitude during the Indian summer monsoon.

Characteristics of wide-spread low level clouds over subtropical oceans: Properties of low-altitude clouds, their radiative impact and day-night changes over the subtropical oceanic regions of prominent stratocumulus occurrence (the Northeast and the Southeast Pacific, the Southeast Atlantic, and the South Indian Ocean) were investigated using multi-year (2006-2010) CloudSat, CALIPSO and CERES observations. In all these regions, the occurrence, thickness and longwave radiative impact of clouds are enhanced during the night time, while the altitude of peak cloud occurrence (960-1200 m) remains steady. On average, the nighttime enhancement in the absolute magnitude of low-altitude clouds is ~140-180% of their daytime values at the altitude of peak occurrence. Probability distribution functions of cloud top altitude show broad peak between 960-1940 m. Compared to the daytime, average night time cloud top altitudes are higher by ~100 – 180 m. The altitudes of peak cloud occurrence are least (typically 720 m) near the coastal regions and systematically increase by ~240-480 m within 10° westward from the coast during both day and night. Radiation transfer simulations and observed day-night changes in the vertical distribution of clouds suggest that the diurnal amplitude of the LWCRF and their regional variations arise primarily because of the vertical distribution of clouds.

A new perspective of Tropical Tropopause Layer (TTL) boundaries based on thermal and stability profiles: A new method proposed to delineate the Tropical Tropopause Layer (TTL) based on static stability criteria defined it as the region extending from the level of minimum static stability (LMinS) to the level of maximum static stability (LMaxS) with a secondary minimum (LSM) in-between. The study using radiosonde data from three tropical stations (Singapore, Trivandrum and Gadanki) and COSMIC GPS RO data over the tropics during 2011-2014 demonstrated that, in terms of stability, the TTL is a composite of three sub-layers, viz., the bottom layer (BL)-the region between LMinS and LSM, the

Middle Layer (ML) the region between LSM and Cold point tropopause (CPT) and the Upper Layer (UL)- the region between CPT and LmaxS. Annual variation of the TTL boundaries and thickness of BL, ML and UL of TTL showed (Fig. 10) relatively large annual variation at Trivandrum, but relatively small variation at Gadanki and minimal variation at Singapore. A major advantage of the new definition for the TTL is that it provides a definite criterion to characterize the TTL for delineating the thermal and dynamical processes in terms of tracer motion, transport and radiative effects. It can delineate the short time temporal variations of the TTL at a given location.



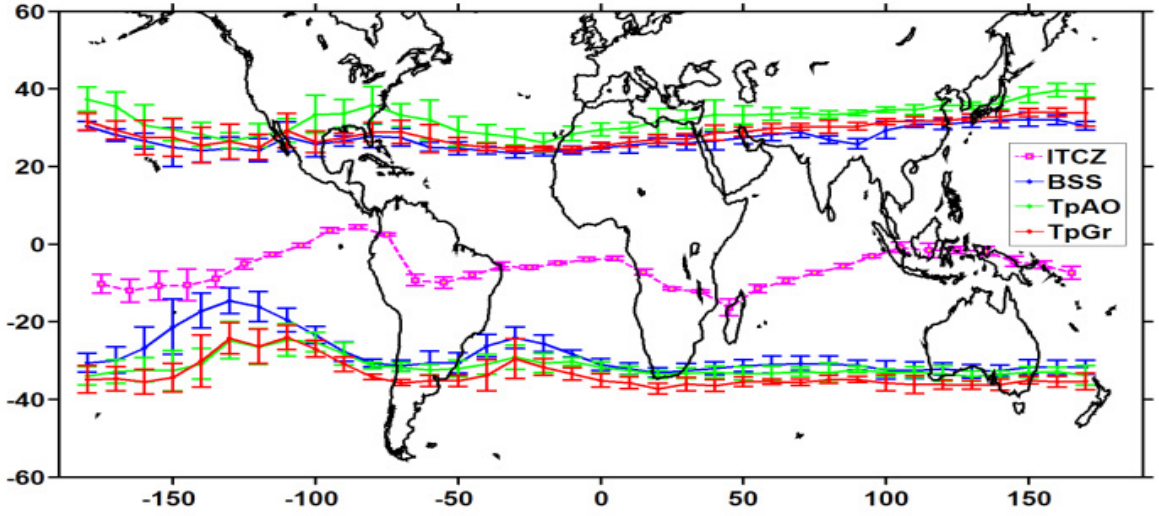
Mean annual variation of TTL boundaries (top panel) and thicknesses of TTL, BL, ML and UL (bottom panel) during December 2010 to March 2014 over Trivandrum and Gadanki. Vertical bars indicate the standard errors.

Fig 10

Stratospheric air intrusion into the troposphere during the passage of tropical cyclone: Plausible mechanisms to account for the intrusion of dry ozone-rich stratospheric air into the troposphere during the passage of the tropical cyclone have been proposed. Overshooting convection associated with deep convective system is found to be the prime candidate for the generation of turbulence in the vicinity of tropopause (VOT). In addition, the presence of strong updrafts and downdrafts in the VOT weakened the stability of the tropopause which allowed the dry ozone-rich stratospheric air to penetrate downwards to the upper troposphere. Indian MST radar observations shows a significant modulation in the tropopause structure which is found to be accompanied by structures linked with shear instability. Concurrent ozone measurements also indicate the intrusion of stratospheric air mass into the upper and middle troposphere. The most significant and new observation is the increase in the upper tropospheric ozone by 20-50 ppbv, which has extended down to the lower troposphere. Further, the enhanced upper tropospheric ozone penetrated down and increases the surface ozone concentration. Enhancement of surface ozone concentration by ~ 10 ppbv in day-time and 10-15 ppbv in the night-time is observed during the passage of tropical cyclone. The descending rate of enhanced ozone layer is found to be ~1 km/day. Observations of relative humidity using MT-SAPHIR indicate the presence of sporadic dry air in the upper and middle troposphere over the cyclonic region, providing experimental evidence for enhancement and redistribution of tropospheric and surface ozone during cyclonic storms.

Distribution of the multi-layered clouds across the globe using CloudSat observations: It is essential to establish the vertical distribution of clouds and study their role inmodifying the atmospheric circulation, for better understanding of cloud feedback mechanisms in totality. Using 4 years of (2007–2010) CloudSat and CALIPSO observations, the distribution of multi-layered clouds and associated dynamics across the globe were studied. The single layer clouds were more or less uniformly distributed over the entire longitudinal belt over 60-70^0 S and it ranges from 60-70% with minimal seasonal variations over this region. Two, three, four- and five-layered clouds showed equatorial maxima during all the seasons, with pronounced maxima during summer over the Indian sub-continent.

Regional features of Hadley Cell: The regional features of Hadley Cell (HC) width has been investigated using three objectively defined tropopause-based metrics for the first time, using eight years of COSMIC GPS-RO temperature profiles. (Fig 11) Definitions of two of the existing tropopause-based metrics, viz. meridional gradient of tropopause (TpGr) and tropospheric Bulk Static Stability (BSS), are extended to determine the zonally resolved HC widths. In addition, a third metric is proposed based on the pronounced amplitude of annual oscillation of the tropopause (TpAO) height over the subtropical region. Reliability of the tropopause-based metrics in delineating the zonally resolved HC width is established by comparing it with the annual cycle of the zonal mean HC width obtained from the MSF metric estimated from the ERA-I reanalysis dataset. Regional features of the total width of the HC and their relationship to the location and movement of the ITCZ has been investigated. The present results have potential applications in investigating the zonally resolved trends in HC expansion.

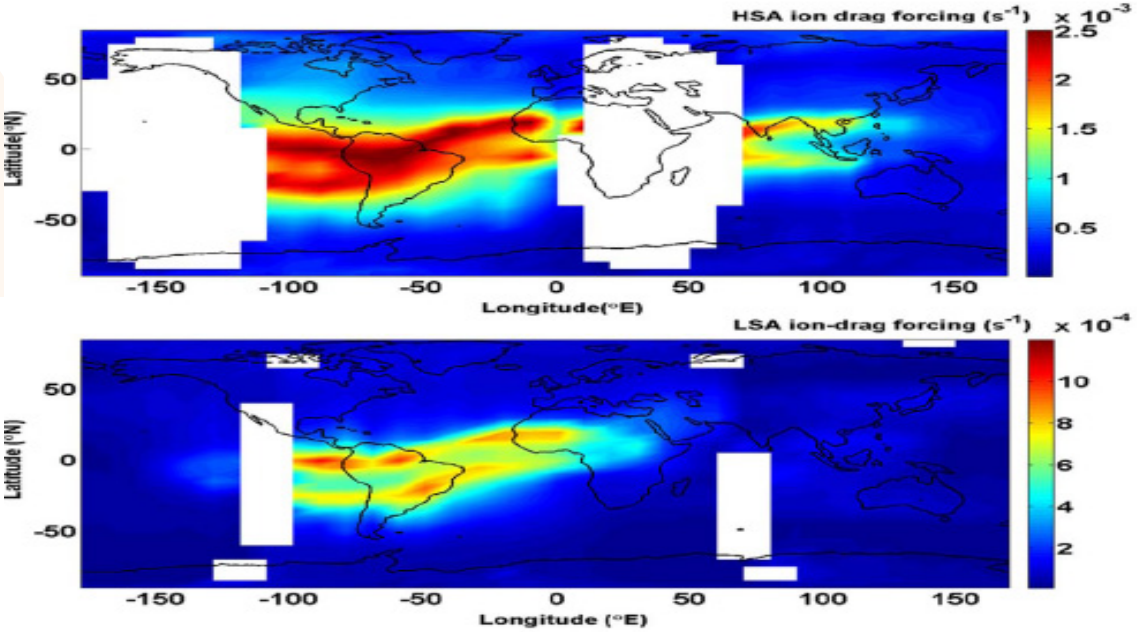


Zonally resolved HC edges using three tropopause metrics along with location of ITCZ for the Northern Hemispheric winter season derived using COSMIC Observations during 2006-2013.
Fig 11

2. IONOSPHERE, MAGNETOSPHERE, AND SOLAR – TERRESTRIAL RELATIONSHIP

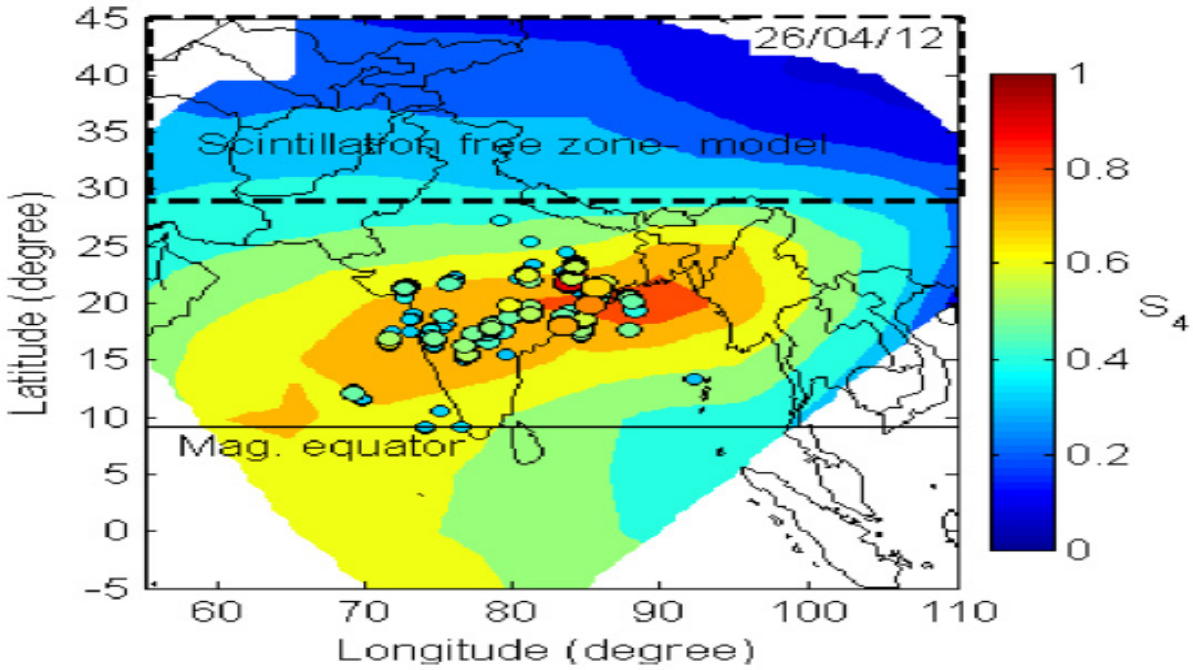
Terrestrial Ionosphere/Space Weather: With an objective to monitor the impact of space weather events on the Indian low latitude Ionosphere-Thermosphere (IT) system and the coupling between magnetosphere and high-latitude ionosphere and its implications on the low latitude IT system, Space Physics Laboratory (SPL) has initiated two major science programs called, Indian network for Space Weather Impact Monitoring (InSWIM) and Energetic Coupling in the Sun-Earth System (ECSES). Under the ECSES program, a GNSS receiver was installed at the Indian Antarctic station Bharati and is continuously operational since 2014. Under the aegis of the InSWIM program, a set of multi-frequency, multi-satellite GNSS Receiver systems have been installed at various places in India. The results indicate that when negative ionospheric storm was observed over high-latitudes, the mid-latitude region showed positive ionospheric storm effect, due to the changes in the global wind system and the storm-induced composition changes. Fast fluctuations in the IMF Bz are found to lead to counter electrojet-like condition at the dip equator and produced a positive storm impact in the entire low-latitude ionospheric region in the Indian sector. The study also showed that storm-induced Joule heating at the auroral region can give rise to gravity waves propagating equatorward at velocity as high as 800 m/s. The InSWIM data have also been used to study the disturbance dynamo effects on EIA. It is observed that as a result of the westward DD electric field, the daytime zonal electric fields can become westward during the late main phase to recovery phase of a storm and because this happens from the morning hours, the fountain can completely cease, showcasing another important aspect of the space weather impact on low-latitude plasma distribution. The GNSS network of InSWIM has also been utilized to study the characteristics of plasma bubble-induced ionospheric irregularities and their drift velocities and east-west spatial widths.

Nocturnal thermospheric meridional winds over Indian longitudes - Solar activity dependence: A comprehensive analysis of nocturnal thermospheric meridional wind pattern in the Indian longitude sector encompassing two solar cycles has been carried out. Significant difference is seen in winds between high and low solar activity epochs, with less equatorward winds during pre-midnight hours for high solar activity years. The solar flux dependence of mean winds during post sunset hours has been established. An integrated approach using ground as well as space based observations, and models have been employed to understand the underlying causative mechanisms behind the observed solar activity responses of thermospheric winds. It has emerged that the major reduction in nocturnal equatorward meridional wind during high solar activity years is a consequence of enhanced ion drag, as depicted in Fig.12. This study highlights the need to improve the existing thermospheric models by incorporating the effects of physical processes like the ion drag.



Ion drag force estimated for Autumnal Equinox during high and low solar activity years.
Fig 12

Satellite Based Augmentation System(SBAS)derived TEC: A new tool to forecast the spatial maps of maximum probable scintillation index over India: Understanding L-band scintillation with a goal to forecast is extremely important as it affects the accuracy and reliability of satellite-based navigation services. The strength of the scintillation on any given day forms one of the crucial elements to be a part of any scintillation forecasting scheme. An attempt has been made to forecast the strength of scintillation using the SBAS derived Total Electron Content (TEC). The superposition of actual S4 measurements, obtained from the GAGAN network of receivers, on the forecasted S4 max map (Fig.13) shows that the predicted S4 fair well when compared with actual measurements, though magnitudes are somewhat underestimated. This simple technique has the potential to provide the 2D maps of maximum probable scintillation index for the whole night which, with more refinements, could evolve into a viable forecast or forewarning system.



Comparison of forecasted scintillation strength with actual measurements of the S4 index on April 26, 2012.The circles denote the S4 measurements at different ionospheric pierce points (IPPs) observed by ground stations. The colour code inside circles depicts the strength of measured scintillation—S4 index. The dashed rectangular region represents the scintillation-free zone
Fig 13

3. SOLAR SYSTEM BODIES, INCLUDING PLANETARY SCIENCE

Science Results From Chandrayaan-1

Science Results From Sub-keV Atom Reflecting Analyzer (SARA)

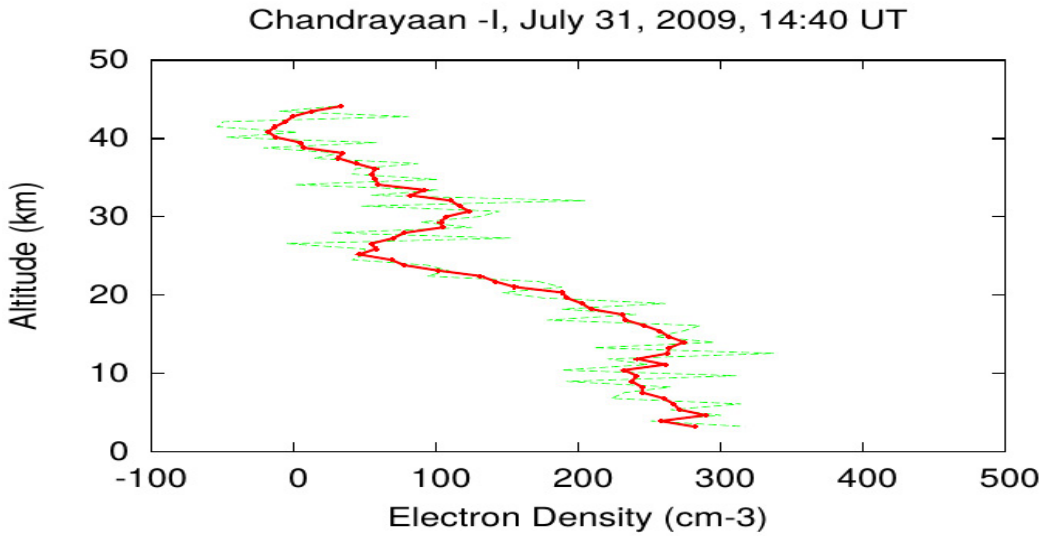
The Sub-keV Atom Reflecting Analyzer (SARA) experiment onboard Chandrayaan-1 consisted of a low energy neutral mass analyzer namely 'Chandrayaan-1 Energetic Neutrals Analyzer' (CENA) and an ion mass analyzer, namely 'Solar Wind Monitor' (SWIM). SARA observations have yielded several path breaking results on the solar wind interaction with the Moon, and on the lunar environment. The recent findings from the SARA experiment are described below.

- **Discovery of a new population of Suprathermal protons around Moon:** Anew population of suprathermal protons (H^+) has been observed around the Moon by the SWIM/SARA. The observations were made when the Moon was located outside Earth's bowshock. The observed protons are found to have energy of about 1.5 to 3 times that of solar wind. The comparison of the observed flux (density) with that expected from these sources and the velocity distribution suggests that an additional source is required to explain the population.
- **First observation of Energetic Neutral Atoms from the Lunar NightsideSurface:** SARA observed for the first time, the energetic neutral atoms that originate from the lunar night side surface. ENAs are not confined to the lunar dayside surface, and there is a substantial amount of ENAs from just beyond the terminator, which are seen forming a wide ring structure parallel to the terminator. Two distinct hydrogen ENAs are observed with distributions parallel to the terminator. The spectral shape, and the intensity indicate that these particles originate from the bulk solar wind flow. This study not only showed the surface interaction of solar wind accessing the near wake region, but also provided the first observations indicative of the solar zenith angle dependence of the positive dayside surface potentials.

Science Results From VIS-NIR data Compositional Studies of Mare Moscoviense: Moscoviense is one of the prominent mare-filled basin on the lunar far side holding key insights about volcanic activity on the far side. The spectral and elemental maps of mare Moscoviense, derived using the Moon Mineralogy Mapper (M^3) and Infrared Spectrometer-2 (SIR-2) data-sets are analysed. Detailed analysis of the entire Moscoviense basin indicates that the concentrations of orthopyroxene, olivine, and Mg-rich spinel, named as OOS rock family are widespread and dominant at the western and southern side of the middle ring of the basin with one isolated area found on the northern side of the peak ring.

Science Results in Radio Occultation Experiment for Studying Lunar Ionosphere: The origin of the Moon's ionosphere has been explored using Chandrayaan-1 radio occultation (RO) measurements and a photochemical model. The electron density near the Moon's surface, obtained on 31 July 2009 (~ 300 cm^{-3}) (Fig 14), is compared with results from an indigenously developed photochemical model which includes production and recombination of sixteen ions, solar wind proton charge exchange and the electron impact ionization. The model calculations suggest that in the absence of transport, inert ions dominate lunar ionosphere, whereas the interaction with solar-wind, leads to their complete removal. Assimilating

the information on the major neutral components of the lunar exosphere from previous observations, including that from CHACE/MIP, the model calculations suggest that the lunar ionosphere may be dominated by molecular ions with near surface density ~ 250 cm^{-3}.



Altitude profile of electron density at Moon during the occultation of Chandrayaan-1 radio signal at 1440 UT on 31 July 2009. The green curve in this figure represents actual data points while the red curve represents three point running average smoothed profile. Fig.14.

4. INTERACTION OF SOLAR RADIATION WITH PLANETARY ATMOSPHERES:

It has been found that models overestimate the electron density on Titan's dayside ionosphere by a factor of 2 to 3 around the peak when compared to the observations made by the instruments onboard Cassini mission. To explore the possible reasons for this discrepancy, a 1-dimensional photochemical model has been developed and density profiles of ions and free electrons on the dayside ionosphere of Titan are calculated. It is found that the Cassini observed density profiles are consistent with model calculations when the parameters which influence the loss of ions and electrons, viz. electron temperature and dissociative electron recombination rate coefficients are varied. The study suggests that even though the overestimation in the production parameters may contribute towards the disagreement between the modelled and observed plasma densities to some extent, a more significant role is played by the loss processes. It is probable that some important chemical reactions are missing that may account for the additional loss of ions and electrons.

- **Solar wind interaction with the Mercury:** Both the Moon and Mercury possess surface bound exosphere. However, Mercury is a magnetized planet, which makes the interaction of solar wind with Mercury a unique scenario. Based on the knowledge of the solar wind scattering from the Moon, the scenario of similar process happening at Mercury is investigated. The empirical angular scattering function and the energy spectrum derived for the ENAs and for the protons scattered from the Moon based on the SARA observations are used for a range of incident plasma parameters since the solar wind conditions at Mercury are different from that of the Moon. From these, the differential fluxes of hydrogen ENAs and the protons from Mercury are estimated for the different plasma precipitation conditions happening on Mercury.

- **Study of planetary neutral atmospheres/exospheres:** The Mars Neutral Composition Analyzer (MENCA) onboard the Indian Mars Orbiter Mission (MOM) is a neutral mass spectrometer, which provides the in-situ measurement of the low latitude neutral exosphere of Mars. The altitude profiles of Argon-40 (Ar), which is a minor constituent in the Martian exosphere, are studied using MENCA observations. It was observed that the upper limit of Ar number density corresponding to this period is ~ 5×10^5 cm^{-3} (~250 km), and the typical scale height is ~16 km, corresponding to an exospheric temperature of ~275 K. However, on two orbits, the scale height over this altitude region is found to increase significantly making the effective temperature > 400 K. The Neutral Gas and Ion Mass Spectrometer observations on the Mars Atmosphere and Volatile Evolution (MAVEN) mission also indicate that a change in scale height in Ar and CO_2 densities occurs near the upper exosphere (around 230–260 km). These observations confirm significant suprathermal CO_2 and Ar populations in the Martian exosphere.

- **Composition of Jupiter irregular satellites sheds light on their origin:** Observations are made on three Jovian irregular satellites; Himalia (JVI), Elara (JVII), and Carme (JXI), using the SpeX instrument on the NASA Infrared Telescope Facility(IRTF). The objective is to identify spectrally dominant minerals on the three irregular satellites that could provide insights into a narrow time window when our solar system was forming. A linear spectral unmixing model was constrained the major minerals phases on the surface of these three bodies. A broad absorption feature was observed at 1-μm and a moderately red slope between 1.4 and 2.5 μm. Similarly, Elara spectra show a moderately red slope between 1.4 and 2.5 μm but with shallower absorption band at 1 μm compared to Himalia. Carme spectrum shows an absorption band at 1.6 μm that is broader than the other two objects.The modeling results of Himalia and Elara suggest a much reduced environment with negligible amount of Fe^{3+} present on these bodies. A comparison of NIR spectra of Himalia and Elara with the two large main belt asteroids Themis and Europa suggest that the parent body(s) of these irregular satellites family might have been derived from the main asteroid belt.

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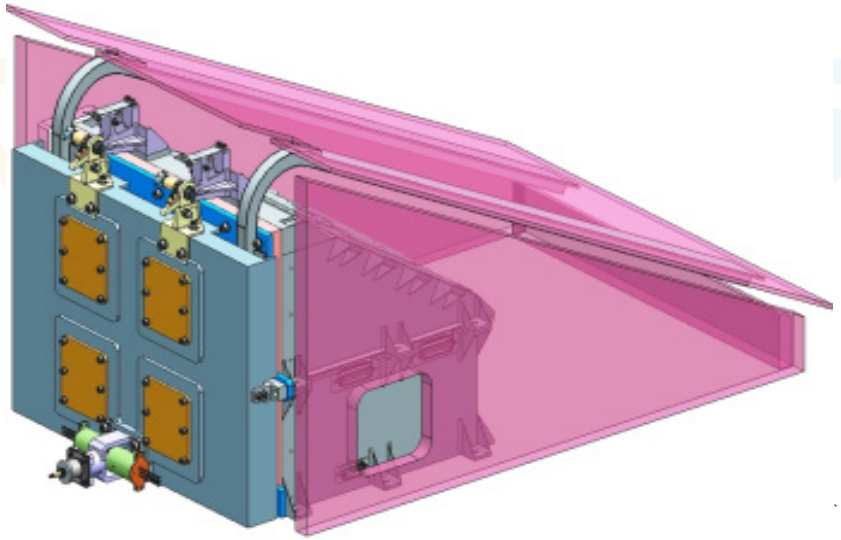
CHAPTER - 5
SPACE ASTRONOMY GROUP (SAG), URSC BENGALURU

The Space Astronomy Group (SAG) at URSC is involved in research in optical, X-ray and gamma-ray astronomy with a strong emphasis on design and development of novel instrument concepts for space-based payloads as well as ground experiments/facility. SAG is also involved in the analysis and interpretation of existing astronomical data from space-based and ground-based facilities around the world.

A. MAJOR INSTRUMENTATION DEVELOPED

1. CLASS payload on-board Chandrayaan-2

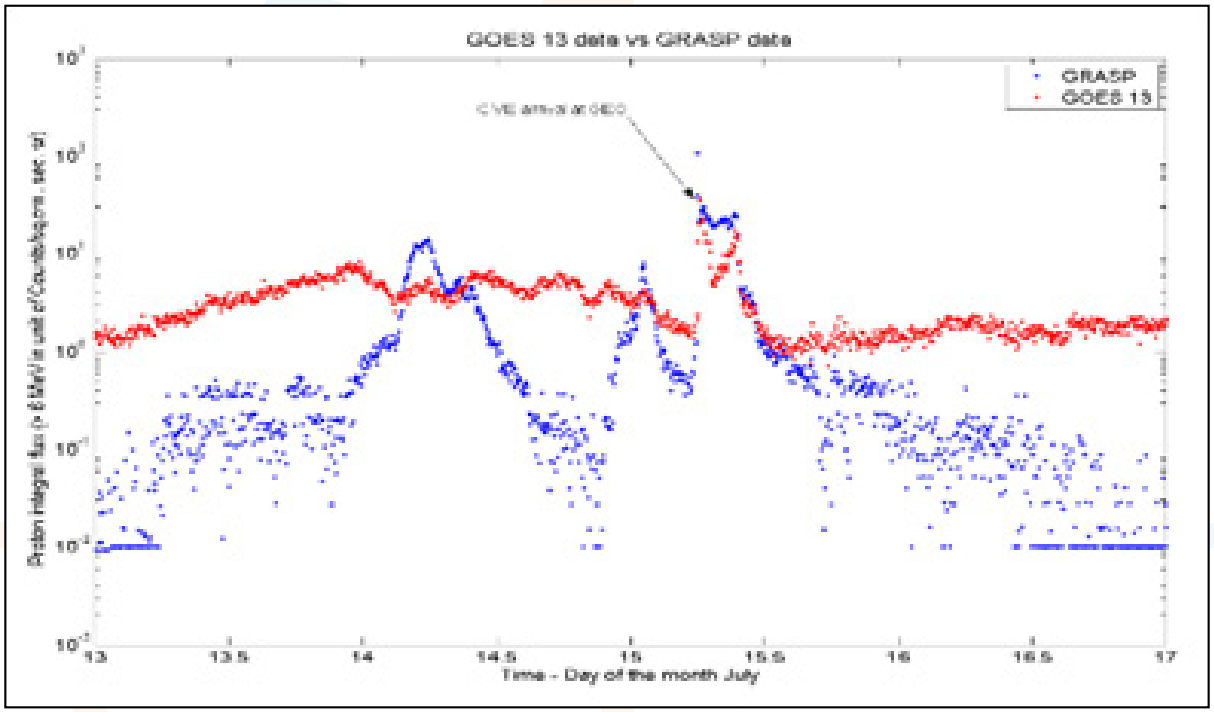
The Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS; Fig 1) experiment aims to map the abundance of the major rock forming elements on the lunar surface using the technique of X-ray Fluorescence (XRF) during solar flare events. This payload has been developed and tested.



CLASS Payload
Fig 1

2. GRASP on-board GSAT-19 .

Geostationary Radiation Spectrometer (GRASP) is a light weight (2.5kg) and compact instrument on-board GSAT-19, designed to detect charged particles in the energy range 500 keV-10MeV, 4-85MeV and 17-85MeV for electrons, protons, and alphaparticles respectively in the geostationary orbit. The initial observations of a Coronal Mass Ejection(CME) event is displayed in Fig 2.



GRASP (blue) Vs GOES data (red), Showing the passage of a CME event on the 16th July 2017.
Fig 2

B. SCIENCE RESULTS

1. ASTRONOMY & ASTROPHYSICS

AstroSat

AstroSat is the first dedicated Indian astronomy mission aimed at studying celestial sources in X-ray, optical and UV spectral bands simultaneously. The payloads cover the energy bands of Ultraviolet (Near and Far), limited optical and X-ray regime (0.3 keV to 100keV). One of the unique features of AstroSat mission is that it enables the simultaneous multi-wavelength observations of various astronomical objects with a single satellite.

The Scanning Sky Monitor is one of the instruments onboard AstroSat which is a contribution from this group.

- **X-ray Transients Observations with Scanning Sky Monitor (SSM)**

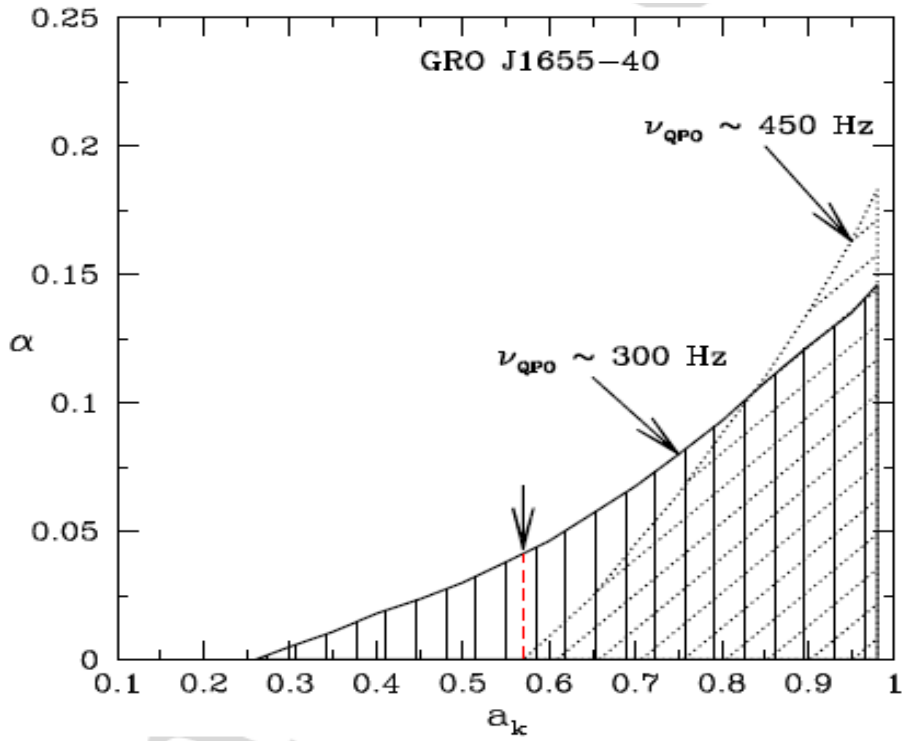
  The Scanning Sky Monitor (SSM) observed a number of X-ray sources till date. The light curve of ~300 sources observed by SSM are made available in the SSM website hosted at ISSDC. An Atel was generated on the detection of a transient outburst from a neutron star X-ray transient, Aql X-1 (ATel#10452). SSM continues to monitor the X-ray sky for transients.C2 studies of Compact objects.

- **Neutron Star (NS) X-ray Binaries:**

  A neutron star X-ray binary system, 4U 1705-44 was observed with LAXPC*/AstroSat on 2nd June 2017*. The correlated spectral and timing behaviour of this low mass X-ray binary revealed that the source in its high-soft state traced out a banana type track with a peaked noise ranging from 1-12 Hz in the Power Density Spectrum (PDS). The complex X-ray spectra has components from Comptonized corona, a power-law and a broad iron line. The results have been published.

- **Galactic Black Hole (GBH) sources**

  Several GBH sources (GRS 1915+105, XTE J1859+226, H 1743-322, GX 339-4, IGR J17091-3624, GRO J1655-40) were studied using X-ray observational data from RXTE, Swift, NuSTAR etc. Modelling and interpretation of the observed features (in Radio and X-rays) were carried out based on physical accretion-ejection model. A method has also been evolved in order to constrain the spin of the black holes based on observed high Frequency Quasi Periodic Oscillations (HFQPOs) in GBH sources. Several BH sources (GRS 1915+105, Cyg X-1, LMC X-3) have been observed with AstroSat and analysis is underway. Fig 3 depicts possible range of flow viscosity (α) as a function of spin (ak) parameter for GRO J1655-40, based on observed HFQPOs.

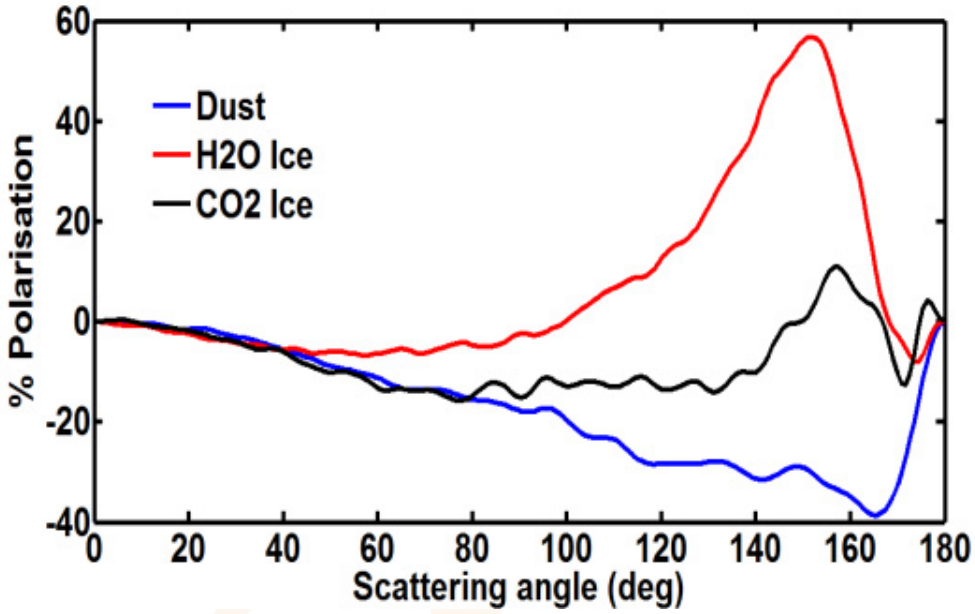


Possible range of viscosity based on modeling of HFQPos for GRO J1655-40
Fig 3

2. SOLAR SYSTEM BODIES INCLUDING PLANETARY SCIENCE

- **Radiative Transfer Model for Mars Atmosphere**

The process of condensation on Mars is a close interplay of water vapor, dust and clouds present in the atmosphere. It can be understood by the study of spectrum and polarization of sunlight scattered from Mars atmosphere. In order to simulate the spectrum and the degree of linear polarization of scattered sunlight in the limb, a vector radiative transfer model was developed which includes multiple scattering in the spherical geometry of Martian limb. Results show that (Fig 4) explains scattered polarization for the three aerosols of the Martian atmosphere), it would be possible to measure the amount of super-saturated water present in the limb. In order to Study the vertical diStribution of water vapor, duSt and clouds, a spectro-polarimeter experiment called PRISM (PolaRisation sensitive Infrared Spectroscopy of Mars) is being developed. Polarization measurements would provide better conStraints on the aerosol size distribution than the existing measurements.



Scattered polarization
Fig 4

- **Surface composition**

  Studies of geological samples are undertaken in NIR and X ray in order to integrate the information for a complete understanding of in-situ measurements in future planetary missions. This work is in collaboration with other research institutes and universities.

- **Solar wind charge exchange emission**

  Highly excited heavy ions in the solar wind exchange charge with neutral atoms in the exosphere of planets. We have proposed X ray spectrometers to measure the line emission from these regions that help us underStand how solar wind leads to atmospheric escape.

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CHAPTER - 6

U.R. RAO SATELLITE CENTRE

(URSC & LEOS)

BENGALURU

U.R. Rao Satellite Centre (URSC), earlier called ISRO Satellite Centre (ISAC), being the lead centre for satellite realisation and advanced satellite technology development activities, has made significant contributions in Space Research Activities. Besides these, the Centre has also taken necessary measures towards capacity building activities in terms of establishing required Infrastructure catering to increased number of projects as well as for the future missions. URSC is a key player in the upcoming missions including Chandrayaan-2 the mission to Moon and ADITYA-L1 a dedicated solar mission around the first Lagrangian point L1 of Sun-Earth system. An X-ray polarimetry satellite XpoSat is under development which will cater to X-ray polarisation observations of bright objects.

The detailed list of highlights are provided in following sections:

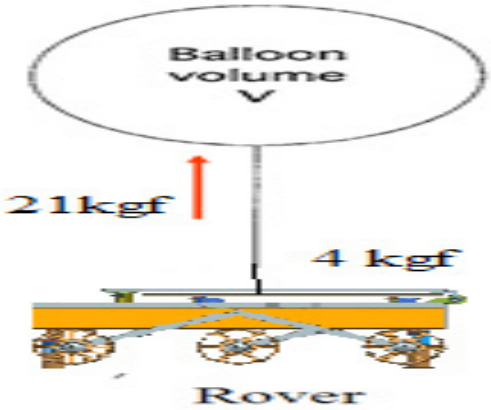
Lunar Terrain TeSt Facility
Fig 1

A. MAJOR FACILITIES/INSTRUMENTATION DEVELOPED:

1. Lunar Terrain Test Facility:

Chandrayaan -2, India's second mission to the moon aims for a precise, soft and safe touchdown of the Lander on the Lunar surface. The Chandrayaan-2 Composite Module comprises of an Orbiter, Lander and Rover The rover module will move on the lunar surface and will pick up soil or rock samples for in-situ chemical analysis. In order to test the rover on ground, a Lunar Terrain Test Facility with soil similar to lunar soil has been established. The following are the major features of the Facility that simulate the Lunar Environment:

- Facility having Test bed with Lunar Simulated Soil (LSS) Fig 1
- A balloon system to simulate the 1/6th 'g' effect on the Rover Fig 2
- Illumination system with 0.2 solar constant to simulate Solar irradiation



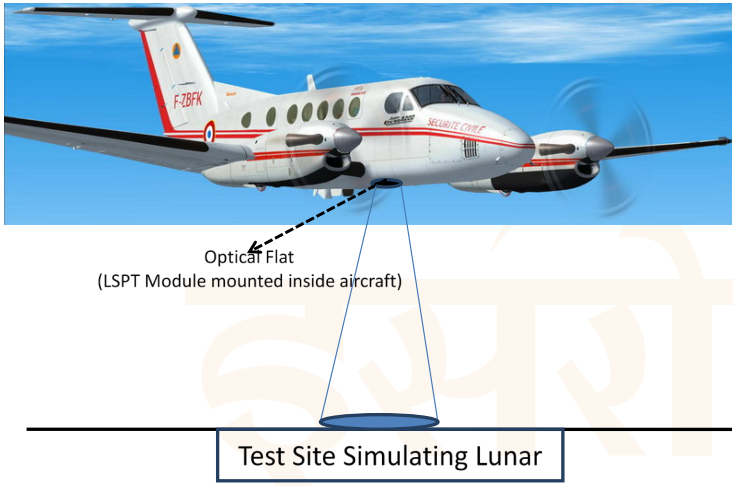
Rover with Balloon attachment
Fig 2

Lander Sensors Performance Test (LSPT Phase 1 and 2)

For soft landing, many new sensors have been developed to assist the lander in identifying its instantaneous position, attitude and velocity, etc. The performance of all these newly developed sensors are evaluated in Lander Sensors Performance Test (LSPT). LSPT module comprises of Sensors & Supporting systems such as structure, power distribution unit, GPS receiver, Solid state Recorder (SSR)etc. Towards this, the sensors were positioned on the LSPT module to achieve their FOV requirements while viewing through the aircraft optical flat. The module was mounted inside the aircraft. The aircraft chosen to conduct this test was NRSC's Super King Air B-200 aircraft (Fig. 3).

During the lander's descent to the moon's surface, the LPDC (Lander Position Detection Camera) will image the lunar surface and match the images with respect to the reference craters stored on-board the lander. This phase in the actual lunar descent is simulated by flying the aircraft over a specially prepared site where the scaled down artificial craters have been created (Fig. 4).

The first phase of the LSPT was completed in October 2016 & the second phase was completed in March 2017.



Pictorial view of LSPT
Fig 3

Artificial Lunar Cratersite
Fig 4

2 INTEGRATION and TESTING OF SATELLITES FOR REMOTE SENSING OF EARTH'S RESOURCES , ENVIRONMENT, ATMOSPHERE AND CLIMATE:

Following satellites are launched to study the Land, ocean and climate.SCATSAT-1 is a continuity mission for Oceansat-2 Scatterometer to provide wind vector data products for weather forecasting, cyclone detection and tracking services to the users. The satellite carries Ku-band Scatterometer similar to the one flown onboard Oceansat-2. The mission life of the satellite is 5 years. The data is being down loaded by national and global users..Payload data is uploaded to NRSC web portal every 3 hours. It caters to worldwide users for ocean wind studies, cyclone studies, numerical weather prediction and studies related to climate change and polar ice caps. SCATSAT1 and INSAT 3DR are used for meteorological studies.

RESOURCESAT-2A has onboard a high resolution Linear Imaging Self Scanner (LISS-4) camera operating in three spectral bands in the Visible and Near Infrared Region (VNIR) with 5.8 m spatial resolution and steerable up to ± 26 deg across track to achieve a five-day revisit capability. There is a coarse resolution Advanced Wide Field Sensor (AWiFS) camera operating in three spectral bands in VNIR and one band in SWIR with 56 m spatial resolution used for remote sensing. The Cartosat 2 series satellites with their

Panchromatic and Multi-spectral cameras are similar to the earlier Cartosat-2, 2A and 2B, and are used for cartographic applications, urban and rural applications and infrastructure planning.

LABORATORY FOR ELECTRO-OPTICS SYSTEMS (LEOS)

The Laboratory for Electro-Optics Systems (LEOS) is a unit of URSC situated at Peenya Industrial Estate, Bengaluru. It is actively engaged in design, development and production of Electro-Optic sensors and camera optics for satellites and launch vehicles. The sensors include star trackers, earth sensors, sun sensors & processing electronics. The Electro-optic sensors are used for attitude determination and navigation of Low Earth Orbit (LEO), Geosynchronous Earth Orbit (GEO) and inter planetary Spacecrafts, Landers and Rovers. Optics both refractive and reflective of various dimensions are used for imaging and meteorological applications. LEOS is also actively engaged in developing laser based and other payloads for scientific/interplanetary missions, variety of thin film coatings for optics, detectors and micro electro-mechanical systems (MEMS).

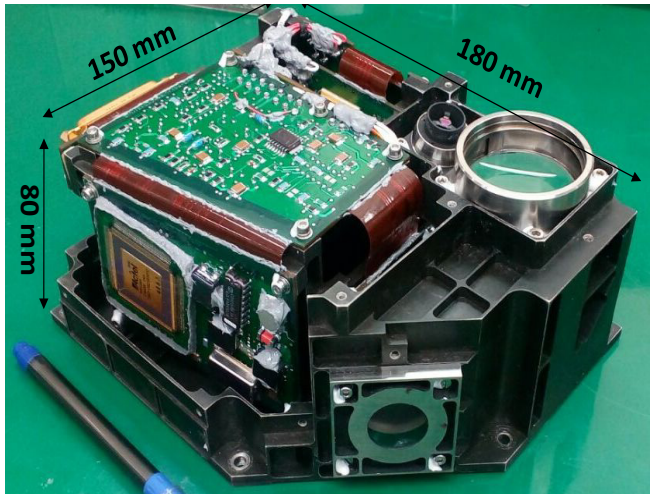
A. MAJOR FACILITIES/INSTRUMENTATION DEVELOPED:

1. Breakdown Spectroscope (LIBS) Instrument for Chandrayaan-2 Rover

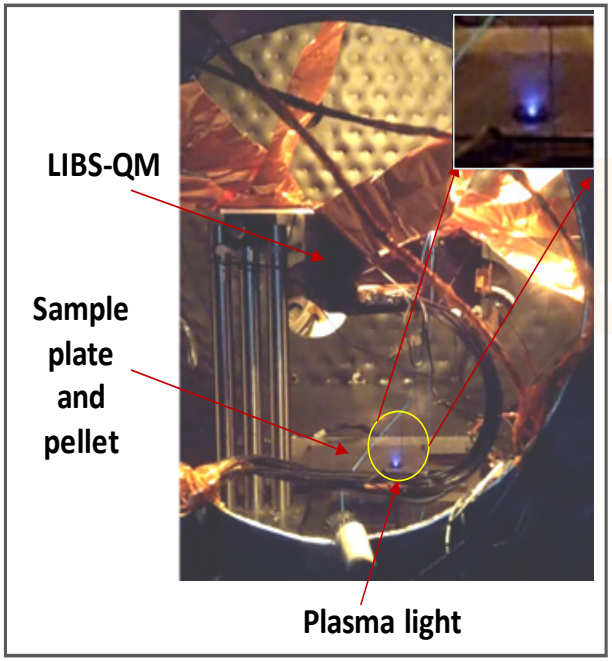
Rapid analyzing capability for simultaneous multi-element detection of matter in any of its diverse forms using an intense nanosecond pulse duration of laser beam makes laser induced breakdown spectroscopy (LIBS) a potential tool for planetary surface exploration via both in-situ and stand-off measurements. India's second moon mission , Chadrayaan-2 will carry a 6 - wheeled rover aimed to investigate the lunar surface of the roving area. One of the two scientific instruments, named, Laser Induced Breakdown Spectroscope (LIBS), is being developed at at LEOS. It will be housed beneath the rover's deck and perform observations of the lunar regolith/surface from an in-situ distance of 200 mm from the surface.

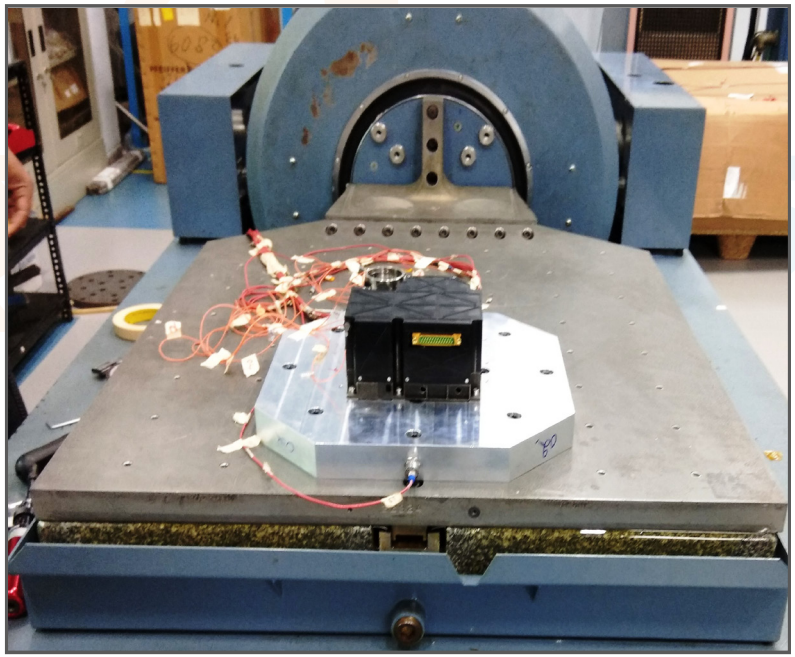
Figure 5 shows the integrated LIBS instrument which is developed and qualified for space use. The realized instrument is light weighted (<1.2 kg), low power consuming (≤ 5 W) and miniaturized capable functioning in the -20^{0}C to +55^{0}C temperature range.

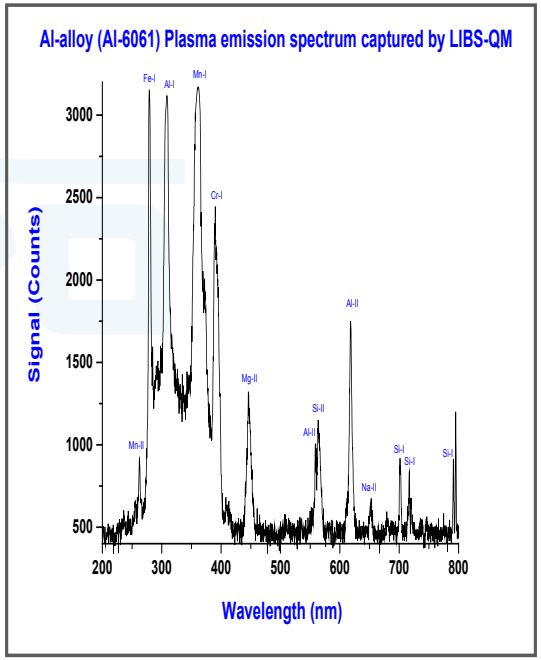
The instrument is being tested in vacuum at pressure levels better than 5x10^{-7} mbar and is vibrated successfully to 19g. In principle, LIBS instrument zaps the investigation site by means of a high peak power laser pulse which will create a plasma. The plasma during its decay will emit radiation which is observed by the LIBS instrument as a spectrum and analyzed to detect the elemental presence and abundance. Figure 6 a shows the LIBS payload being tested in thermo-vacuum chamber (inset shows the plasma generated from the sample upon laser fire); figure-6b shows the LIBS instrument on vibration shaker while figure-6c depicts the acquired spectrum in vacuum using a 2mm-thick aluminium alloy metal sheet (detected elements are shown in the plot).



LIBS - Qualification Model
Fig 5







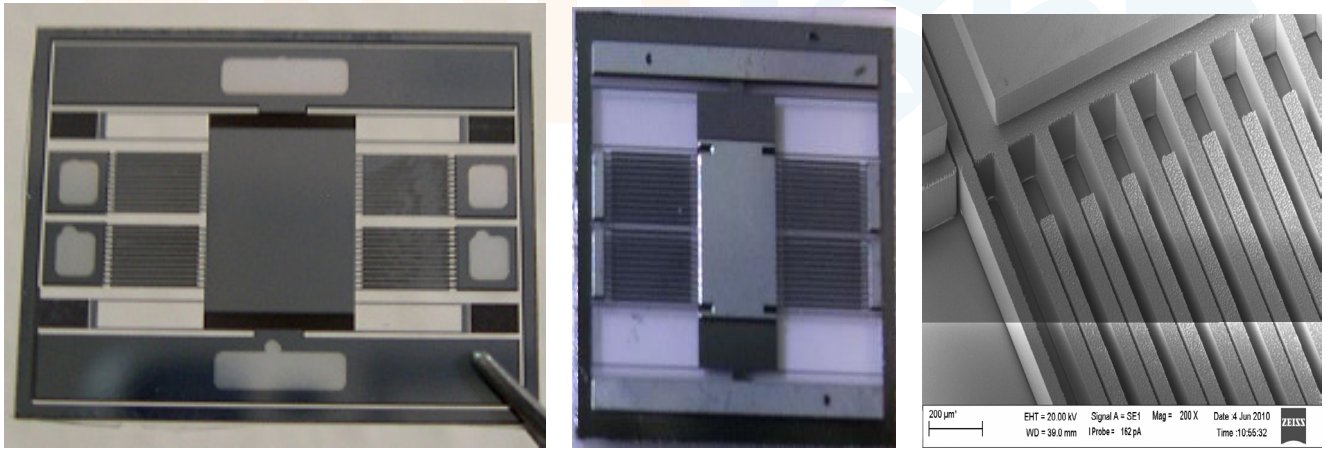
(from left to right): 6a LIBS in TVC chamber; 6b LIBS on Vibration Shaker; 6c Acquired emission spectrum of Al-alloy in Vacuum
Fig 6

2. Micro Electro Mechanical System (MEMS) based Instrument for Lunar Seismic Activity Studies

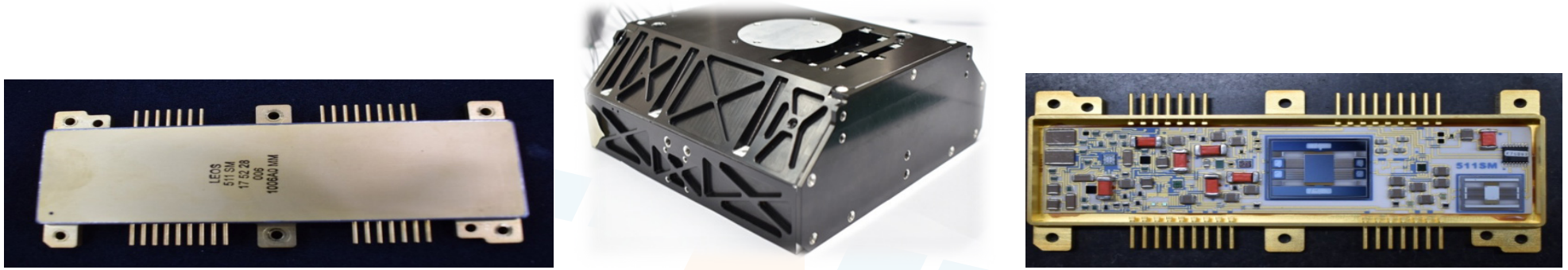
LEOS has successfully developed very high sensitivity micro-accelerometer to function as seismometer. The payload is a part of Lander of Chandrayaan 2 mission and is termed as Instrument for Lunar Seismic Activity Studies (ILSA). The instrument has indigenously developed silicon micromachined Micro Electro Mechanical System (MEMS) based sensing elements.

The ILSA instrument is a single package containing seismometers with output from three axes. The sensing elements are high sensitivity capacitive accelerometers. Each axis will have two sensor chips, one chip meant for measurement in fine range and the other meant for coarse range. The sensors have different mechanical sensitivities. This is the practical approach adopted to achieve the very wide dynamic range of operations for the seismometers required. Preprocessing electronics with MEMS sensors is packaged in a Hybrid Micro Circuit (HMC) package. Three HMC's are mounted in orthogonal direction such that the sensor sensitive axes are along X, Y and Z directions. The processing circuits, power regulators and clock generating circuits are implemented in PCBs. All are integrated and housed in a mechanical package forming the instrument. ILSA can resolve upto 100 nano-g $Hz^{-½}$ and has a dynamic range of ±0.5 g, where g is 9.8 ms^{-2}. It has a bandwidth of 40 Hz. It weighs 1.5 Kg, consumes <4 W power and has dimensions 170 x 170 x 72 mm and provides digital output. The MEMS based sensing elements are designed and fabricated at LEOS. The present instrument is custom configured for its mechanical design to meet the Lander requirements. The ground acceleration data due to quakes can be processed further to obtain ground velocity and displacement. The MEMS based inertial sensor has the heritage created by the performance of MEMS Accelerometer Package (MEMSAP) tested on board GSAT-19 where the delta-velocity measurements were carried out during transfer orbit operations. Two axis MEMS based inclinometer is also realized based on same technology for application in Chandrayaan 2 mission.

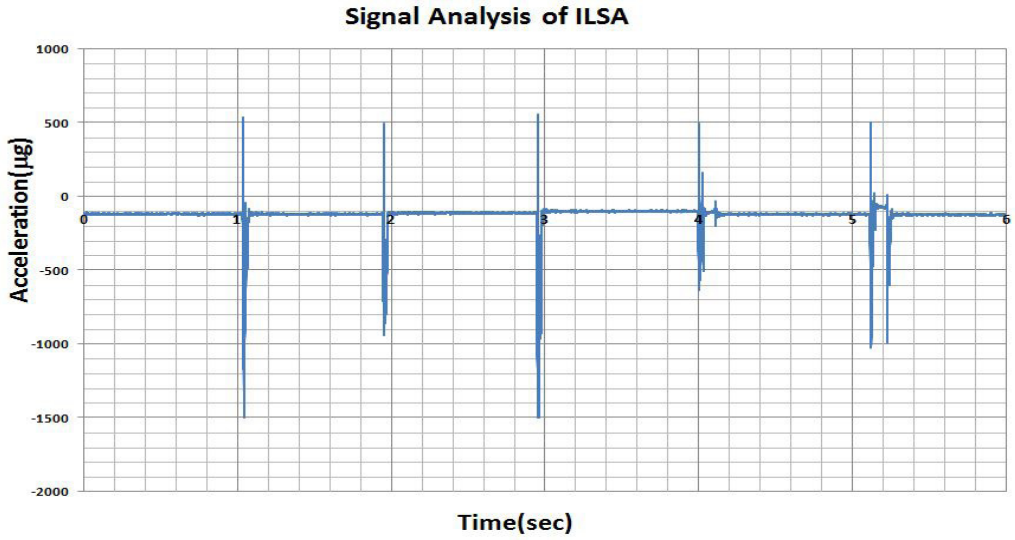
The images of the sensing elements realized and qualified at LEOS, the HMC fabricated , the ILSA instrument and the response from the instrument to an artificially generated un-calibrated ground vibration on the floor is shown in Figure 7a, 7b, 7c below.



MEMS Sensors with scanning electron microscope (SEM) image showing fine details
Fig 7a



HMC packages, sealed and open view and the photograph of ILSA instrument inbetween
Fig 7b

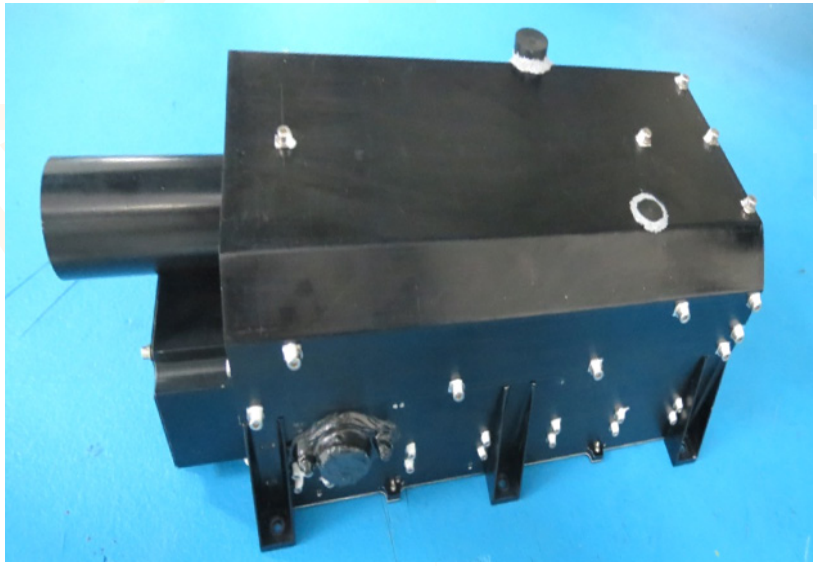


Response of the instrument to artificially created un-calibrated signal on the ground
Fig 7c

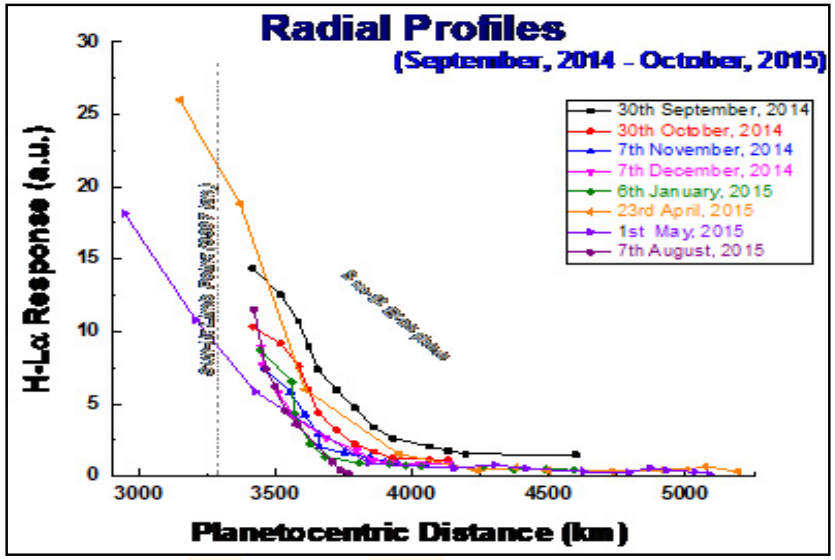
B. SCIENCE RESULTS

1. Science Results of Lyman Alpha Photometer (LAP) for MARS ORBITER MISSION

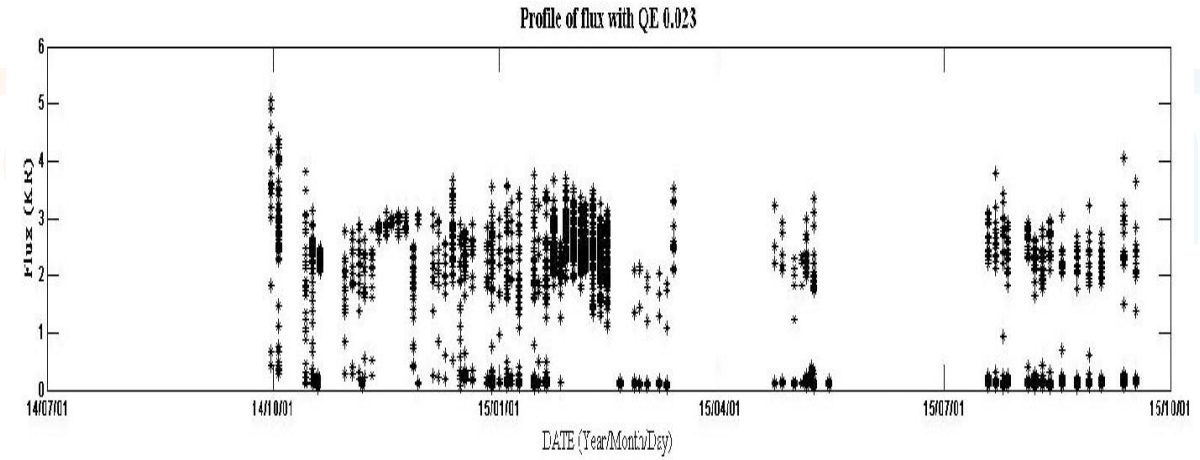
Lyman Alpha Photometer-LAP, one of the five scientific instruments of MOM spacecraft's payload suite developed at LEOS_ISRO, is the first Indian space-borne absorption gas cell photometer that operates on the principle of resonant scattering and resonance absorption at Lyman-α wavelengths of hydrogen (121.567 nm) and deuterium (121.534 nm) respectively. This type of instrument is best suited to measure the line-of-sight Lyman alpha intensity of hydrogen and deuterium and thereby the D/H ratio (deuterium to hydrogen ratio) estimation of a planet's atmosphere. Till date, LAP instrument has been operated on-board successfully for more than 185 times during various phases of spacecraft's journey, namely, cruise-phase, Martian orbit phase, deep-space observations for assessment of payload dark count measurements and stellar source observations to perform on-board photometric calibration. Figure-8 depicts the LAP instrument being flown in MOM spacecraft. Useful scientific data sets are received and are currently under analysis. Analyzed data so far has revealed successful registration of the hydrogen Lyman-α brightness as well as clear hydrogen Lyman-α flux absorption signatures of Martian atmosphere. Maximum Lyman--α response recorded is observed to be in zones very close to the bright limb of Martian disc. Figure-9 shows the plot of generated radial profiles based on the 1St year's MOM data, while Figure-10 presents the plot of estimated Lyman--α brightness plot during 1st year of MOM operation using the calibration factor extracted from on-board photometric calibration observations.



LAP flown on MOM spacecraft
Fig 8



Radial Profiles
Fig 9



Variation in Lyman-α brightness based on 1st Year Observations
Fig 10

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CHAPTER - 7
SPACE APPLICATIONS CENTRE
AHMEDABAD

Space Applications Centre (SAC) is one of the major centres of the Indian Space Research Organisation (ISRO), located in Ahmedabad, Gujarat. SAC focuses on the design of space-borne instruments for ISRO missions and development and operationalisation of applications of space technology for national development and societal benefits.

Remote Sensing applications at SAC cover projects/activities in the field of Physical Oceanography, Satellite Meteorology, Agriculture, Environment (Terrestrial, Coastal and Marine), Water Resources, Climate change and Planetary Science. The activities are carried out under a number of programmes linked to Indian satellites and available data from global sources. Remote sensing of Earth observations covers marine biological system, ocean color, ocean bio-geo-chemistry, marine lithosphere, coastal processes, geo hazards, mineral exploration, geo-archaeology, desertification and land degradation, Himalayan and Polar cryosphere, improved techniques for crop assessment and forecasting, assessment and modeling terrestrial biosphere, and study of impact due to climate change and hydrological modeling are carried out.

The thrust areas of activities for Remote sensing & GIS applications are:

- Utilization of data from Indian Missions
- Advance R & D on retrieval of Geophysical and Bio-geophysical parameters
- Simulation and Modeling
- Early Warning for Disasters
- Planetary Science Studies

The research activities carried out by SAC during 2016-2017 are summarized in this chapter.

A. MAJOR FACILITIES / SOFTWARE DEVELOPED

- **Bio-Optics Lab development**

  A Bio-optics laboratory is developed at SAC/ISRO. The laboratory is equipped with state-of-art equipment such as High Performance Liquid Chromatography (HPLC), Total Organic Carbon Analyser (TOC), UV-VIS Spectrophotometer, Probe sonicator, Cool centrifuge, Inverted Microscope & Hyperspectral radiometer to meet the in-situ data requirements of Ocean Colour Monitoring (OCM) data and future Ocean Colour measurements from missions of ISRO.

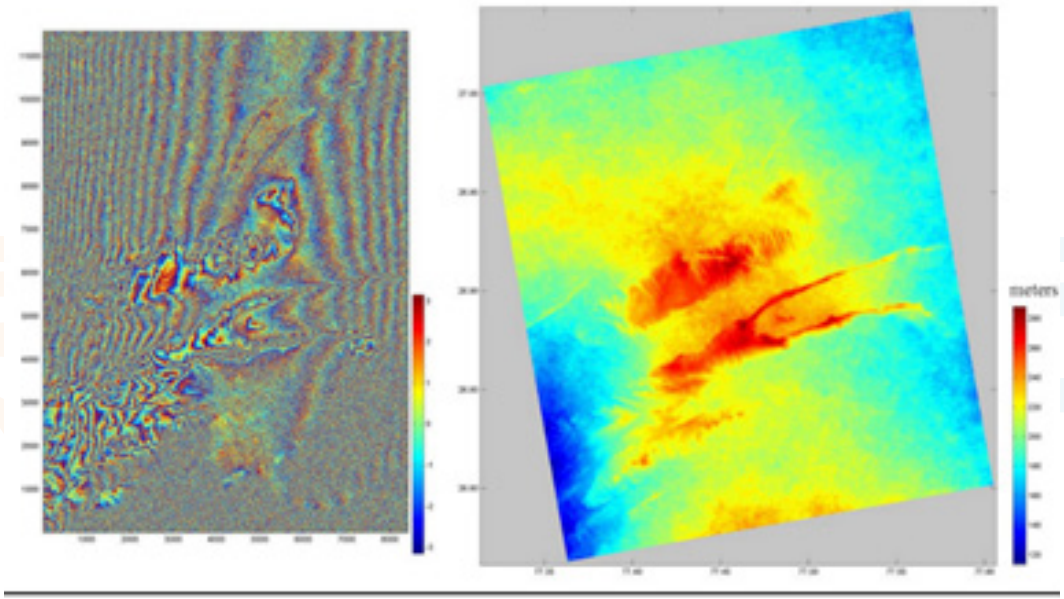
- **Calibration and Validation**

  Radiometric Calibration Stability Assessment of RISAT-1 SAR sensor:

  In order to assess the radiometric calibration stability of RISAT-1 SAR sensor, standard point targets of various types (triangular trihedral, square trihedral and dihedral) with known Radar Cross Section (RCS) are deployed prior to satellite overpass with precise azimuth and elevation angles in Desalpar, Rann of Kutch Cal-Val site in India.

- **S/W Development for RISAT-1 Interferometry**

  An indigenous software module for RISAT-1 Fine Resolution Strip Map (FRS) data for Interferometric processing was developed. The s/w includes modules for image importing, orbit conversion and modelling, image co-registration, interferrogram generation, flat earth removal, phase filtering, phase unwrapping and geocoding. (Fig 1)



A- Interferogram and B- Digital Elevation Model (DEM) derived using RISAT-1 SAR data for parts of Bharatpur region, Rajasthan

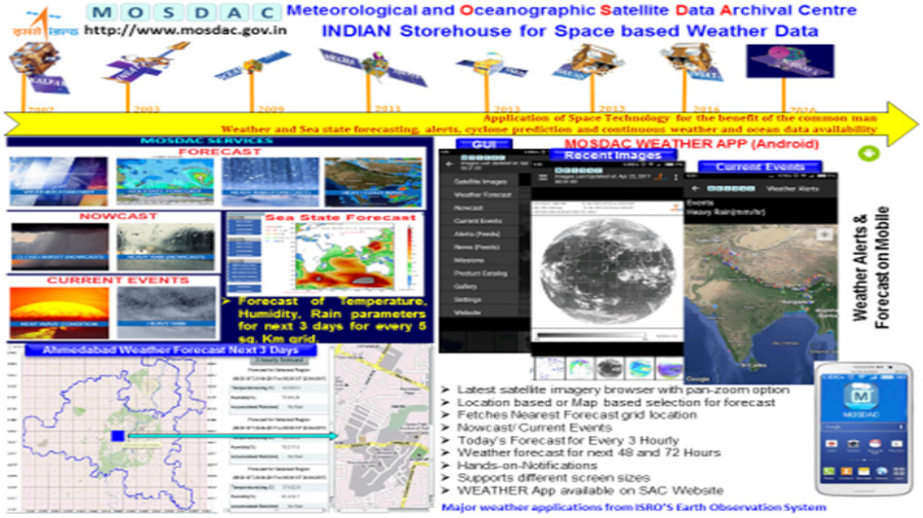
Fig 1

- **Microwave Data Analysis Software (MIDAS): In-house software for MW Data Analysis & Processing**

The software has Hybrid Pol and Full Pol processing and decomposition capabilities which includes numerous amplitude filters such as Enhanced Frost & Lee, Gamma map, Kuan, etc., including advanced filters like Polarimetric refined Lee filter. It supports Airborne and Spaceborne SAR data from various sensors. Thematic module in the form of Himalayan Glacier Classification has also been added and operationalised.It has other features such as polarimetric signature, slant range to ground conversion, and data conversion to various Polarimetric SAR (Polsar) matrices.

- **MOSDAC / VEDAS Services**

New version of MOSDAC web portal released to users, this contains advanced capability for visualization, integrated decision support and location based services. Coastal geophysical products from SARAL/AltiKa, SCATSAT-1 data product, geophysical parameters (31 products) from INSAT-3DR are hosted on MOSDAC. New Applications were released on MOSDAC for operational use, RIP current forecast, OCEAN EYE and Forecasts of Discomfort Index. Operationalization of total 31 products from INSAT-3DR algorithms for geophysical parameters was hosted on MOSDAC. Diagnostic Rip current forecasting system was made operational for Goa coast on MOSDAC. Developed algorithm for aerosol optical depth retrieval from INSAT-3D/3DR data and operationalization of aerosol product has been completed on VEDAS and MOSDAC. VEDAS portal is hosting WEB GIS based applications and tools such as, Vegetation Monitoring, New and renewable energy, Himalayan Glacier Information System (HGIS), Air quality monitoring and Urban Sprawl Information System (USIS).



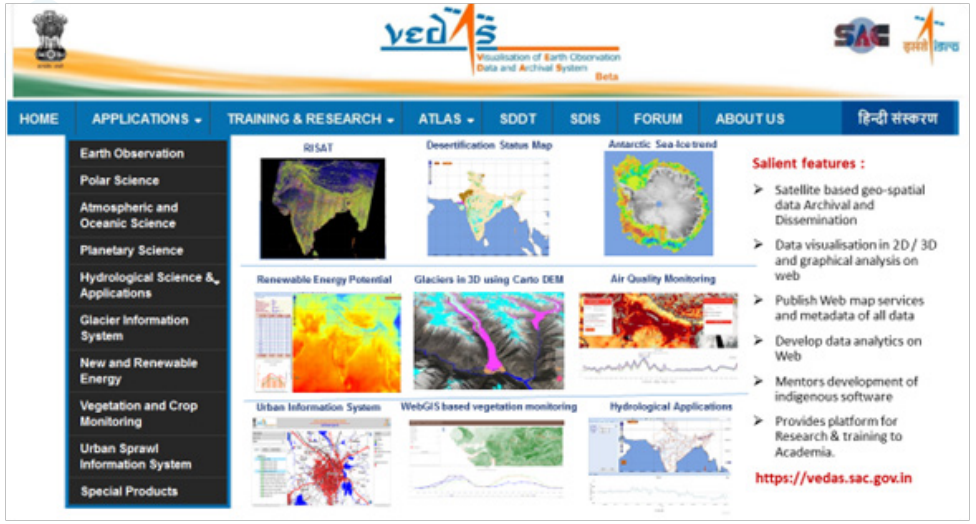


Fig 2

B. MAJOR APPLICATION ACTIVITIES / PRODUCT GENERATION:

- **INSAT-3DR Operational Products:** Procedures for the retrieval of geophysical parameters from INSAT-3DR are made operational. Initial validation of the products is carried out, a sample of which is shown in Fig 3. A few new products are also generated and operationalized for Clear sky brightness temperature, Cloud Properties, Ozone Retrieval, T-Phigram, Retrieval of Totally Precipitable Water (TPW) from INSAT-3D/3DR TIR observations and improved SST.

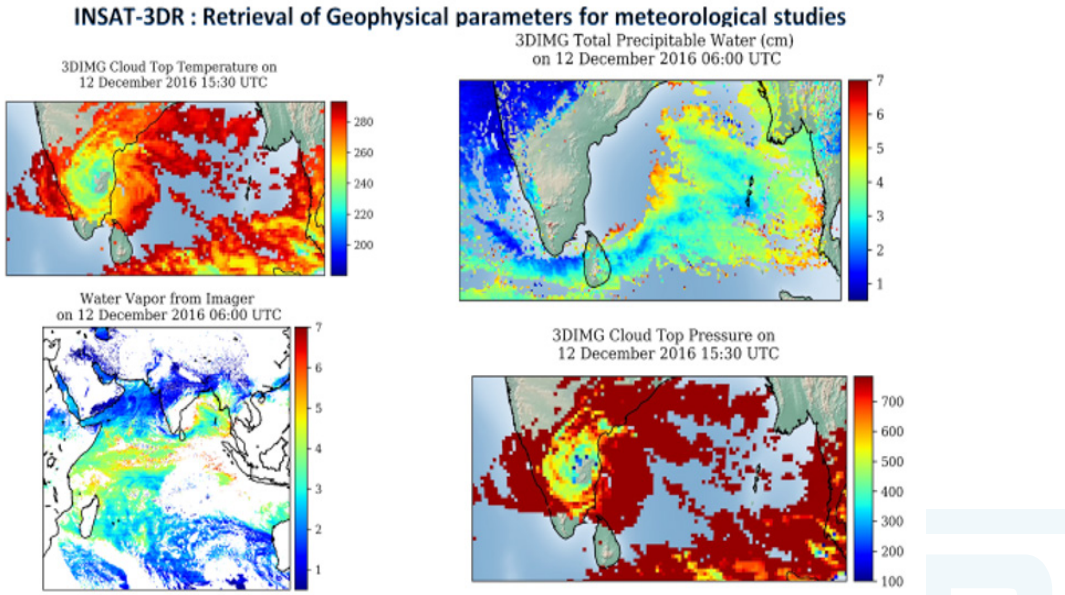


Fig 3

- **Operationalization of GSICS Calibration:**
A procedure is operationalized at Meteorological and Oceanographic Satellite Data Archival to generate near real time correction (NRTC) of Global Space-based Inter-Calibration System (GSICS) coefficients for INSAT-3D imager and sounder. These operational NRTC products have entered in the Demo-phase after approval from GSICS Coordination Center (GCC).

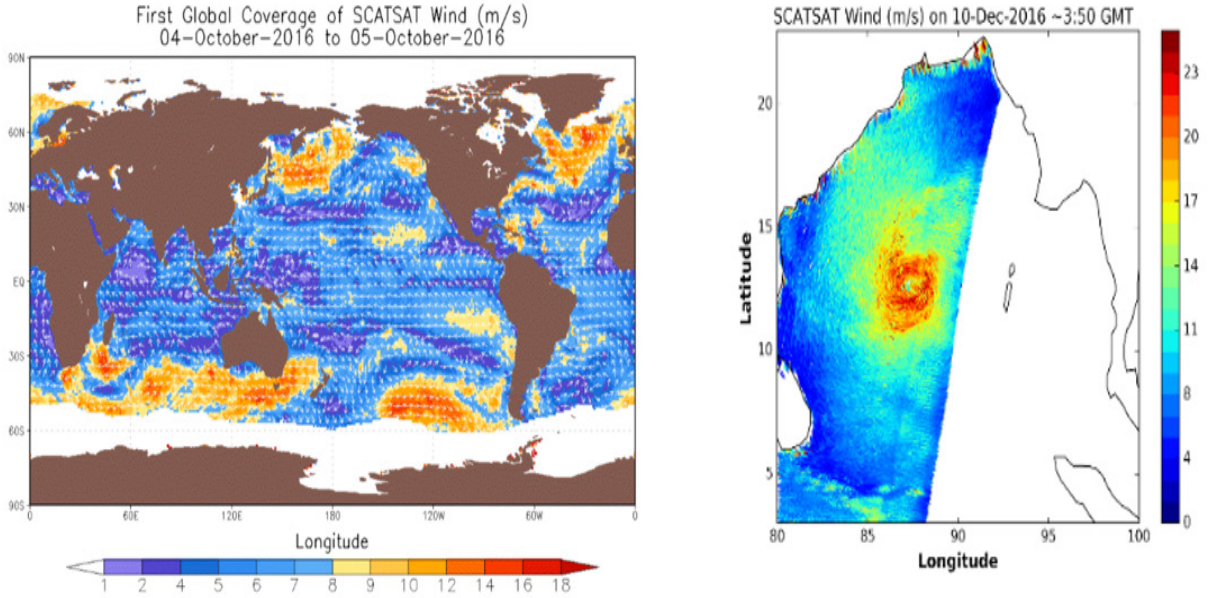
- **Operationalization of MT-ROSA Products:**
The Geophysical products from Radio Occultation Sounder for Atmosphere (ROSA) payload on Meghatropique satellite derived from Level-1 Refractivity is operationalized and products available for dissemination at MOSDAC. Products are routinely used by National Centre for Medium Range Weather Forecasting (NCMRWF).

- **Determination of Atmospheric Boundary LAYER(ABL) height from Radio Occultation Refractivity:**
ABL height is determined from radio occultation derived refractivity profile using “N-grad SW” method.

1. ATMOSPHERE AND CLIMATE

- **Ocean Wind Vector from SCATSAT-1:**

The Ocean wind vectors (OWV) from SCATSAT-1 observations are retrieved (Fig 4 left). High resolution wind at 6.25 km swath gridded using backscatter data by employing the combined scatterometer and SAR based wind retrieval method in an iterative manner is also generated (Fig 4 right).

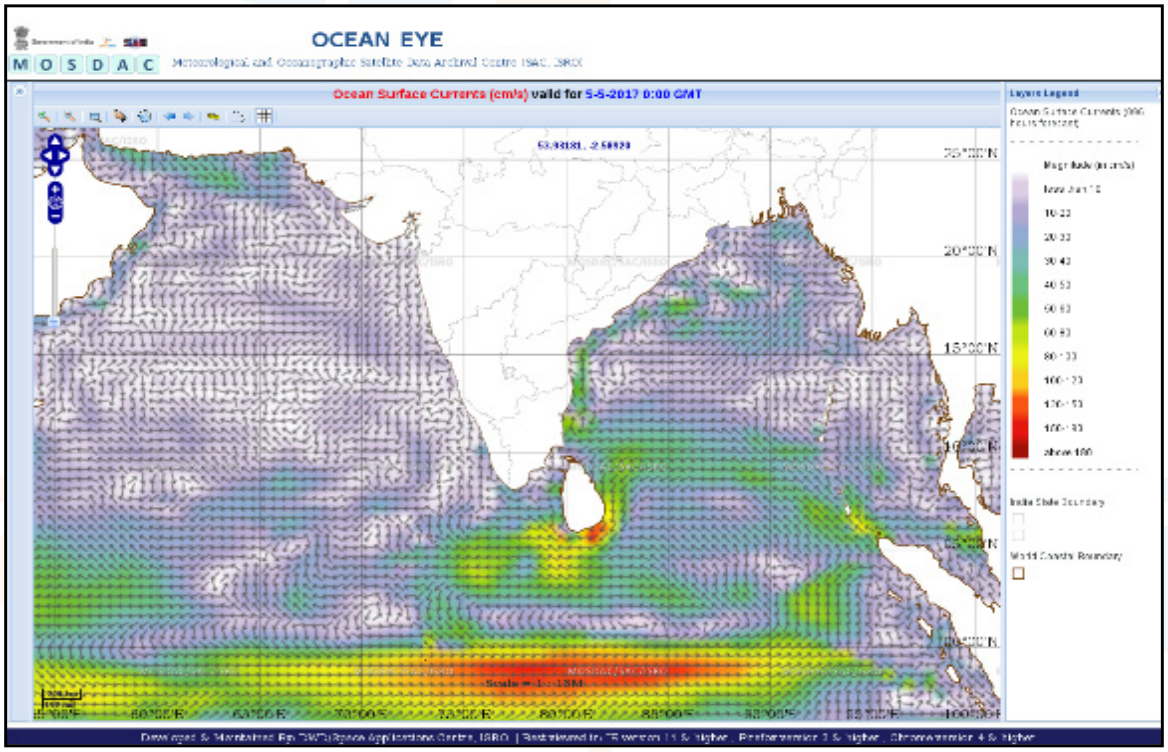


Scatsat-1 derived ocean winds
Fig 4

- **Global Navigation Satellite System (GNSS)GNSS-Reflectometry and Ocean Wind Geophysical Model Function (GMF) development:** A study is done for a quantitative estimation of wind speed from the bistatic GNSS-Reflectometry technique. The Elfouhaily wave spectral model is used for simulation of directional mean square slope (DMSS) and that correlated to the marine surface wind. A Geophysical Model Function is established between the marine surface wind speed and DMSS.

- **Retrieval of Integrated Water Vapour (IWV) from ground GPS receivers:** 4-GPS receivers (2 existing and 2 installed) were used to collect data during Monsoon of 2016. Integrated Water Vapour (IWV) is estimated using this GPS data.

- **Geophysical Data Assimilation, Numerical modeling & Advanced Ocean State Forecast (AOSF):** Satellite data assimilative wave and circulation forecasting system is operational at SAC since September, 2015 and forecasts are being provided to different stake-holders through MOSDAC. Continuous efforts have been put for improving the quality of forecast since then. Significant Wave Height (SWH) from Jason2, Jason3 and SARAL/AltiKa are getting assimilated in the model. The data assimilation algorithms were transferred and implemented in the operational wave model at Indian National Centre for Ocean Information Services (INCOIS), Hyderabad. An OCEAN EYE system is developed (Fig 5). Real-time predictions of storm surge and wave height were generated for cyclones Kyant, Nada and Vardha under Disaster Management Support Programme (DMSP) of ISRO.



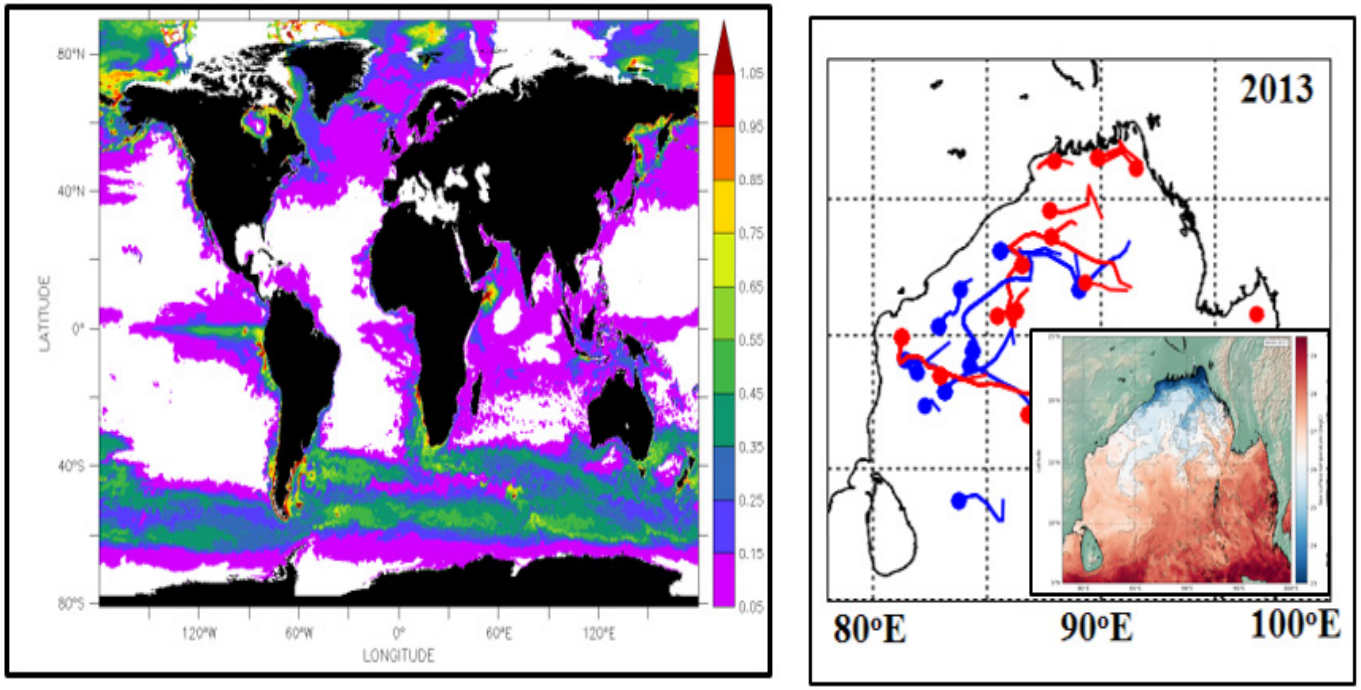
"Oceaneye" webpage on MOSDAC
Fig 5

- **Ocean Process Studies:**

Study of ocean processes is crucial in understanding the ocean dynamics. Towards this, many studies are carried out. e.g.,

(i) A state-of-the-art coupled biogeochemical-physical model is configured to study the interannual variations in coupled physical and biological ecosystem.

(ii) Ocean fronts and eddies are vital to understand the energy cascading processes in the ocean. Hence altimeter derived Sea surface height based eddy detection algorithm and high resolution sea surface temperature based (INSAT-3D & GHRSST) thermal front detection algorithm developed for Bay of Bengal. Cyclonic (blue) and anticyclonic (red) eddies detected are shown here. (Fig 6) Thermal fronts are also shown in inset.

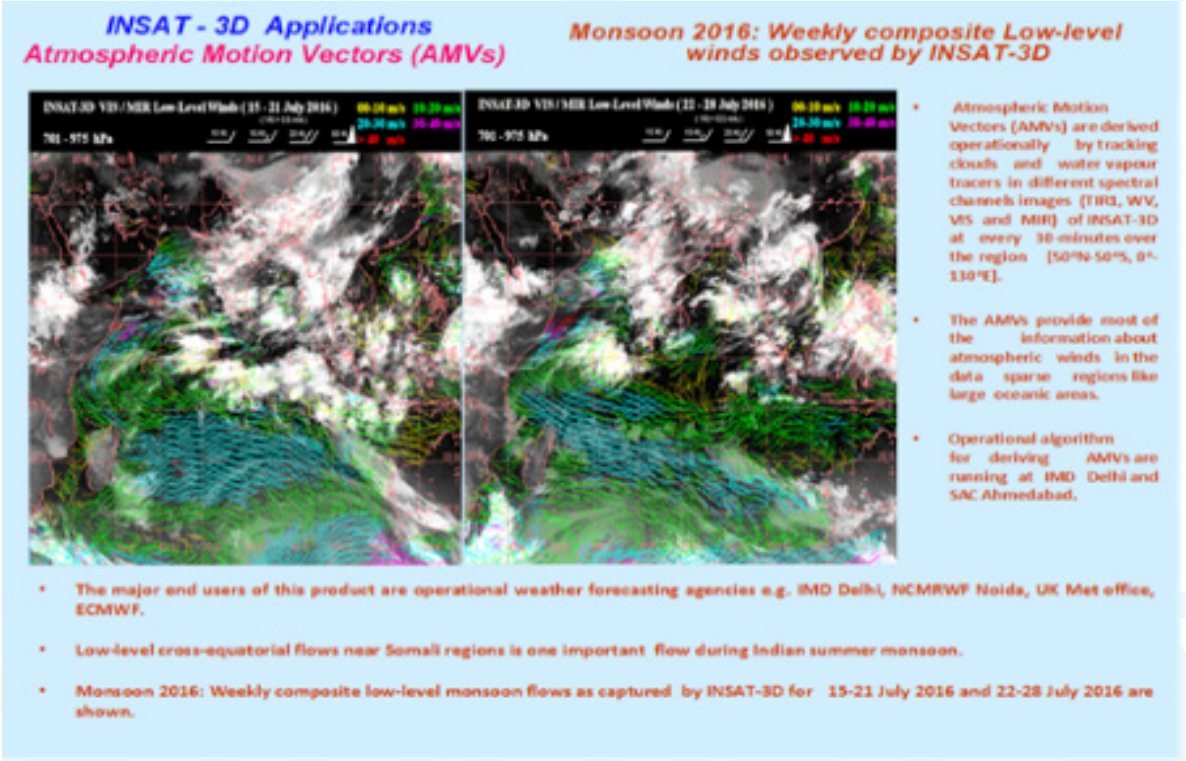


Global chlorophyll distribution and fronts and eddies products
Fig 6

SAMUDRA: Satellite-based Ocean Program: Satellite-based Marine Process Understanding, Development, Research and Applications (SAMUDRA) program encompassing physical, biological and coastal oceanography formulated to demonstrate effective utilization of space-borne observations to develop nation's economy.

Integrated oceanography of satellite derived information and numerical ocean models developed to simulate and predict the 3-D ocean state. These ocean states are extremely useful for navigation, communication and naval operations. "Ocean Eye" for Shipping Corporation of India is a web portal providing the ocean state forecast (currents, wave height, sea surface winds and pressure) for smart navigation.

- **Monsoon Monitoring**
  INSAT-3D Atmospheric Motion Vectors (AMVs) for the monitoring of Monsoon 2016 & 2017: (Fig 7) The Atmospheric Motion Vectors **(**AMVs) are derived operationally using different spectral channels viz. Infrared, Water Vapor, Visible and Mid-Infrared of INSAT-3D.



INSAT-3D derived AMV and Wind products
Fig 7

- **Real-time generation of satellite based cyclone centric products:** A procedure was developed to generate the cyclone centric products in the real-time using the Indian satellite observations viz., INSAT-3D, SCATSAT and SAPHIR.

- **Real-time tropical cyclone (TC) prediction:** Real-time prediction of TC formed over the north Indian Ocean was generated using satellite observations and in-house developed algorithms (Fig 8).

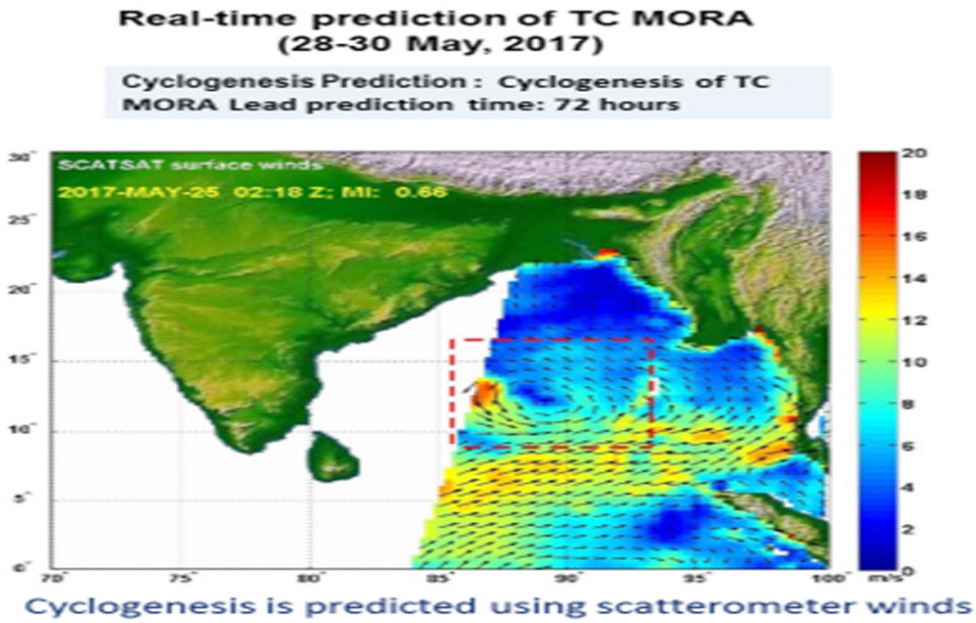


Fig 8

- **City scale heat wave prediction:** A technique has been developed to predict the temperature of scale of a city using numerical weather prediction model forecasts and satellite derived land surface temperature.

- **Satellite based tracking and nowcasting of convective/heavy rainfall events:** Real-time nowcasting of heavy rainfall and cloudburst events were carried out for the year. Additionally, a technique was developed to utilize combined 15-minutes observations from INSAT-3D & 3DR data.

- **Cloud Microphysical Parameters (CMP) derived from AVIRIS-NG:** A new technique is developed to estimate cloud micro-physical parameters (CMP) namely the cloud effective radius and the cloud optical thickness using AVIRIS-NG imaging spectroscopy data.

- **Assimilation of INSAT-3D rainfall and SCATSAT-1 winds:** A procedure has been prepared to assimilate INSAT-3D retrieved rainfall in the WRF model using variational data assimilation method, after preliminary verification with IMD gridded rainfall observations.

- **Seasonal Prediction of Indian Summer Monsoon rainfall using AGCM:** Seasonal prediction of Indian summer monsoon (ISM) rainfall has been carried out every year through ensemble based Community Atmosphere Model (CAM) simulation.

2. REMOTE SENSING OF EARTH RESOURCES

- ### Horticulture Applications

Space Applications Center (SAC) in collaboration with Mahalanobis National Crop Forecasting Centre (MNCFC) & NRSC, Hyderabad has developed geo-spatial inventories for seven major horticultural crops in about 185 districts across India. Geospatial applications for horticultural development for management planning has been demonstrated on pilot scale. The remote sensing based crop acreage estimates were compared with the official estimates and the relative deviations were observed to be within the acceptable limit.

- ### Agricultural Activities

National-scale Inventory of pulse crops was carried out for Rabi season 2016-17 using time series AWiFS data and the methodology has been transferred to MNCFC, DAC, Ministry of Agriculture & Farmers' Welfare for operationalization. Multi-date cloud-free data of AWiFS during October to March period were used for 90 districts of Madhya Pradesh, Uttar Pradesh, Rajasthan, Maharashtra, Karnataka and Andhra Pradesh contributing nearly 80% of total Rabi pulses area and production of India. In the Rabi season of 2016 – 17, an increase of the order of 22.3% in Rabi pulses crop area is noticed as compared to 2015-16. The developed procedure will lead to operationalization of Rabi pulses area estimation through Mahalanobis National Crop Forecast Centre, New Delhi under Ministry of Agriculture and Farmers' Welfare from 2017-18 onwards.

- ### Fodder Crop Assessment

Assessment of Fodder crop during summer season was carried out for parts of Gujarat state using multi-date LISS-III data. The study has been extended to other districts of Gujarat, Rajasthan and Haryana states. The fodder crop area was estimated using 120 multi-date IRS LISS-III scenes obtained from March to June 2016 which were processed using Interactive Self Organising Data Analysis (ISODATA) clustering, segregation of NDVI temporal profiles of dominant fodder crops from other field crops and ground truth data collected over 500 sites.

- ### Air Quality monitoring from Space

Aerosol optical depth (AOD) retrieval technique has been developed using INSAT-3D data. Developed Air Quality monitoring web portal (Fig 9) having information on INSAT-3D based Aerosol Optical depth, wind forecast, MODIS AOD and other ancillary data for Central Pollution Control Board (CPCB), New Delhi.

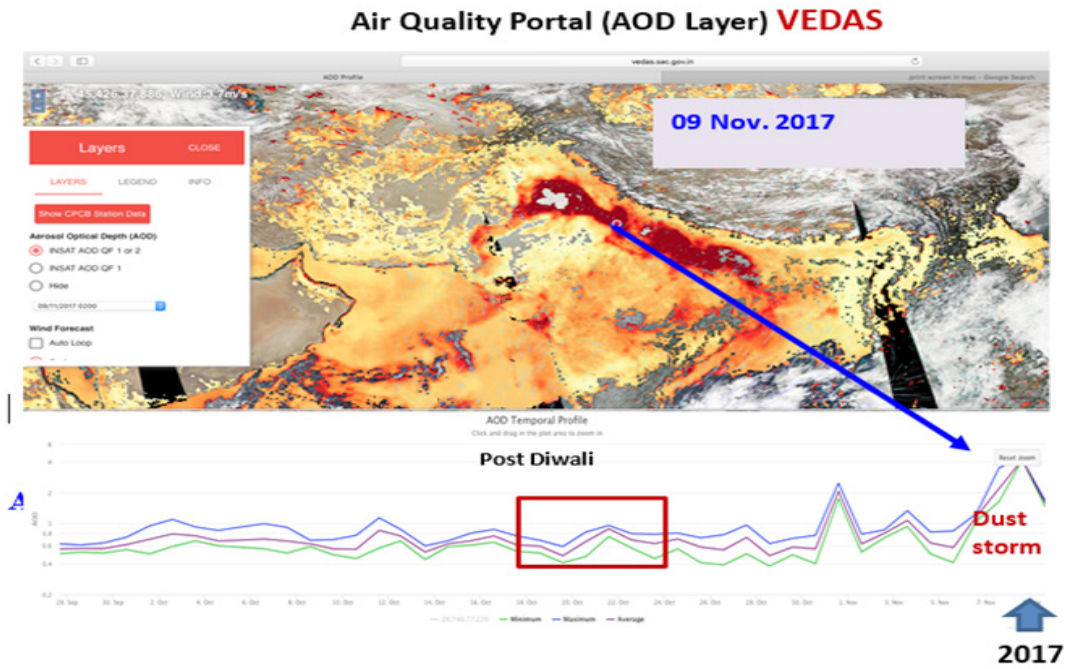


Fig 9

INSAT-3D Imager based Aerosol products along OCEANSAT-2 Ocean Color Monitor (OCM) data were used to monitor the Air quality over New Delhi using multi-date data sets. It was found that post kharif rice residue burnig in Punjab was major contributor to bad air quality in Delhi-NCR region. A portal for air-quality monitoring across north-India was developed for CPCB. SAC has also contributed to national System for Air quality Forecasting And Research (SAFAR) program by hosting an air-quality lab in SAC campus. This facility was also developed during this period.

- **Desertification and Land Degradation Studies**

Desertification Status Mapping of India has been taken up at the behest of Ministry of Environment, Forests and Climate Change (MoEF&CC) to cater to the needs of India's reporting to United Nations Convention on Combating Desertification (UNCCD). Preparation of Desertification status Maps at 1:50,000 scale for selected 78 vulnerable districts using IRS LISS-III data for 2011-13 and 2003-05 time frames in GIS environment has been completed. In addition, prepared and published "Desertification and Land Degradation Atlas of India (Based on IRS AWiFS data of 2011-13 and 2003-05)". (Fig 10) The Atlas was released on the occasion of "World Day to Combat Desertification", on June 17, 2016 in a program jointly organised by the MoEF&CC and AFRI at Jodhpur, Rajasthan.

Published Atlas available on Web Portal of MoEF&CC & SAC Web Portal VEDAS is being used as a ready reference by concerned policy makers, regional planners and researchers.

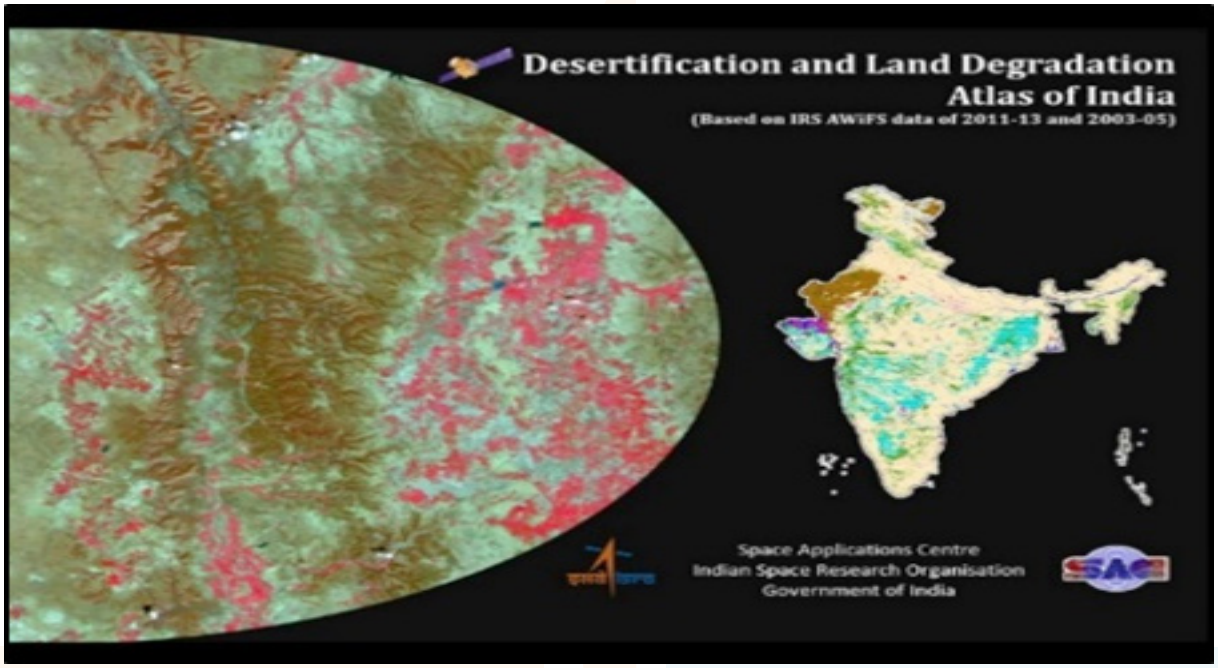


Fig 10

- **Shoreline Change Atlas of the Indian Coast**

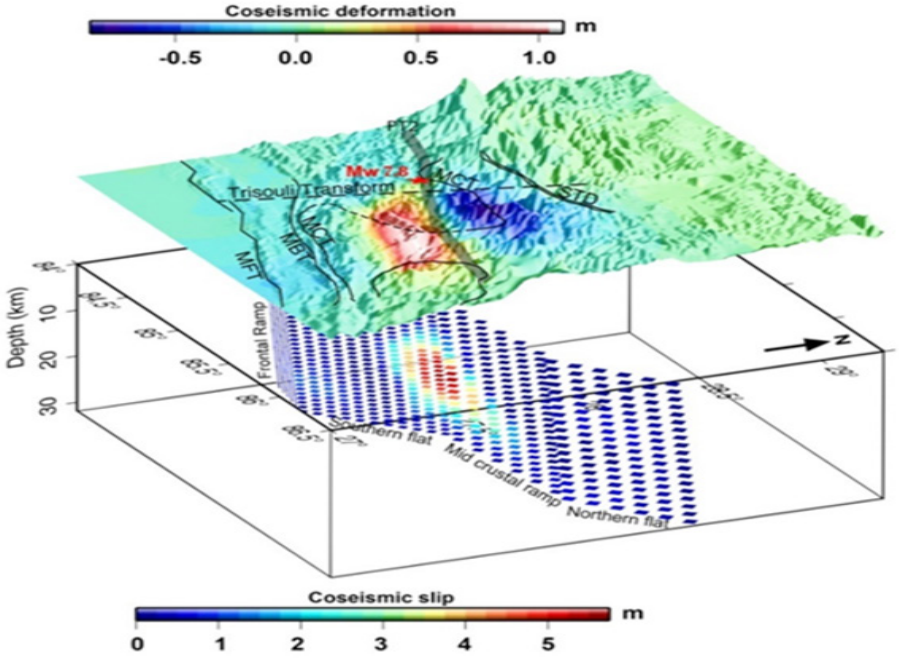
Based on the request received from Coastal Erosion Directorate, Central Water Commission, Ministry of Water Resources, New Delhi, work for shoreline change mapping of the Indian coast on 1:25, 000 scale using IRS LISS-IV data of 2014-16 and 2004-06 (selected hot spot areas on 1:10, 000 scale) has been taken up. Work has been completed for the states of Karnataka, Kerala and Gujarat.

- **Mineral Exploration using AVIRIS-NG**

Mineral exploration studies were carried out using airborne hyperspectral data of AVIRIS-NG for regions around Ambaji (Gujarat), Jahazpur, Pur-Banera and Udaipur (Rajasthan) for mineral exploration studies. Based on analysis of field spectral measurements, library spectra and AVIRIS-NG image data, various minerals such as calcite, dolomite and kaolinite were identified to map prospective zones of marble and base metals.

- **Earthquake Precursors**

Crustal deformation associated with major earthquakes of the Indian subcontinent were studied using InSAR and GPS technique. Coseismic and postseismic deformation associated with the 25 April 2015, Mw 7.8 Gorkha, Nepal, earthquake were mapped using Sentinel-1 SAR data. Joint inversion of the InSAR and GPS data revealed coseismic and postseismic slip distribution on the Main Himalayan Thrust (Fig 9), the causative fault of the earthquake. The study revealed that the shallow portion of the MHT toward south has neither been ruptured during the Gorkha earthquake nor slipped aseismically after the earthquake, suggesting possibility of large events in future. (Fig 11)



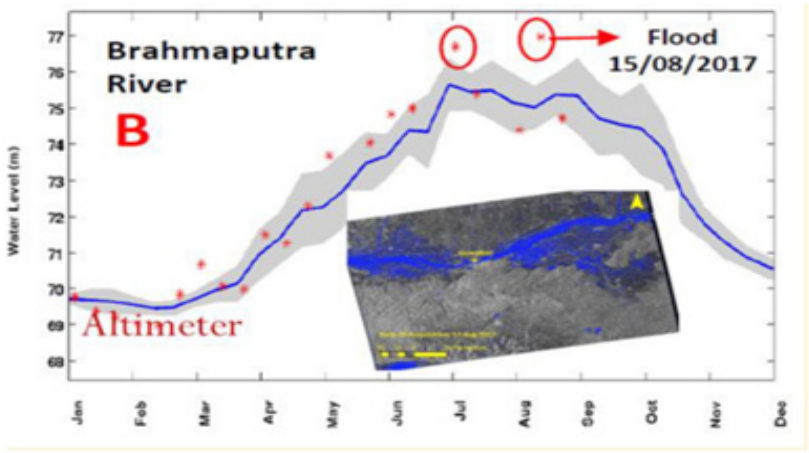
3D illustration of the coseismic deformation caused by the 2015, Gorkha earthquake and modeled slip on the Main Himalayan Thrust
Fig 11

- **Land Hydrological Studies**

Studies were carried out towards observations and modeling of water resources of India using field based observations, remote sensing and advanced analytical modeling techniques. Major outcomes are estimating water spread at national scale using RISAT-1 data, water level measurements over reservoirs and rivers using SARAL-Altika altimeter data and SCATSAT-1 data.

Saral-Altika satellite data are regularly used to monitor water levels in different rivers Altimeter derived river and reservoir water level product (Fig 12) is made available at MOSDAC and VEDAS SAC web portals in near real time. Modeling of hydrological processes and water balance variables (precipitation, Runoff, ET, SM) from field to National scale by satellite data driven hydrological models adapted to Indian region were carried. A Satellite based Hydrological Model (SHM) for National scale water balance has been developed in a collaborative research work.

Flood affected region in India was detected using SCATSAT-1 & SARAL/Altika in near real time basis. Developed Satellite based Hydrological Model which simulates surface water balance (Runoff, Infiltration ET, Soil Moisture, Snow melt etc.) using satellite inputs over India at 5x5 km Grid.



Flood (Red Circle) detected in Brahmaputra River using Altimeter retrieved water levels

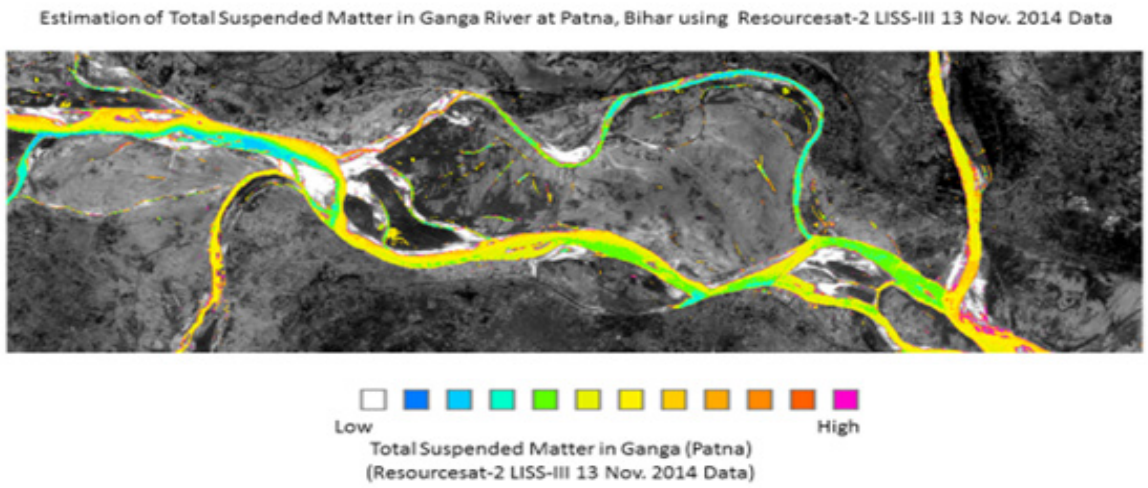


Fig 12

- **Monitoring snow in Himalayan Region**

The project on Monitoring Snow and Glaciers of Himalayan Region has been successfully completed and Final Technical Report has been prepared. This work was taken up at the behest of Ministry of Environment, Forests and Climate Change (MoEF&CC), being nodal Ministry which represents India in key International forums of climate change. Geospatial database of 5 and 10 daily sub-basin wise snow cover maps generated using IRS AWiFS data and NDSI approach for 35 sub-basins of the Indus, the Chenab, the Satluj, the Ganga, the Tista & the Brahmaputra river basins (for ~ 2835 snow cover products/year) and glacier inventory data (34919 glaciers along with 48 attributes covering 75, 779 sq km area) have been hosted on SAC Web Portal VEDAS for wider dissemination and usage. In addition, Snow cover results have been compiled in 42 Snow Cover Atlases providing basin/sub-basin wise information on snow cover extent, area statistics and time sequential analysis. A Himalayan Glacier Information System has been developed.Book entitled, “Monitoring Snow and Glaciers of Himalayan Region”, was released on November 18, 2016.

Snow cover monitoring using IRS AWiFS data at interval of 5 days for time frame 2015-16 has been carried out for entire Himalayan region.

All derived products are made available to scientific community through SAC Web Portal VEDAS for wider usage.

- **Polar Region**

Algorithm was developed to retrieve sea-ice extent using scatterometer data and global sea ice extents products are being generated. Sea ice advisories were sent to Indian expedition ship for smooth passage to Antarctica, based on analysis of multisensor satellite data products. Utilizing SARAL AltiKa data, elevation changes of ice over Antarctic continent have been estimated which are used to infer ice volume changes of the icy continent. Technique for retrieving ice velocity of Antarctica glaciers using image correlation technique was developed. Field investigations over Antarctica were carried out during December, 2016 to February, 2017. GPR of multiple frequencies were used to collect data of snow cover and ice stratification over sea ice and land ice.

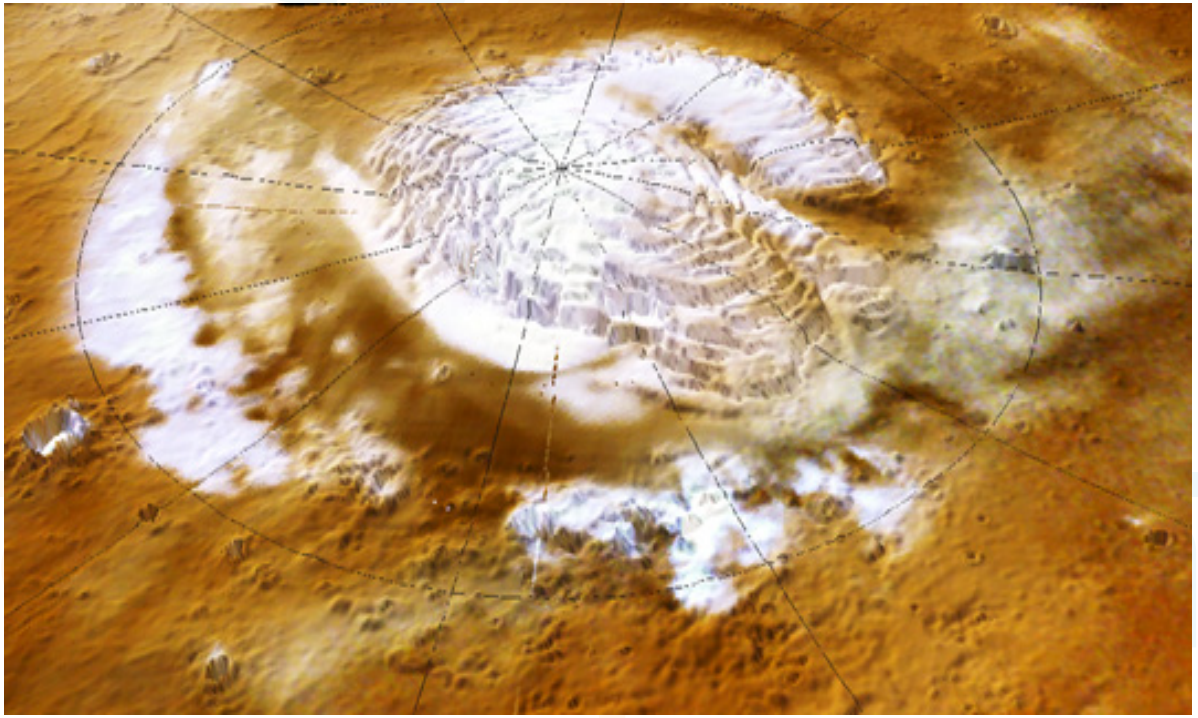
RISAT-1 Coarse Resolution ScanSAR (CRS) mosaic of the Antarctica using more than 300 scenes covering the major parts of Antarctica was prepared. The single CRS image mosaic along with regional mosaic images were provided to SAC Web Portal VEDAS A mosaic using RISAT-1 FRS scenes was also prepared for area around Maitri region, Antarctica. The visual analysis of the mosaic led to detection of an uncharted ice berg that had disintegrated from the ice shelf nearby India Bay, Antarctica.

SAC team participated in the 35th and 37th Scientific Expedition to Antarctica. In-situ observations were carried out using SAC developed GPR at 15 locations near Bharati and Maitri which include the observations on Sea Ice, Ice berg, Ice Shelf and Ice Sheet.

3 SOLAR SYSTEM BODIES INCLUDING PLANETARY SCIENCE

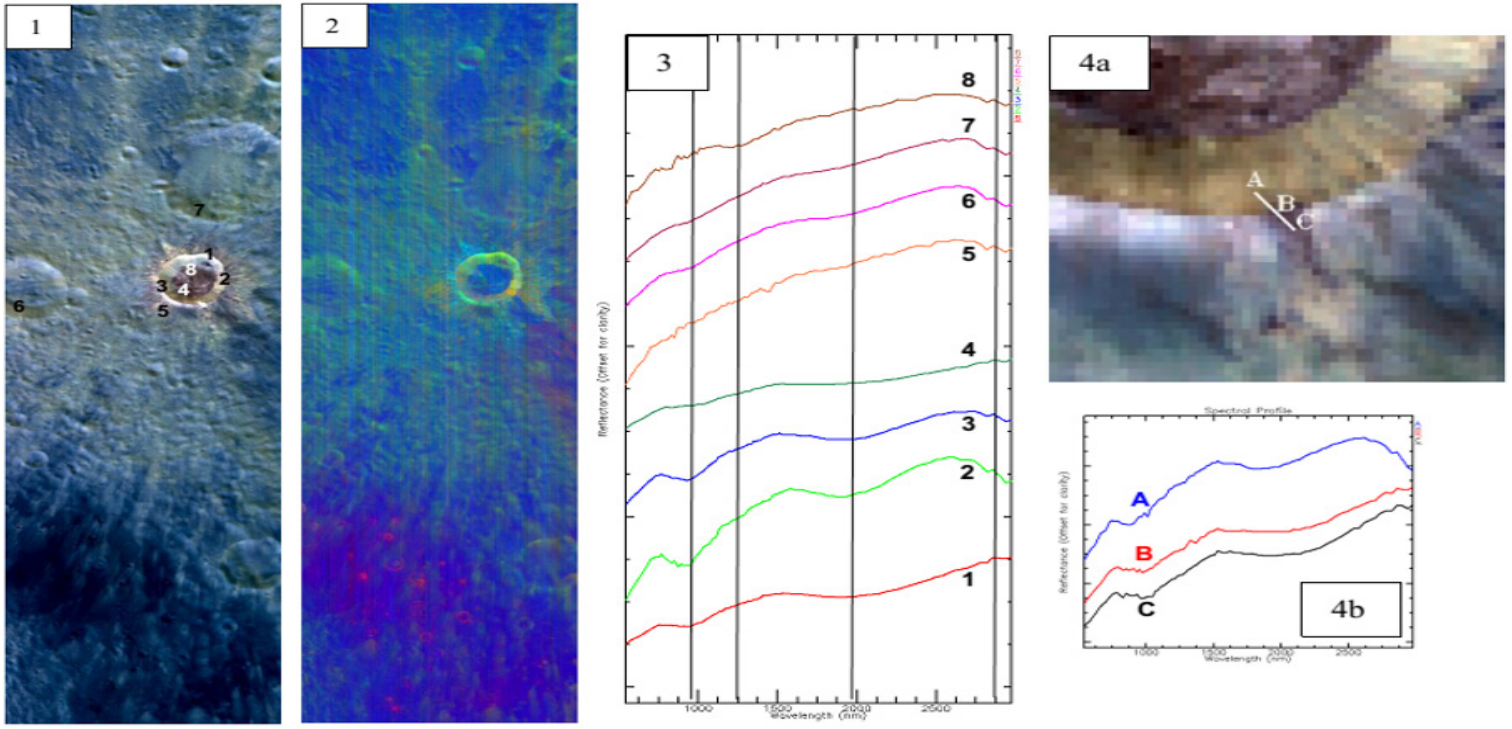
Mars Polar Ice cap Studies

Northern Mars Polar Cap was observed using Mars Colour Camera (MCC) on-board Mars Orbiter Mission (MOM) of India. Nine images of MCC were photometrically corrected and a complete mosaic of north polar ice cap of Mars was developed, showing distribution of ice. This mosaic were also super-imposed over topography data of Mars and a vertical distribution of ice over north polar region of Mars was generated. (Fig 13)



North polar Mosaic of Martian ice cap from MCC data, overlaid on digital elevation data from MOLA.
Fig 13

Discovery of endogenic/exogenic water on the Moon at Giordano Bruno crater (Fig 14) Integrated analyses of Chandrayaan-1 Moon Mineralogy Mapper (M3) data and LRO Mini-RF data over the Giordano Bruno crater has shown the presence of enhanced hydration features associated with the ejecta blanket and impact melts of the crater and their physical characteristics. It has been investigated for its origin i.e. endogenic or exogenic.



RGB FCC showing the extent of ejecta blanket; 2. Rock Type Composite highlighting compositional diversity of Giordano Bruno crater and its ejecta blanket; 3. Representative spectra showing prominent 2800-nm OH/H_2O absorption feature from across the crater and its ejecta banket; 4 (a & b). Spectral profile along crater inner flank, crater rim and outer crater flank as given by A, B and C respectively showing variation of the 2800-nm feature across the profile.

Fig 14

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CHAPTER - 8
NATIONAL REMOTE SENSING CENTRE (NRSC)
HYDERABAD

National Remote Sensing Centre (NRSC) is the major centre of ISRO, at which remote sensing data from Indian satellites are downloaded, processed and disseminated.

A. MAJOR FACILITIES / INSTRUMENTATION DEVELOPED

Established an Outreach Facility in Hyderabad, with 300 seats having access to all satellite data sets and associated softwares with thin clients to promote utilisation of Geo-Spatial technologies.

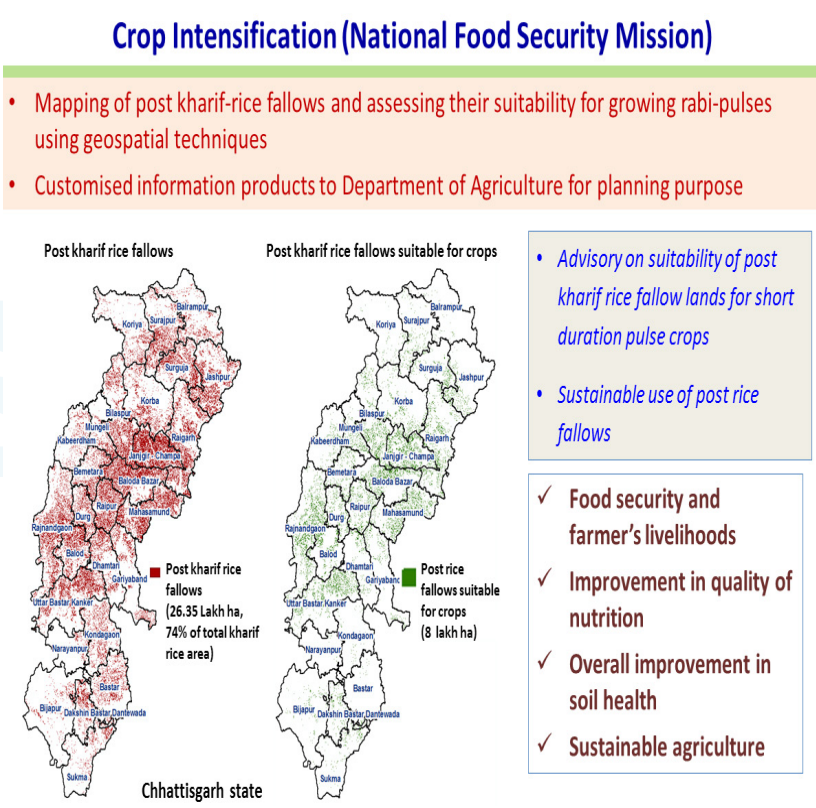
Developed several applications for Governance applications on Bhuvan – Geo Portal for visualisation and analysis for Monitoring and Evaluation of Flagship programmes taken up by Govt. of India.

B. SCIENTIFIC/APPLICATION RESULTS

1. REMOTE SENSING OF EARTH RESOURCES

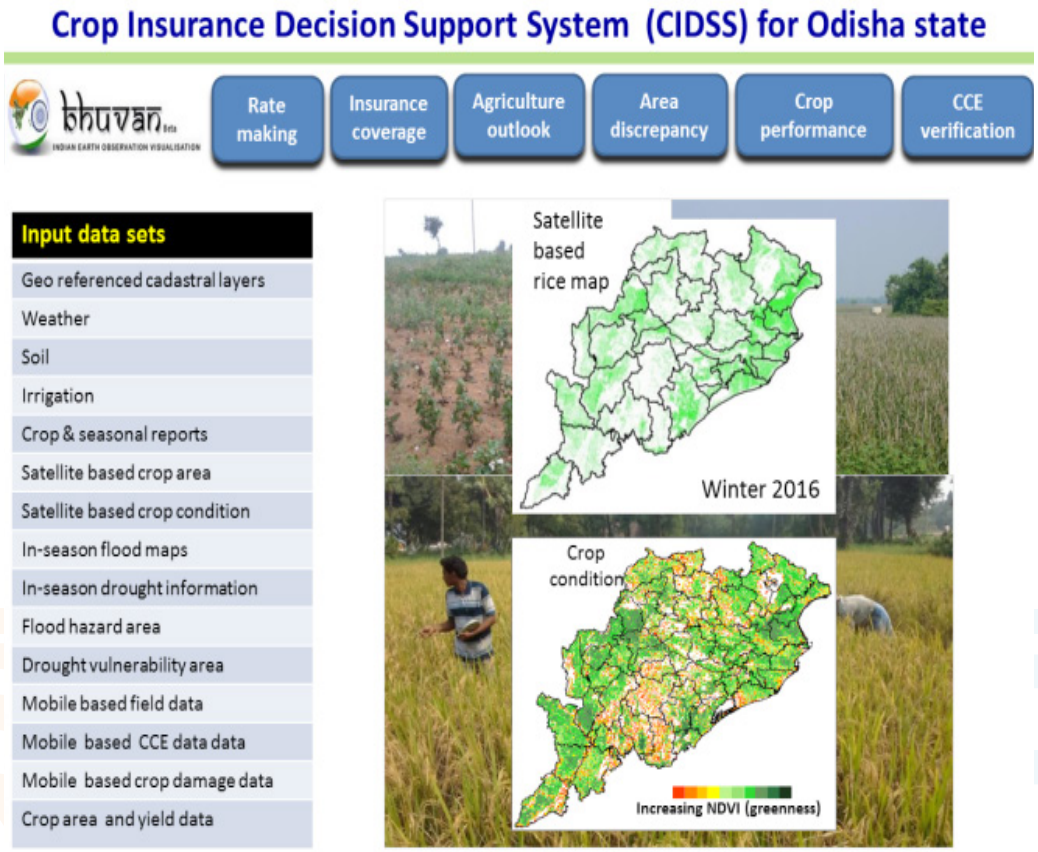
Remote sensing applications, derived through synergistic use of data from earth observation, communication & navigation satellites and complemented with ground based observations is applied for harnessing the benefits of space technology for socio-economic security, sustainable development, disaster risk reduction and efficient governance. The major areas of remote sensing of Earth's resources in the last two years have been towards agriculture, forestry, water, rural & urban development, geodynamics, mineral resources and disaster risk reduction.

- Targeting sustainable agriculture and enhancing agriculture land utilization (crop intensification), Earth observation data was used to map post-monsoon (kharif) rice fallow areas that have potential for second season crop (Figure 1) such as pulses.



Site suitability for crop intensification
Fig 1

- Scientifically proficient and transparent crop insurance mechanism with a Decision Support System is under development using Earth observation inputs covering complete value chain of the crop insurance framework (Figure 2).



Geospatial Technology Support to crop insurance
Fig 2

- Geo-spatial hydrological modelling framework is developed using satellite based multi-terrain information (elevation, land use/land cover, cropping pattern) to re-assess India's water availability at present time-scale.

- High resolution satellite data (both multi-spectral and panchromatic) is conjunctively used to support Watershed development (planning, development, implementation monitoring and impact assessment) in the country.

- Land use/land cover ((LULC) change trajectories with emphasis on utilisation of wastelands are captured for selected hotspots in the country (2006-15) using time-series satellite data sets (Figure 3).

Monitoring LULC Change Trajectories in Selected Hotspots of India

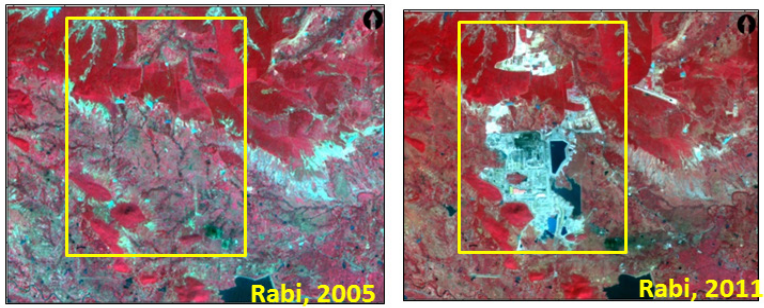
Objectives

- Identify the areas of major change based on LULC 2005-06 and 2011-12 databases;
- Identify and describe the areas of major land cover change and bring out hotspots for further monitoring

Deliverables

- LULC database for the test sites for the hotspot areas on 1:10,000
- Technical report detailing the land transformations
- LULCC maps for Bhuvan

Start Date	November 2014
End Date	March 31, 2017
Budget (Rs Lakhs)	972.93
Project Type	NR Census
Status	completed

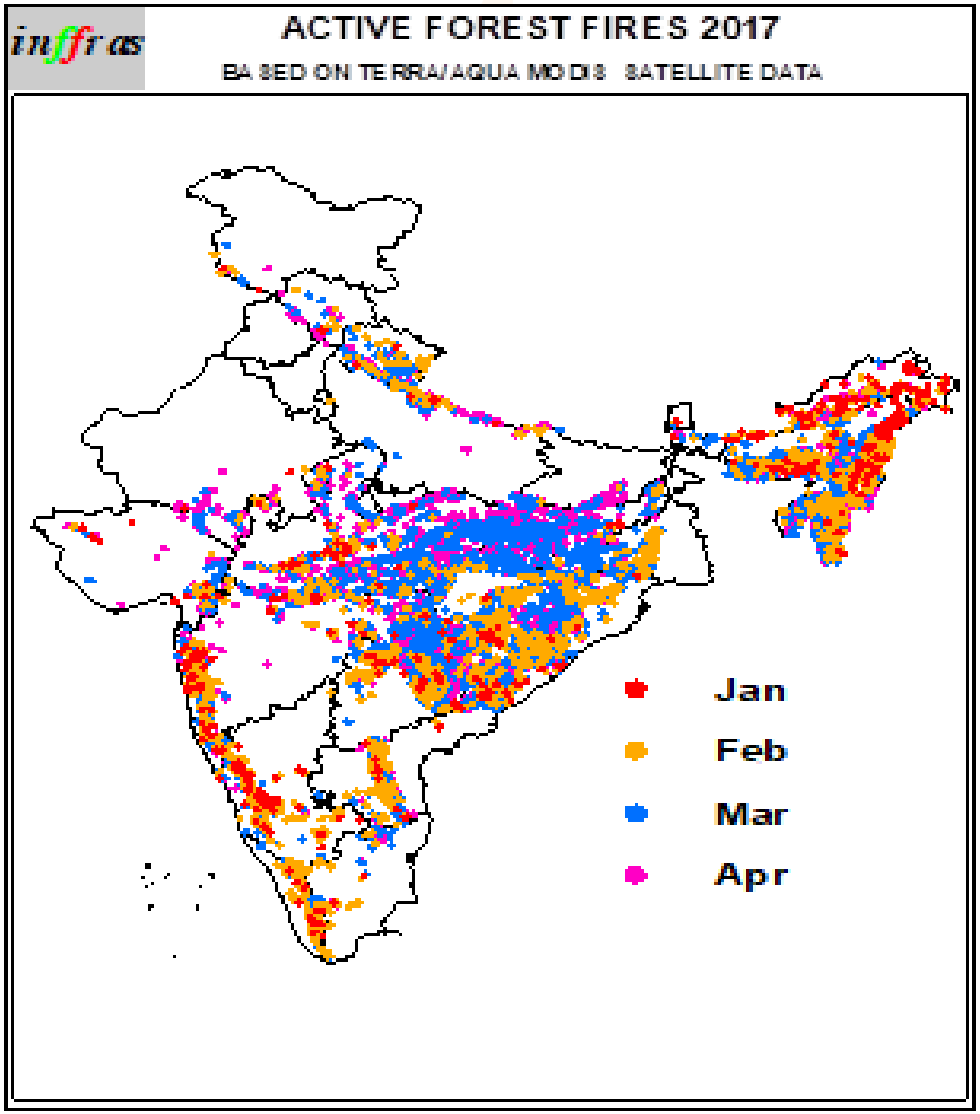


Impact of industrialisation on agriculture
Angul District, Odisha State

Industrialisation on agricultural land (Angul District, Odisha State)
Fig 3

- Historic topographical maps and Earth observation datasets were used to map the forest cover of South Asian Association for Regional Cooperation (SAARC) countries over last eight decades (1930, 1975, 1985, 1995, 2005 and 2013/2014). It contributes for the evaluation of international Aichi biodiversity target 5 (habitat loss and fragmentation) for south Asian countries through analysis of decadal scale forest cover change.

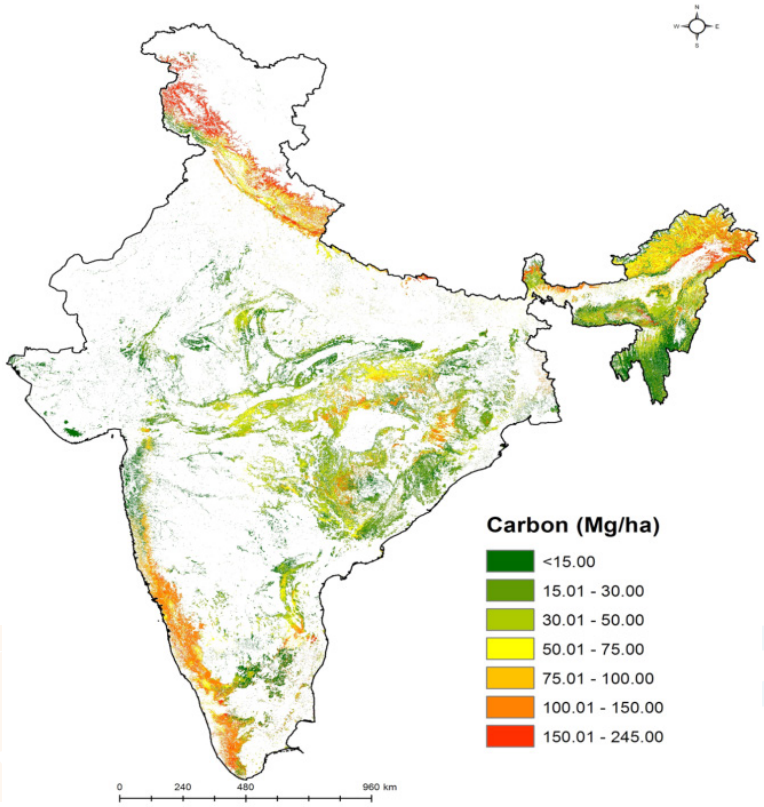
- A fully automated processing and product generation chain is operational to generate and disseminate forest fire location alerts to the user departments using Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible InfraRed Imaging Spectrometer (VIIRS) data (Figure 4).



Monthly distribution of Forest Fire alerts

Fig 4

- As part of terrestrial carbon studies, efforts are being made to assess vegetation (forest) carbon pools and fluxes over representative forest ecosystems across India in support to national activity under National Communication to United Nations Framework Convention on Climate Change UNFCCC (Figure 5).

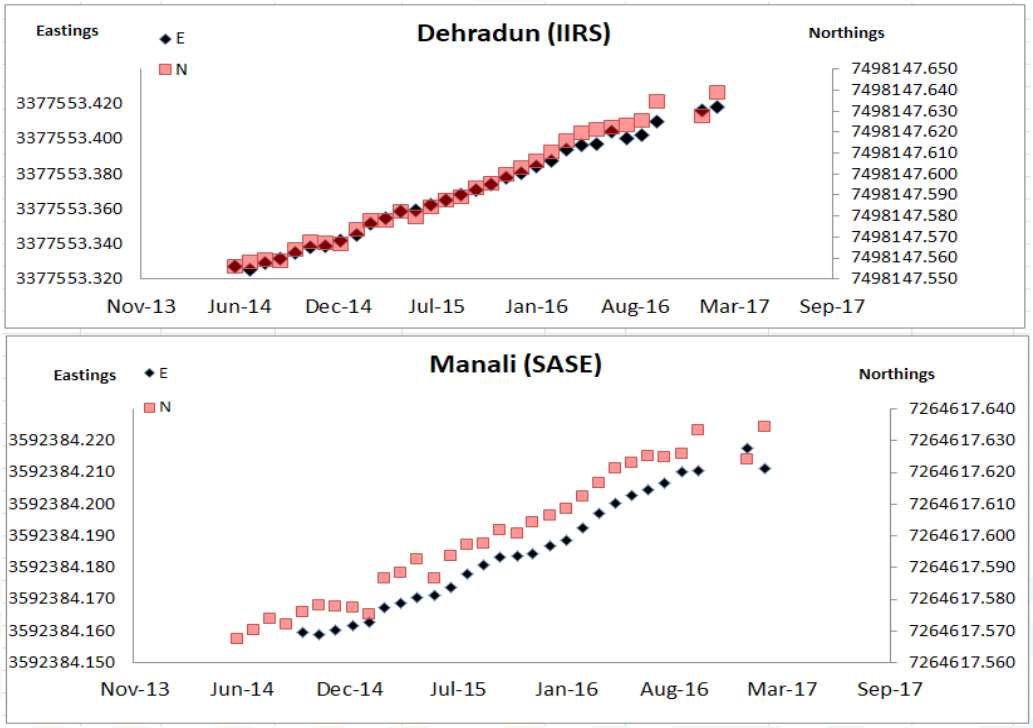


Forest carbon density map 2010

Fig 5

- Baseline spatial information on forest types, forest canopy density and land cover on 1:50,000 scale at every five years interval for four Biosphere Reserves (Nilgiri and Agasthyamalais of Western Ghats, Similipal of Eastern Ghats and Kachchh of Arid zone, Gujarat) towards biodiversity conservation and development of sustainable management aspects.

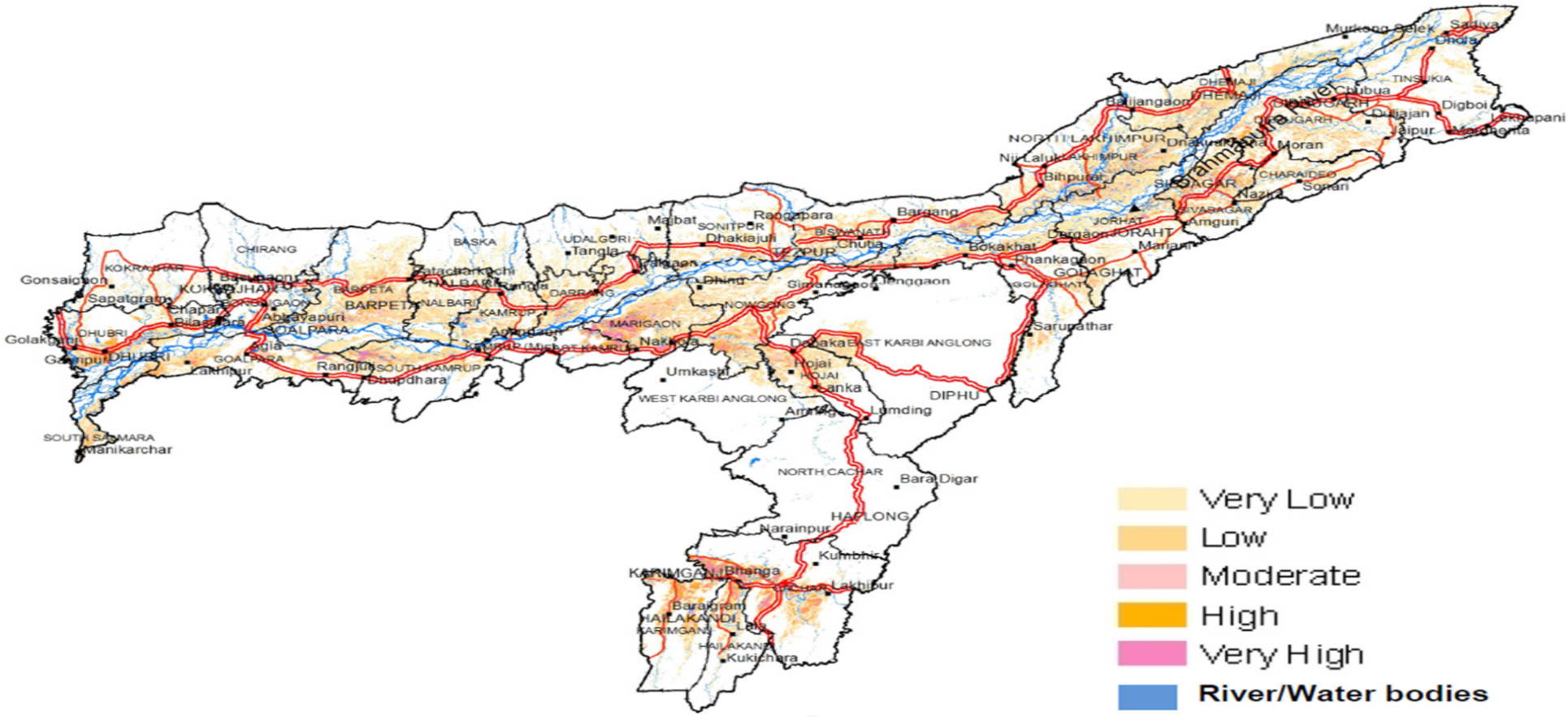
- Geodynamics of the Indian plates is being studied with Continuous Observation Reference station (CORS) and Campaign mode GPS survey in the parts of Himalayan region especially in the seismic gaps which has not witnessed major earthquake in the past. Plate movement vectors were used in 2D / 3D modelling to understand the stress built up in the fault system of theses gaps. This was used to understand the seismic potential of the area Disaster Support (Figure 6).



GPS based geodynamic observation in Himalayas
Fig 6

- Debris flow modelling of landslide, which is essentially triggered by heavy rainfall events, is being studied using ground instrumentation and differential interferometric (DInSAR) observations.
- Hyperspectral data acquired from the Airborne Visible InfraRed Imaging Spectrometer - Next Generation. AVIRIS-NG data were used to understand the alteration zones / diagnostic minerals for exploration of minerals like Diamond, Iron, Gold and clay.
- In the planetary sciences, hyperspectral data has been used for the terrestrial analogue of MARS especially to understand the Martian mineralogy and space based weathering process.

- Shallow aquifer studies, especially saline and fresh water interface for the coastal aquifer is being studied using Ground Penetrating RADAR **(**GPR) and high resolution data sets.
- Flood hazard zonation maps have been generated using multi-parametric approach considering time-series satellite data based inundation maps, socio-economic and geographic data sets for sustainable management and development of flood plains (Figure 7).



Flood hazard map of Assam state
Fig 7

2. REMOTE SENSING OF ENVIRONMENT

Geophysical Products generation for National Information system for Climate and Environment studies (NICES):

64 geo-physical products, including 35 terrestrial, 3 atmospheric and 26 ocean parameters, are being generated and hosted in NICES portal on Bhuvan platform:

http://bhuvan.nrsc.gov.in/bhuvan_links.php

https://nrsc.gov.in/nices.

Standard procedures are being developed for total alkalinity (TA) and dissolved inorganic carbon (DIC) estimates of ocean waters.

Land Surface Processes:

- As part of the Network of Boundary Layer Experiments (NOBLE) project of ISRO-Geosphere Biosphere program(GBP), a 32m meteorological tower has been operational at NRSC, Shadnagar since December 11, 2015. Using the data collected, roughness parameter and zero-pane displacement are estimated. Data also has been processed to examine the surface energy budget and radiation budget over this location.

- Focused on quantifying the impact of Land Use Land Cover (LULC) on meteorology and climate change, it is being assessed over the Indian land mass. Soil moisture–temperature and soil moisture–precipitation interactions, and their possible modifications with climate change are being analysed.

- A Methodology for operational day-ahead forecast of surface reaching solar energy for clear skies has been developed using satellite data and WRF-Solar model. The model forecast output is thoroughly validated against 5 locations in India and agrees with corresponding ground-based instruments within 5% for hourly data. This methodology is being improved for cloudy skies. The same model is also being fine-tuned for wind forecast.

Environmental & Atmospheric Indicators

- Particulate matter (PM2.5): A methodology is developed based on aerosol optical depth particulate matter (AOD–PM2.5) relationship. and is used as a surrogate to fill the spatial gaps of ground-based monitoring network.

- Hot weather outlook alerts at district and mandal levels were generated continuously during the 2017 summer months for Andhra Pradesh, Odisha and Telangana states and disseminated through Bhuvan portal. The methodology incorporated from ground observations from AWS network, vegetation index and OLR from Satellites in conjunction with IMD forecasted air temperatures.

- An air parcel must have sufficient potential energy for convection and the indicator for this energy is Convective Available Potential Energy (CAPE). CAPE product is generated using satellite sounding data. Observed values in extreme environment cases may exceed 3,000 j/kg. However, as with other indicators, there are no threshold values above which severe weather becomes imminent.

- Long term trends in absorbing aerosols, total aerosols and cloud properties over the Indian land mass and surrounding oceanic regions have been examined using long term (2000-2015) satellite observations. Also vegetation-albedo climate forcing and soil moisture-climate interaction studies are being carried out.

3. ATMOSPHERE AND CLIMATE

Measurements of Atmospheric Black Carbon (BC), GHGs at Antarctica on a long-term basis:

- As part of 35th Indian Scientific Expedition to Antarctica (ISEA), during austral summer period of Jan-Feb, 2016, measurements carried out on atmospheric CO2 and average concentration of CO_2 were found to be 396.25±2.37 ppm. Influence of meteorological parameters on atmospheric CO_2 observed at Bharati research station was analysed and documented. It has been observed that precipitation is the major meteorological parameter responsible for the dilution of CO_2 concentration in the atmosphere.

- During 36th ISEA, measurements were carried on Black Carbon, Aerosol and green house gases (GHGs) over Antarctica research station. Measurements were also carried out on CO_2,CH_4& H_2O using Ultra portable Greenhouse Gas Analyser and AOD using microtops sun photometer during voyage towards Antarctica. Observations shows CH_4 varied from 1.785 ppm to 1.788 ppm during summer, 2017. Surface level atmospheric concentration of BC were observed to be 23 ng m^{-3} at Bharati during Dec, 2016 to January,2017. Mean value of Aerosol Optical Depth was observed to be 0.08 during the same period. Further analysis using surface level BC mass concentration from MERRA2 also corroborated this observation, showing an increasing trend from 2000 to 2017 at the rate of 10.85% per year. *Paper on "Influence of meteorological parameter on atmospheric CO_2 observed over Antarctica" has been accepted in "Polar Research" journal.*

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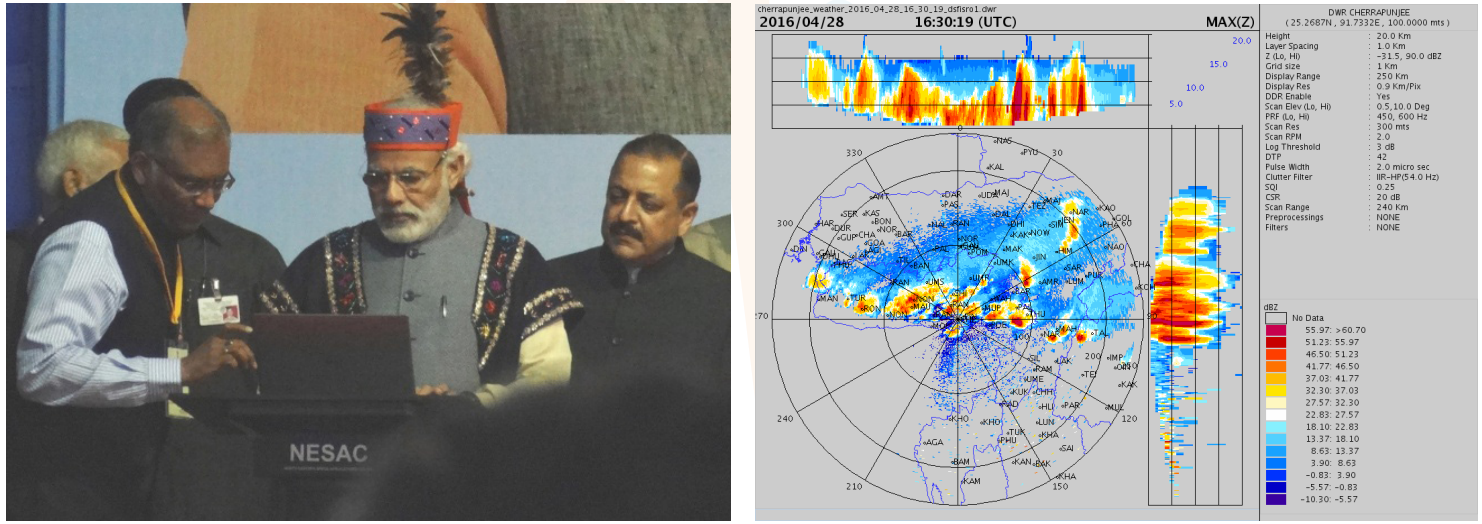
CHAPTER - 9
NORTH EAST SPACE APPLICATIONS CENRE
SHILLONG, MEGHALAYA

North Eastern Space Applications Centre (NESAC) was established in the year 2000 as an autonomous organization under Department of Space, Government of India with an objective to cater to the needs of the North Eastern region (NER) of India towards preparation of geospatial data for management of natural resources, providing satellite communication support, conduct Space & Atmospheric Science research, provide space based disaster management support, and capacity building in the areas of space science and technology.

A. MAJOR FACILITIES / INSTRUMENTATION DEVELOPED

1. The first indigenously developed dual polarimetric S-band Doppler Weather Radar (DWR) has been installed at Cherrapunjee, Meghalaya in collaboration with ISTRAC, Bangalore and India Meteorological Department (IMD) to support operational services for disaster management like flood, storms, lightning, landslide, etc. and support research on Indian Monsoon system, cloud dynamics, etc. The DWR was inaugurated and dedicated to Nation by Hon'ble Prime Minister of India on 27 May, 2016. The DWR is the first of its kind in S-band (operated at 2.75 GHz) and dual polarimetric Radar in India. The data collected by the DWR are transferred to IMD, New Delhi and MOSDAC, SAC, Ahmedabad in near real time for archival and dissemination.



Shri Narendra Modi, Hon'ble Prime Minister of India dedicating the Polarimetric DWR, Cherrapunjee to Nation (left). A typical Range Height Indicator (RHI) product for Maximum reflectivity.

Fig 1

2. A new aerosol observatory has been set up at Tawang in Arunachal Pradesh at an altitude of 10000 feet above mean sea level.

3. A full fledged laboratory has been created at NESAC for Unmanned Aerial Vehicle (UAV) based remote sensing. Multi-spectral and Hyper-spectral cameras have been procured to fly onboard quadcopters and fixed wing UAVs along with data collection and processing software.

B. SCIENCE RESEARCH AND APPLICATIONS

1. ATMOSPHERE AND CLIMATE

The Space and Atmospheric science group is engaged in research in the areas of Atmospheric science and Space science, with focus on understanding the spatio-temporal distribution of major climate change drivers like aerosols and different greenhouse gases, through collection and analysis of satellite data and in-situ data from fixed stations and land campaigns. NESAC has collaborations with several Universities and research institutions. NESAC is an active contributor to several key ISRO Geosphere Biosphere Programme (IGBP) projects like Aerosol Radiative Forcing over India, Atmospheric Trace Gas – Chemistry and Transport modeling, Network of Boundary Layer Experiments, National Carbon Project, etc. The centre is also conducting research towards improving the short and medium range weather forecasting and nowcasting scenario over NER of India to support agro-meteorological activities and disaster management of major disasters like flood, thunderstorm, landslide, forest fire, etc.

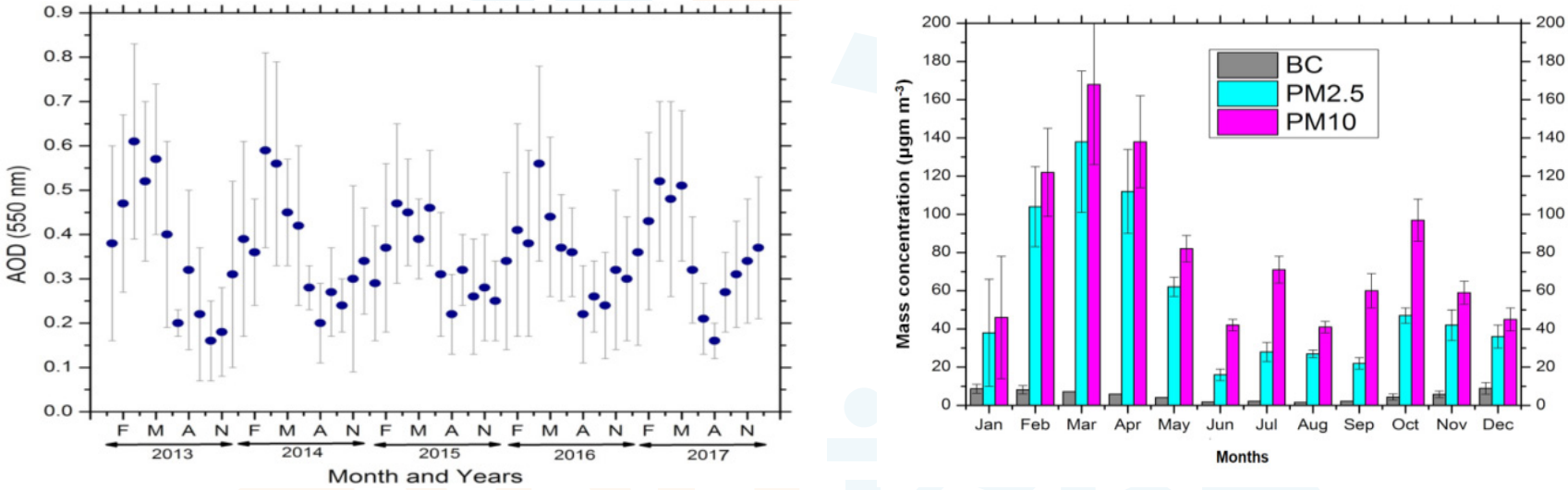
- **Operation of Doppler Weather Radar (DWR) installed at Cherrapunjee**

  The DWR has been calibrated at regular intervals with Sun-calibration technique, bore sight testing, and also using metal sphere calibration technique. The data are validated using Global Precipitation Measurement (GPM) radar data and inter-comparison with Agartala DWR data. The precipitation estimates were validated with rain gauge data and correlation coefficient of 0.91 was observed over Meghalaya. NESAC has developed a product for real time generation of precipitation accumulation using rainfall intensity data. Efforts are also made for development of 3D visualization tool for visualization of reflectivity and other DWR data.

- **Aerosol Radiative Forcing over NER**

  North Eastern Space Applications Centre (NESAC) has been contributing to the Aerosol Radiative Forcing over India (ARFI) project since 2008. Several instruments to measure physical and optical properties of aerosol are operated at NESAC. Two land campaigns were also conducted along the east-west and north-south corridor of NER, to study the spatial distribution of aerosol over the region. One more campaign is being undertaken along the northern Arunachal Pradesh area. Efforts are also made to characterise aerosol over the NER of India using satellite based data and products.

The Aerosol Optical Depth (AOD) has been measured over NESAC, Umiam using a Multi Wavelength Radiometer (MWR) and also using five channels Microtops Sunphotomteter. Figure 2 shows the AOD at 500 nm measured using the Microtops Sunphotometer during 2013-2017 periods. The seasonal variation of AOD remained consistent during all the years and exhibited similar pattern with those observed during earlier years. However, a slight decreasing trend in AOD was observed since 2015 with respect to AOD values in 2013 and 2014. The annual variation of black carbon (BC), PM2.5, and PM10 are also shown in figure 2. The BC and PM concentration increases abruptly during the winter and pre-monsoon season because of large scale forest fire and transport of aerosol from the Gangetic valley in India.



Monthly mean AOD at 500 nm (left) and Monthly variation of Black Carbon (BC), PM2.5 and PM10 (right) over Umiam, Shillong
Fig 2

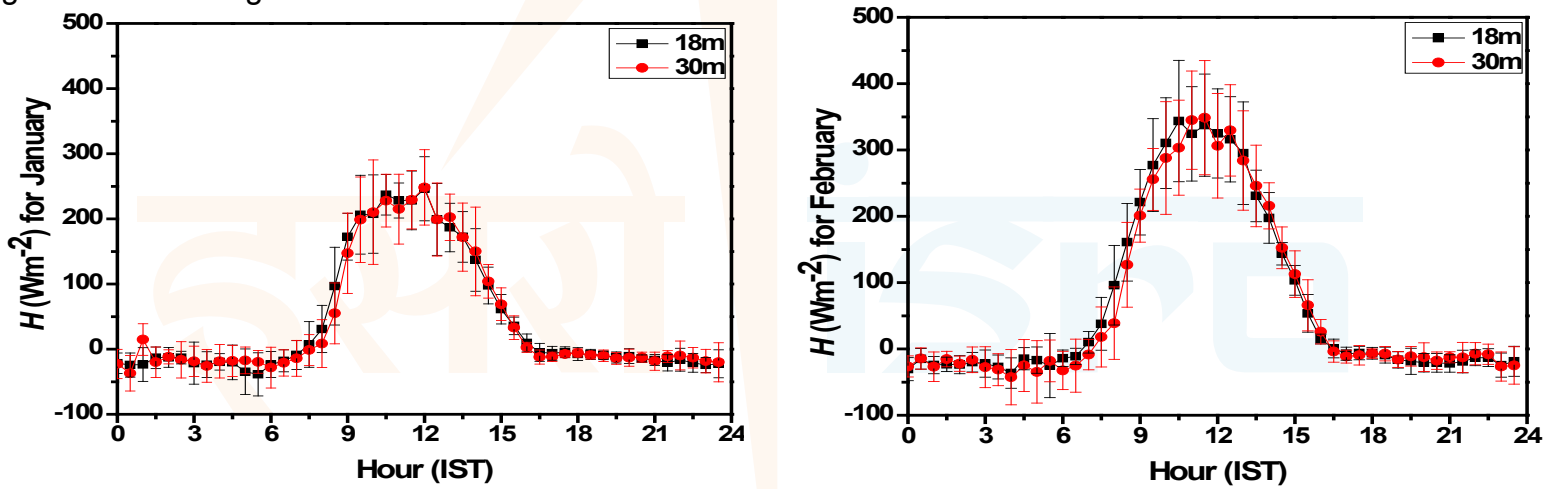
The seasonal mean of number concentration of aerosol showed distinct variation among different seasons both in terms of number concentration and pattern. Almost 99% of the particles observed had aerodynamic diameters ≤1 µm. The primary origin of these particles could be the combustion of fossil fuel and biomass burning. The number-size distribution was bimodal during the post monsoon and winter season. The average particle number in winter was nearly twice as high as in monsoon and post-monsoon season.

NESAC, in collaboration with Space Physics Laboratory (SPL) has set up an aerosol observatory at Tawang (Latitude: 27º 35' 29" N, Longitude: 91º 52' 23" E and Altitude: 2916 m above MSL) on the northwestern corner of Arunachal Pradesh in Eastern Himalaya. The initial BC mass concentration at Tawang is indicative of the very high influence of local vehicular emissions during day and near absolute absence of the anthropogenic sources during night. A sudden jump in BC concentration was observed which could be because of more dynamic boundary layer fluctuations and also local activities characteristic of the life style of the region.

- **Contribution to the Network of Boundary Layer Experiments (NOBLE) project**

The activities under the NOBLE project, being coordinated by SPL are continued at NESAC since 2014. A 32-meter meteorological tower was installed within NESAC office campus with a fast response sonic anemometer at four levels (8m, 10.5m, 18m, 31m). A major campaign was conducted to study "the diurnal evolution of atmospheric boundary layer and its effects on the mesoscale circulations over a mountainous terrain" during 2015.The variation of the major surface layer parameters were studied using the 3D sonic anemometer data collected during 2015-2017 period. The heterogeneity in the surface cover and the topography of the elevated terrain have a significant impact on the micrometeorological parameters, e.g. Heat flux (H), Momentum Flux (τ), Latent Heat Flux (L_h), Drag coefficient (C_d) and the circulation of wind over the terrain. To remove the error in the data collected by the anemometer introduced due to mountainous terrain, General Planar Fit (GPF) technique was applied. After reliable computation of planar fit coefficients, the instrumental offset value was corrected and the surface layer parameters were calculated.

The heat flux (H) was computed from sonic anemometer data fixed at the 18 m and the 30 m height (Figure 3). The diurnal variation of momentum flux (τ) was also computed and the largest magnitudes of τ are observed during daytime hours (09:00 to 16:00 IST). The τ is involved with the covariance of fluctuation in wind components; hence it is probably due to the higher wind shear in the month of February, which led to higher τ at both heights.



Diurnal variation of H for January (left) and February month
Fig 3

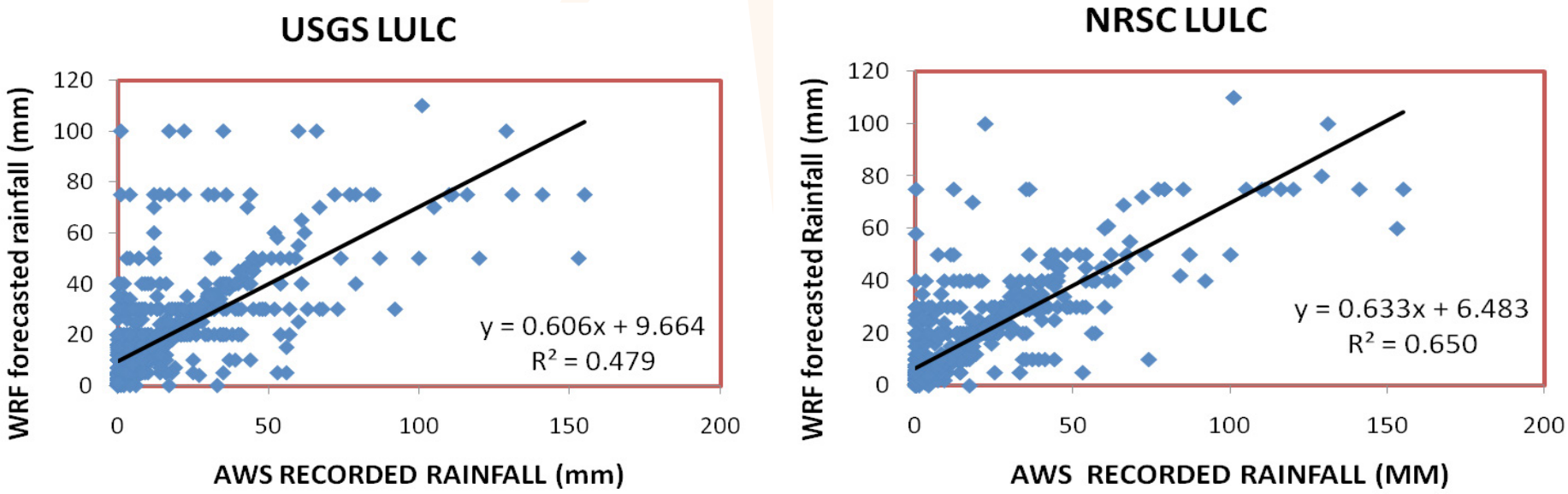
The Diurnal variation of atmospheric stability (ζ) depicted that during the night hours (19:00 to 07:00 IST), when the atmosphere is in the Stable State, ζ has positive scalar. The negative values of ζ could be distinguished throughout the forenoon and afternoon hours (07:00 to 16:00 IST) at the both levels. A clear shift from unstable to the neutral state was observed during evening hours (14:00 to 17:00 IST). During the day hours surface received maximum solar energy as compared to night and morning hours; which hiked the H and τ values throughout the day hours.

- **Improving the weather forecasting over NE region of India**

The weather research and forecasting (WRF) model is being run at NESAC with advanced data assimilation (3DVAR, 4DVAR, Ensemble Kalman filter, etc) technique with higher spatial and temporal resolution (spatial resolution at 3 km and temporal resolution at 1 km) for NE region of India. Data from varied sources like GFS Prepbufr, surface and upper air observations, Radiances from AMSU-A, MHS, HIRES, AWS data and INSAT 3D/3DR wind vector are being assimilated. Efforts are also being made to assimilate the DWR data into the model. The model forecasts are compared with AWS observed rainfall separately for plains and hilly regions.

A new land use database generated by NRSC, Hyderabad has been used along with the default USGS data at a resolution of 30 sec in WRF model. Daily rainfall forecast for June, July, and August, 2016 were compared with AWS recorded rainfall(Fig 4). The use of NRSC land use improved the correlation coefficient from 0.69 to 0.80 as compared to USGS LULC.

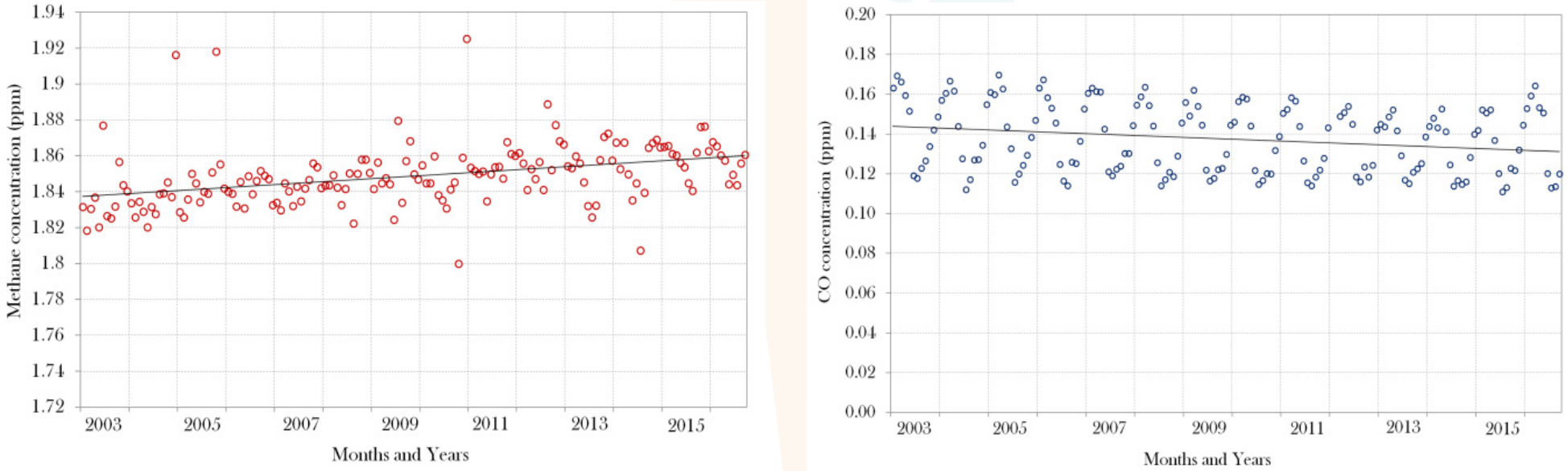
A new high performance computing system (HPCS) has been procured and the WRF model has been configured. The weather forecast was extended for 48 hours and the forecast is made available in public domain through NESAC website (www.nesac.gov.in). A series of new parameters related to atmospheric instability are also generated and made available for assisting thunderstorm nowcasting services. A new module to support lightning forecast over NER, the WRF-ELEC module, has also been implemented and efforts are being made to operationalise the same during the 2018 pre-monsoon season. Implementation of a Land data assimilation system over India for estimating land surface states has also been initiated.



Comparison of WRF forecasted rainfall with AWS rainfall.
Fig 4

- **Long term trend of trace gases over Meghalaya**

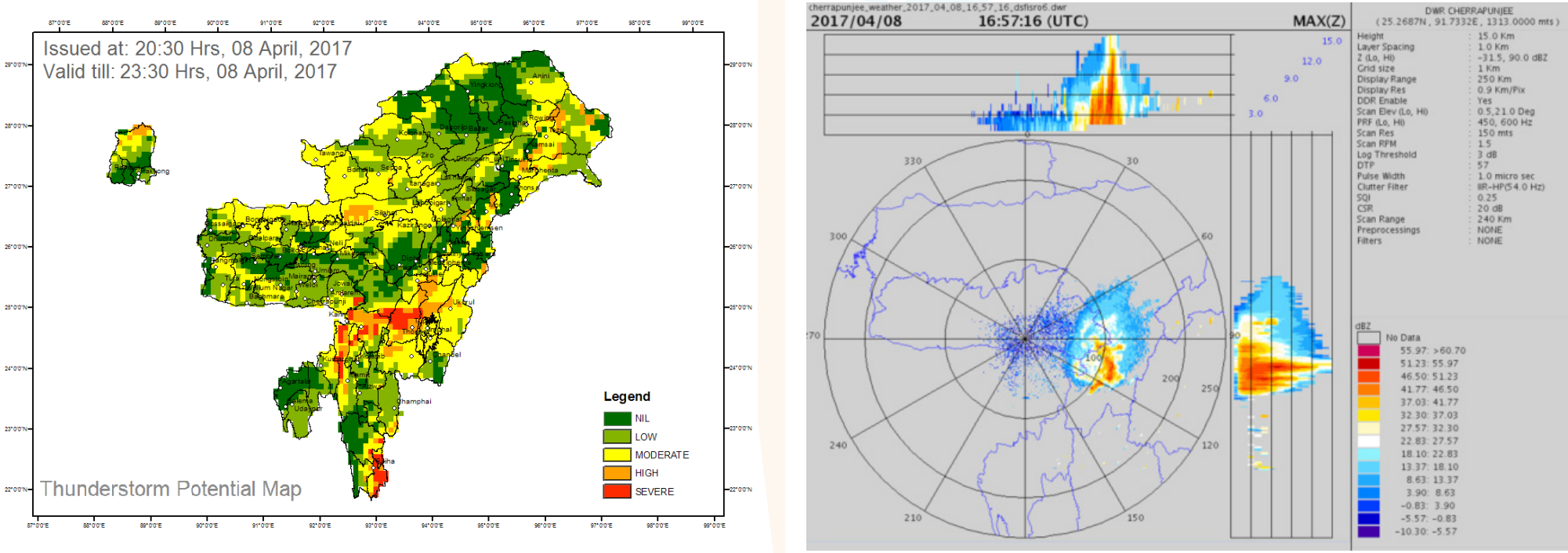
Annual and seasonal trend of surface level concentration of SO_2, CO, NO_2, O_3, and CH_4 over entire Meghalaya region has been studied with the help of 10 years of data retrieved from satellite sensors like Atmospheric Infrared Sounder(AIRS), Ozone Monitoring Instrument (OMI) and reanalysis data of Modern Era Retrospective-analysis for Research and Application(MERRA). An increasing trend in concentration was observed for NO_2, CH_4 and SO_2, while a decreasing trend was reflected from O_3 and CO concentration data. Seasonal variation of NO_2, O_3 and CO reflects a general trend with highest concentration observed during winter or pre-monsoon time and lower concentration during monsoon and post monsoon time. However there was no general seasonal variation observed for CH_4 and SO_2. The concentration of Methane over Meghalaya, which is believed to be the largest contributor to climate change was found to be slightly higher than global average.



Trend of Methane (left) and Carbon-monoxide gas over Meghalaya
Fig 5

- ## Thunderstorm Nowcasting over NER of India

North Eastern Region of India is highly prone to thunderstorms during pre-monsoon season due to its location and topography. The damage caused by thunderstorms includes loss of lives and destruction of property. Efforts are being made to develop a technique for operational thunderstorm nowcasting for the NE region of India under the NER-DRR initiative of NESAC. The data from the DWR, AWS, Sonde, and Satellites like INSAT 3D/3DR are used in addition to the forecast made using WRF model. Thunderstorm warning bulletins are generated three times a day for all states in NE region of India. Additionally, thunderstorm potential maps are being generated since 2017 using the WRF forecast data and DWR data to provide a spatial forecast of thunderstorm probability. The nowcasting warning informations are disseminated to the concerned users using e-mail and web services. The forecasts are validated with ground based observations and satellite observations.



Thunderstorm potential map prepared at 20:30 Hrs (IST) on 8 April, 2017 and the DWR data for Max Z at 22:27 Hrs (IST) showing occurrence of thunderstorm over the region where it was forecasted.

Fig 6

2. REMOTE SENSING OF EARTH'S RESOURCES AND ENVIRONMENT

One of the prime objectives of NESAC is to provide an operational remote sensing and GIS aided natural resource information base to assist planning activities on development / management of natural resources and infrastructure planning in the region. The major activities carried out by NESAC under this area are mentioned below:

- **Preparation of RS and GIS based forest working plan inputs**

  The project has the specific objective of preparation of remote sensing (RS) and geographic information system (GIS) based inputs at 1:10K scale for forest working plan and the project has been taken up for the states of Mizoram, Meghalaya, Arunachal Pradesh, and Assam in collaboration with the respective state forest departments. Based on the input provided, working plan report is approved for Meghalaya by Ministry of Environment, Forests and Climate Change (MoEFCC), Govt. of India.

- **Applications of RS & GIS in Sericulture Development**

  Under this Central Silk Board (CSB) funded project, mapping of potential areas for expansion of sericulture has been carried out in 108 districts from 24 states in the country. Considering the utility of the first phase project CSB has approved the implementation of 2nd phase of the project in 70 priority districts in the country covering 26 states, out of which 20 districts have been selected from NE states. A geoportal called Sericulture Information Linkages and Knowledge System (SILKS) has been developed under this project and made available in public domain in 12 languages.

- **Identification of suitable areas for expansion of Boro rice in Meghalaya**

  Under this project suitable areas for expansion of Boro paddy (Summer Paddy) has been identified for all the 11 districts of Meghalaya. Different thematic maps namely- depth, drainage, flooding, texture, gravel/stoniness, pH, organic matter, and base saturation are prepared using the soil analysis data. All these thematic layers are generated in GIS environment that are used to find out suitability of areas for expansion of areas under Boro rice.

- **Application of geo-spatial techniques for large scale mapping, monitoring and management of mulberry sericulture**

  The project aims to estimate the current spatial extent of mulberry cultivation in selected blocks of West Bengal. Acreage estimation of mulberry plantations have been completed at block level in 4 major Mulberry growing districts of West Bengal. Mulberry leaf protein and moisture content estimation have been attempted using hyperspectral data supported by laboratory based analysis. Mulberry Information System (MIS) has been developed using open source GIS based tools for four selected villages, one each from selected four districts and integrated with SILKS portal.

- **Site Suitability Analysis under Coordinated Horticulture Assessment & Management Using Geoinformatics (CHAMAN) Project for North Eastern States**

  Under this project, mapping of potential areas for one selected horticultural crop in one district of each north eastern state has been carried out. The district level project report has been prepared for each north eastern state.

- **Crop condition assessment under abiotic stress of few selected major crops of NER using remote sensing technique**

  The study has been carried out in collaboration with Assam Agriculture University, Jorhat with the objective of generating spectral signature of selected crops during crop growth stages and to monitor the crop performance under different abiotic stresses due to nitrogen and elevated CO2 and temperature condition.

- **Monitoring and Evaluation of Integrated Watershed Management Programme (IWMP) implemented watersheds**

  The IWMP project is being carried out for NER with the coordination of State Level Nodal Agency(SLNA) and State Remote Sensing Application Centres (SRSACs) for compilation and mapping the changes due to IWMP scheme implementation. It is been initiated in 3rd quarter of 2017and creation of baseline database is in progress.

- **North Eastern District Resources Plan (NEDRP)**

  NEDRP programme was launched with an objective to strengthen the governance policy through geospatial inputs. Around 1750+ geospatial maps in standalone mode, 1620 layers maps via public domain and 1200 geospatial layers through Bhuvan node have been already released to the various users for their developmental planning activities.

- **North Eastern Spatial Data Repository (NeSDR)**

  Under this project, each of the State Remote Sensing Centres in NER is provided with 4 high-end workstations to catalogue the existing geospatial data generated at different scales, different time period with different format by the NESAC/DOS, SRSACs and other agencies for NER in a common format like NNRMS.

- **Use of Unmanned Aerial Vehicle (UAV) Remote Sensing (UAV- RS) for the States of NE region (NER)**

  Total 10 Nos. of UAVs have been developed under the project and handed over to all the State Remote Sensing Applications Centre (SRSACs) of NER (one each) along with data processing software. NESAC has conducted a number of surveys using UAVs such as urban areas survey, crop damage assessment, monitoring of landslides etc.

- **Preparation of district level River Atlas for Assam (User: AWRD/ASDMA)**

  At the request from the Chief Secretary, Govt. of Assam, a proposal submitted by NESAC has been accepted by Govt. of Assam to prepare a high resolution detailed river Atlas for Assam. Contractual manpower under this project has been recruited and work in two districts viz. Lakhimpur and Dhemaji are in advanced stage of completion.

- **Seasonal Landslide Inventory Mapping (SLIM) – Manipur, Nagaland and Arunachal Pradesh**

  Detection of landslide and identification of the affected areas have been carried out for planning post-disaster rescue and relief operations. Landslide Inventory Maps have been prepared using LISS-IV data of pre and post monsoon season. Inventory mapping for the state of Manipur and Nagaland has been completed successfully and the output of the study can be accessed through Bhuvan Portal.

- **Flood Early Warning System(FLEWS)**

  Under this project Flood Early warning system has been developed and operationalised for the State of Assam. On the Embankment breach monitoring component under FLEWS, a large number of embankment failures were identified through the use of Radar data and the report was submitted to Govt. of Assam during post flood season based on which repair works were taken up by Govt. of Assam. FLEWS is being expanded to other states of NER.

- **Forest Fire Assessment in Northeast India**

  Fire alerts were issued daily from February to end of April 2017 to districts of NER under this project. The alerts were issued based on near real time points from Bhuvan, meteorological parameters from AWSs of ISRO and IMD, topographic factors, land use land cover and proximity to water bodies & roads. Based on the weightages of different parameters different vulnerability categories were assigned for each fire points. Forest fire alert SMS service and a Portal on Forest fire monitoring are being developed.

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CHAPTER - 10

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

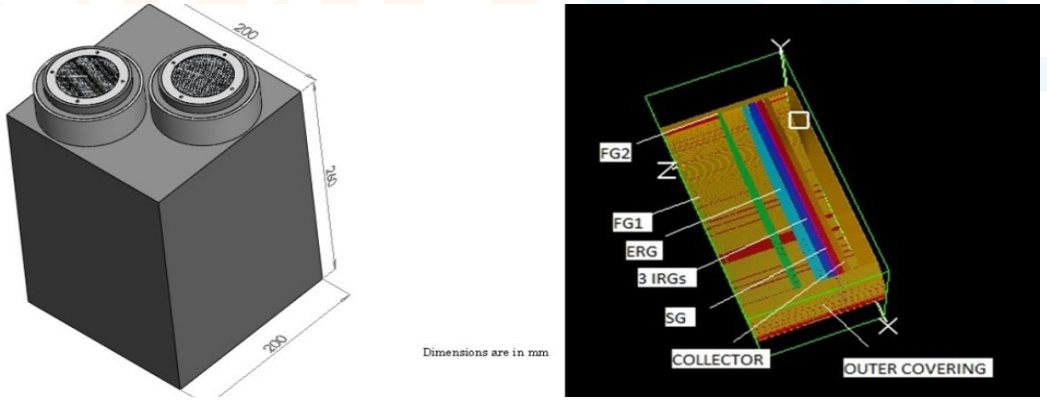
THIRUVANANTHAPURAM

Indian Institute of Space Science and Technology (IIST) is a Deemed to be University under Section 3 of the UGC Act 1956. IIST functions as an autonomous body under the Department of Space, Government of India. The institute is the first of its kind in the country, to offer high quality education at the undergraduate, graduate, doctoral and post-doctoral levels on areas with special focus to space sciences, space technology and space applications.

A. MAJOR FACILITIES/INSTRUMENTATION DEVELOPED

1. Development of satellite payloads for the planetary ionospheric Studies

Development of advanced retarding potential analyser for Martian ionospheric Studies (ARIS): The project is meant for the development of space qualified retarding potential analyser (RPA) for the future MOM-2 mission of ISRO. The project involves the development of ion-mode RPA (I-RPA) and electron-mode RPA (E-RPA). I-RPA measures the ion parameters (ion-temperature, ion-drift velocity, ion-composition, etc.), whereas electron parameters will be measured by E-RPA. The proposed payload (Fig.1) measures the energy distribution of ions and electrons and hence can improve our understanding about the compositional and structural characteristics of Martian ionosphere and the interaction of solar wind with the planetary ionosphere.



(a) Mechanical assembly of ARIS payload (b) Conceptual design of IRPA in exand (or put simulation software)SIMION software
Fig 1

2. Establishment of a hyperspectral remote sensing laboratory

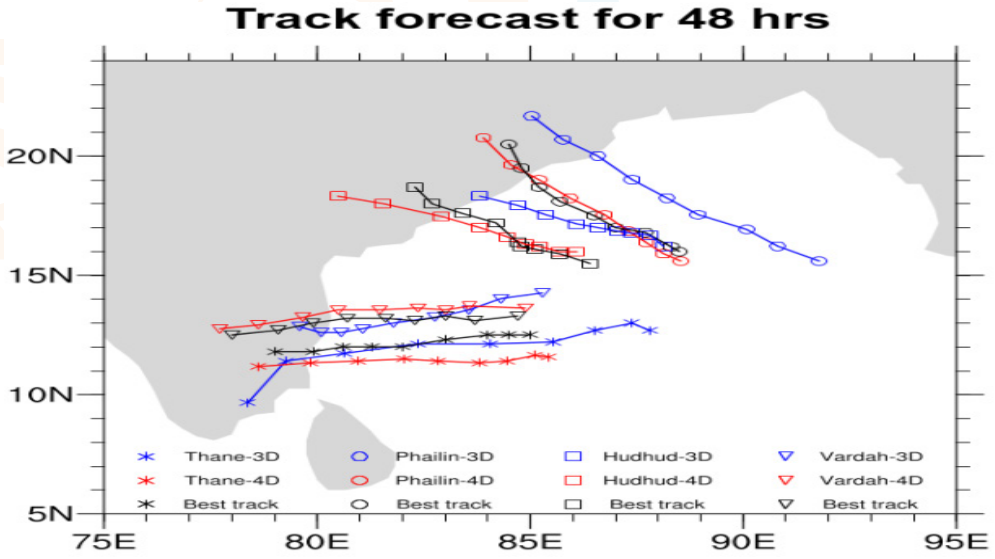
As part of the instrumentation availability for researchers across south India, a central lab facility for hyperspectral remote sensing has been setup in 2017 at IIST, sponsored by Department of Science and Technology, Government of India. This lab contains various high resolution spectral sensors such as full range spectro-radiometer, laser altimeter, hyperspectral imaging system etc.

B SCIENCE RESULTS

1. ATMOSPHERE AND CLIMATE

- **Improved simulation of tropical cyclone track with regional 4DVar initialization using Weather Research and Forecasting (WRF) model**

  In recent times, there have been significant improvements in the numerical prediction of tropical cyclones due to ingesting satellite observations using sophisticated data assimilation techniques. Simulation of four tropical cyclone tracks that occurred over the Indian seas are analyzed using the Weather Research and Forecasting (WRF) model by employing two different data assimilation schemes: (i) three dimensional variational (3DVar) and (ii) four dimensional variational (4DVar) techniques. Conventional as well as satellite observations, including satellite radiances are ingested for all the four cyclones over 12-13 cycles at 6 hrs intervals. Free forecasts for 48 hrs period were initiated from each of the analysis. The track forecast from the final analysis for both 3DVar and 4DVar runs are compared with the observation from IMD and are shown in the Fig.2.

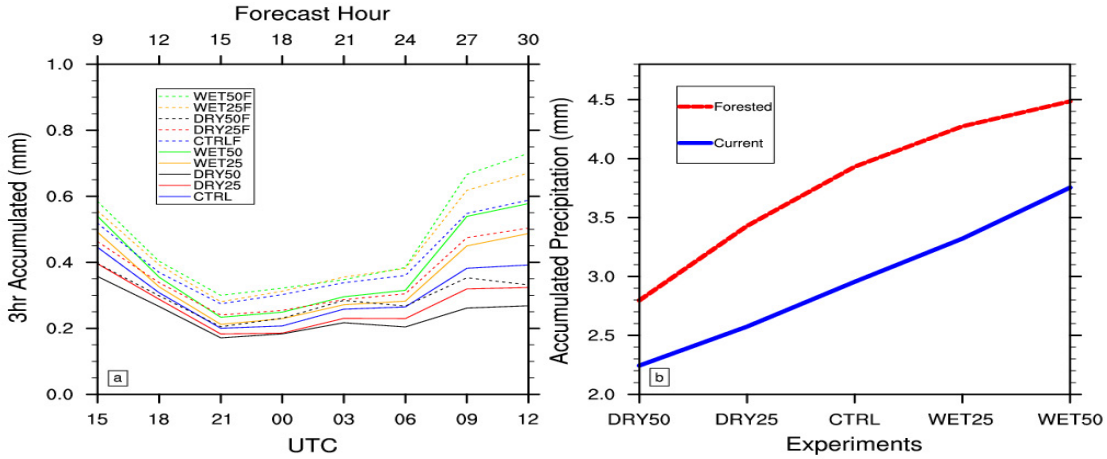


Track of all the cyclones for 3DVar and 4DVar runs with respect to IMD observations for all the cyclones during their landfall phase.
Fig 2

It is evident that the 4DVar runs are superior in simulating the track movement of all the four cyclones and hence the same could predict the landfall position more realistically. Also the 4DVar analyses have captured the initial position of all the four cyclones more accurately ensuring the superiority of the 4DVar assimilation.

- **Land-Atmosphere interactions and its influence in precipitation**

  The Earth's surface has significant influence on the evolution of weather. studies have been conducted to understand the role of soil moisture and vegetation on convective precipitation during the break spell of Indian monsoon through a systematic investigation. It was found that increase in initial soil moisture would lead to increase in precipitation, in general (Fig.3).



(a) Time series showing the domain averaged 3 hour accumulated precipitation.
(b) The domain averaged precipitation for the Soil moisture sensitivity simulations
Fig 3

Compared to the current vegetation cover, conversion to forest produced substantial increase in precipitation. However, precipitation becomes less sensitive to the wet soil conditions in the presence of forests. On spatial scales, the precipitation is found to be more sensitive to initial soil moisture conditions over north-eastern parts of central India. The total surface flux increases considerably with change in forestcover than with the change in soil moisture.

2. IONOSPHERE, MAGNETOSPHERE AND SOLAR-TERRESTRIAL RELATIONSHIP

Ionosphere of any planet is the resultant of interaction between solar radiation and the neutral atmosphere. The structure of ionosphere is very complex because of various dynamical processes like photochemistry, electrodynamics, solar wind interaction etc. We need a theoretical ionospheric model which can simulate the ionosphere based on first principles. The area of research also includes the study of planetary ionospheric studies using observations and in house developed first principle ionospheric models.

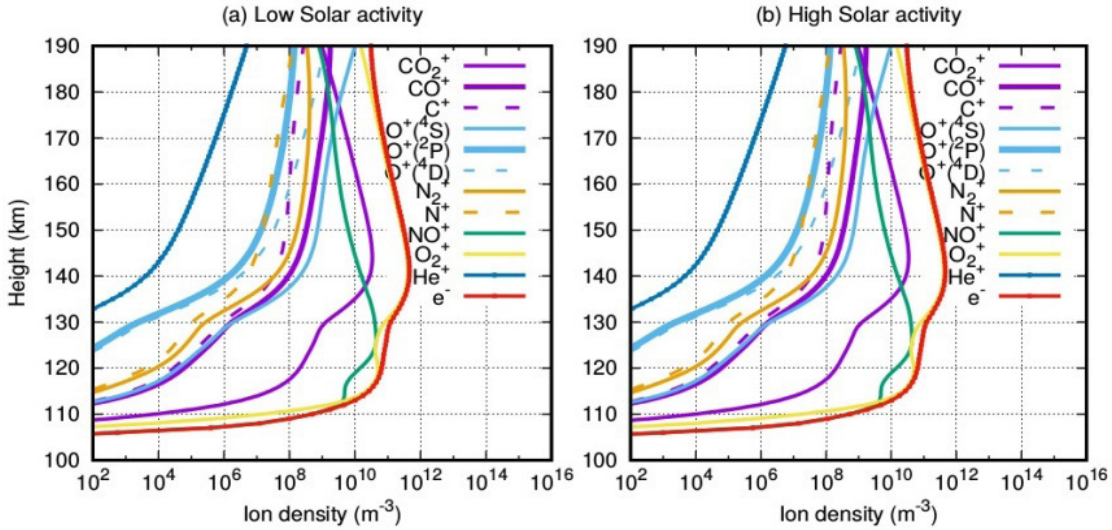
- **Understanding the variabilities of total electron content over equatorial/low latitude regions and their impact on the performance of NaVIC/IRNSS systems over India**

As modern-day activities are increasingly getting dependent on GNSS technologies, the need for understanding the ionosphere and processes affecting the radio signals is immensely felt. Although the gross distribution of plasma in the ionosphere at any place and time is fairly known and modelled, its day to day variations, particularly in the equatorial and low latitude regions is still far from being fully understood, as it can severely depart from its average behaviour. In this context, the Equatorial ionosphere, a narrow region located between ±13 geomagnetic latitudes, assumes significant importance as plasma processes not only affect the electron density in this region but in the entire low latitude region covering ±15 off the geomagnetic equator. In order to understand variabilities in TEC over India, five IRNSS receivers are proposed to be installed across the 77-degree longitudinal chain. The results of these studies can be used in the existing ionospheric models in Satellite Based Augmentation System (SBAS) to improve the efficiency of these models in predicting the variabilities over the Indian ionospheric region.

3. THE SOLAR SYSTEM BODIES INCLUDING PLANETARY SCIENCE

- **Venus Ionosphere:**

A photochemical model for the Venus has been developed. Such a model is useful to address features of V1 & V2 layer, OH+ ion presence in the Venus ionosphere and the features of upper atmospheric bulge observed above V2 layer. It is proved that the neutral density model, VTS3, instead of venusGRAM, could predict the features of V1 and V2 layer during different solar activity and Solar zenith angle conditions This feature was observed earlier by Venus express mission. Fig.4 shows the electron density profile calculated using the photochemical model.



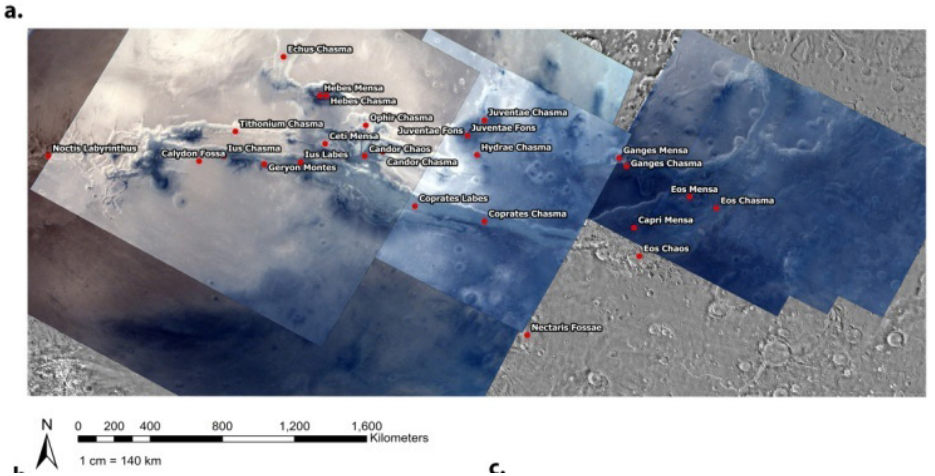
The Venusian electron density profile calculated using the photochemical model.
Fig 4

- **Planetary analogue studies and its implications to the geological processes on Moon and Mars**

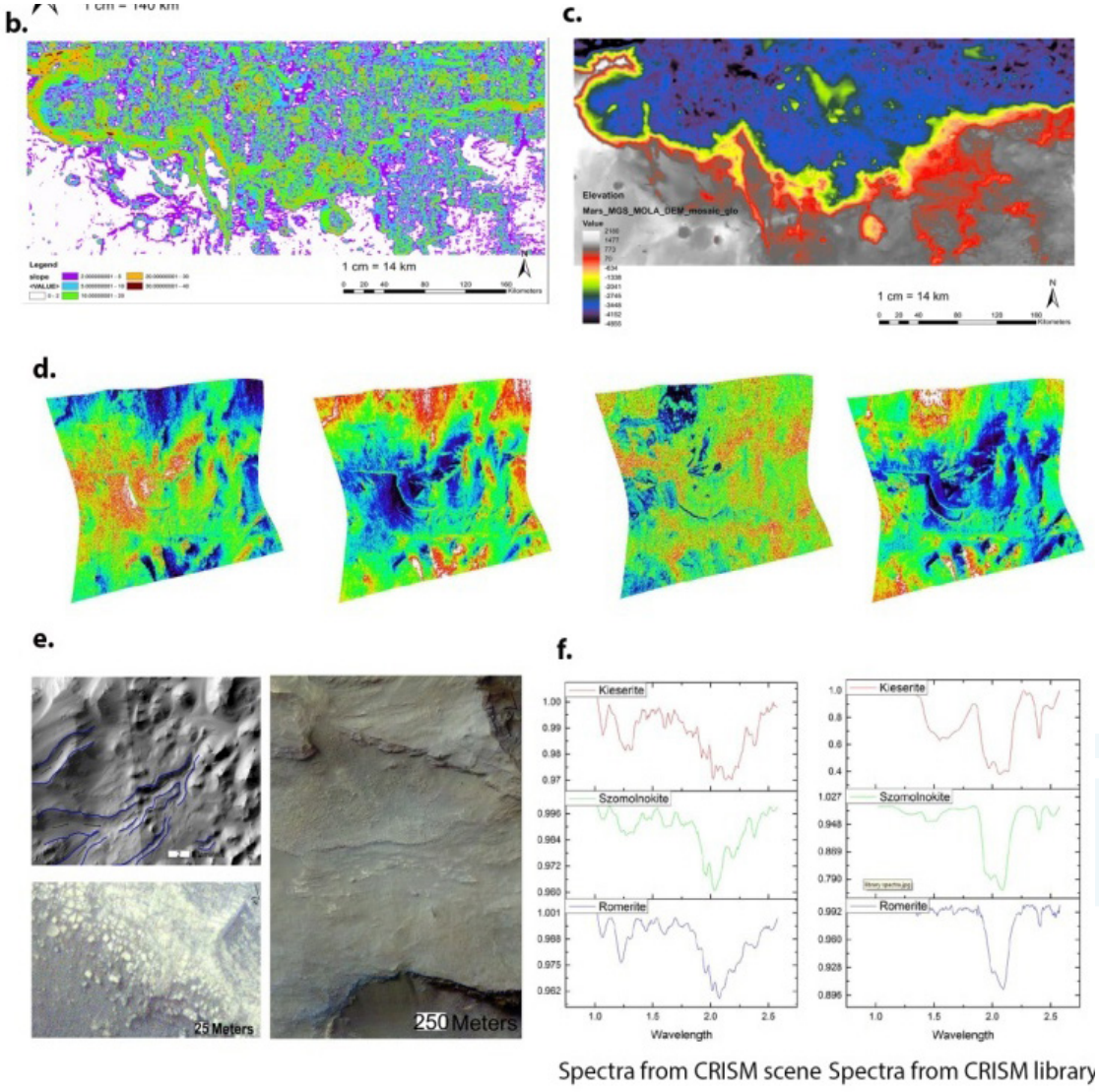
  Planetary analogue studies are useful to unravel geological processes and evolution of other planetary objects. Analogue samples have been characterised spectrally and chemically using X-ray diffractograms (XRD), Fourier Transform Infrared Spectroscopy (FTIR), Laser Raman and reflectance spectroscopic techniques. Integration of these data sets could be useful for future reference and mineralogical studies of other planets. Banded Iron formations (BIF) of Odisha have been proposed as a potential Martain analogue site for layered hematite deposits on Mars. Signatures of primordial life on terrestrial BIF makes it more significant. Characterization of jarosite deposits at Warkalli (Kerala) has implications to the geology and environmental conditions of jarosite bearing regions on Mars. Similarity in chemical and spectral characteristics of hydrous sulphate-phyllosilicates association of Tiruchirapalli (Tamil Nadu), copiapite of Wayanad (Kerala) and Teri sands of Muttom (Tamil Nadu) to Martian counterparts makes them potential Martian analogue site.

- **Lithological and structural evolution of Mars using various planetary datasets**

  Satellite imageries of various Mars missions such as MCC (Mars Colour Camera) onboard ISRO's Mars orbiter mission (MOM) (Fig.5a), CRISM (Compact Reconnaissance Imaging Spectrometer) data on MRO (Mars Reconnaissance Orbiter) and MOLA (*Mars* Orbiter Laser Altimeter) on Mars Global Surveyor have been utilized for better understanding of surface composition and morphological features of western Eos chaos region located in eastern Valles Marineris on Mars (Fig.5b&c).Index maps are created using CRISM Analysis Tool (CAT) summary parameters (Fig.5d). Outflow channels, mesas, distinct layering in chaotic mounts, gullies, and angular fragmented light toned boulders (Fig.5e) have been detected from this area which strongly indicate past fluvial activities this region. Hydrous sulphate minerals like kieserite, romerite and szmolnokite have also been identified (Fig.5f). Zoisite, a mineral stable in low-grade metamorphic conditions is rarely reported on Mars. Spectra with dominant absorption at 1.6513μm are obtained from Western Eos Chaos and are identified as zoisite. Presence of zoisite pinpoints hydrothermal water interaction in subsurface conditions and a model for low grade metamorphic activity in Eos chaos region is under consideration.



(a). Mosaic of Valles Marineris Created using Mars Colour Camera (MCC) and Viking imageries. Corridors selected for the study are marked in the image.
Fig 5a



(b) Slope map of Eos Chaos created using MOLA Digital Elevation Model (DEM).
(c) Elevation map of Eos Chaos created from MOLA Digital Elevation Model (DEM).
(d) Different index maps namely OLINDEX, LCPINDEX, HCPINDEX2, ISLOPE1 of Eos Chaos created from CRISM scene FRT000063C5 using CRISM Analysis Tool (CAT).
Fig 5

- **Exploration of Earth's Moon using orbital remote sensing techniques (Fig 6)**

This study focuses on spectral and chemical characterization of primary mineral assemblages on Moon such as olivine-orthopyroxene-plagioclase-chromian spinel and observing morphological setting of these mineral bearing areas using hyperspectral data and high resolution panchromatic images which provides insight into the lunar crustal composition and crust-upper mantle evolution processes. Lunar impact craters and basins are best sites to explore the upper mantle/ lower crustal composition of the Moon as the impact process excavate to a considerable depth and expose the materials from the deeper regions (Fig.6a & 6b). Fe-Mgspinel mainly on the crater walls and the inner ring of the basin in association with olivine and orthopyroxene are the differentiation products in anigneous pluton that intruded into the lower crust, which might have been exposed by elastic rebound followed by impact excavation. Mg-Al spinel without mafic abundances on anorthositic terrains within the basins must have been formed by the interaction of Mg-suite parental melts with the anorthositic crust.

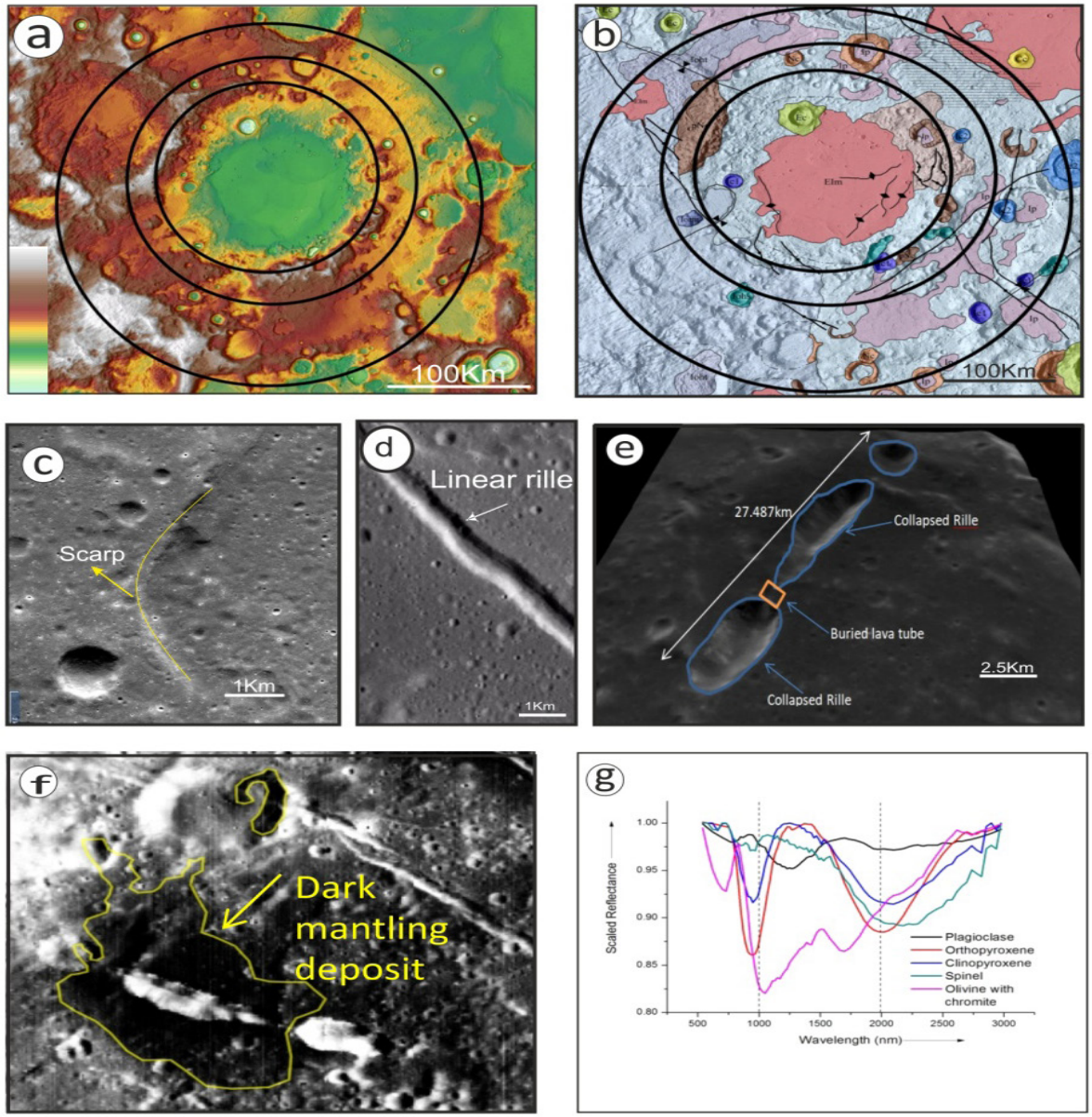


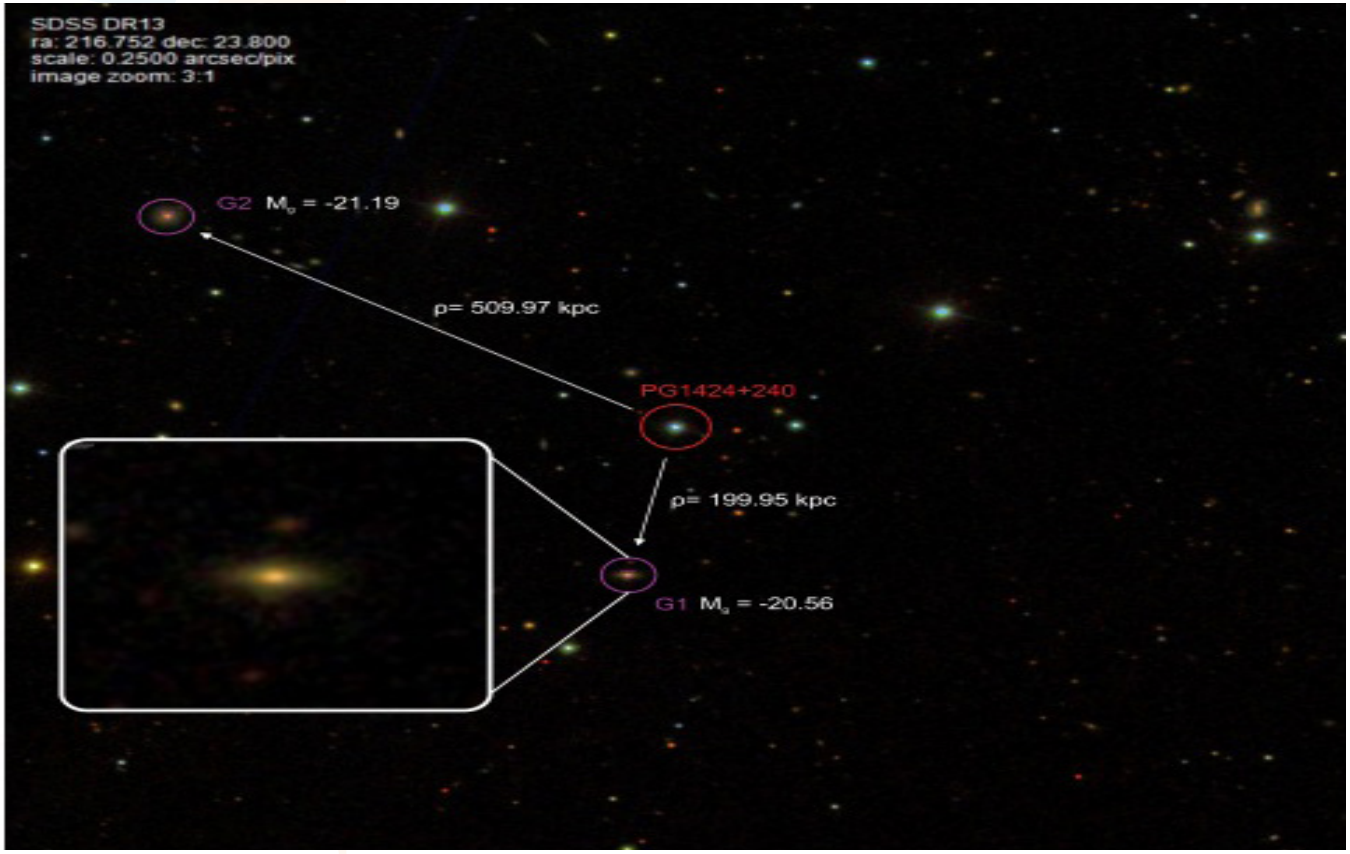
Fig 6 (a) Digital elevation model of the Grimaldi basin on Moon; concentric peak rings have been marked as black circles. (b) Geological map of the Grimaldi basin; major geological units have been mapped; complex morphology and lithological association reveal much about the lunar endogenic processes. (c) Fault scarp in the basin; evidence of extensional tectonics on Moon. (d) Linear rille in the basin; leftover lava channels on Moon (e) 3d visualization of the collapsed lava tube identified in the basin. (f) Dark mantling deposit in the basin; evidence of pyroclastic volcanic activity on Moon (g) Scaled reflectance spectra of the primary mineral assemblages within the basin

The compositional variations among these spinels identified in different terrain settings and their association with the major lunar rock types would be studied to make inferences about their possible origin and propose a petrogenetic model for crust-mantle evolution processes and differentiation history. Evidences of volcanic and tectonic activities such as fault scarps (Fig.6c), linear rilles (Fig.6d), collapsed lava tubes (Fig.6e) and dark mantling deposits (Fig.6f) believed to be formed by explosive volcanic activity have been found on the lunar surface. The spectral and chemical characterization of primary mineral assemblages are given in Fig 6g. Collapsed lava tubes are considered as the potential sites for future human inhabitation on the Moon.

4. ASTRONOMY & ASTROPHYSICS

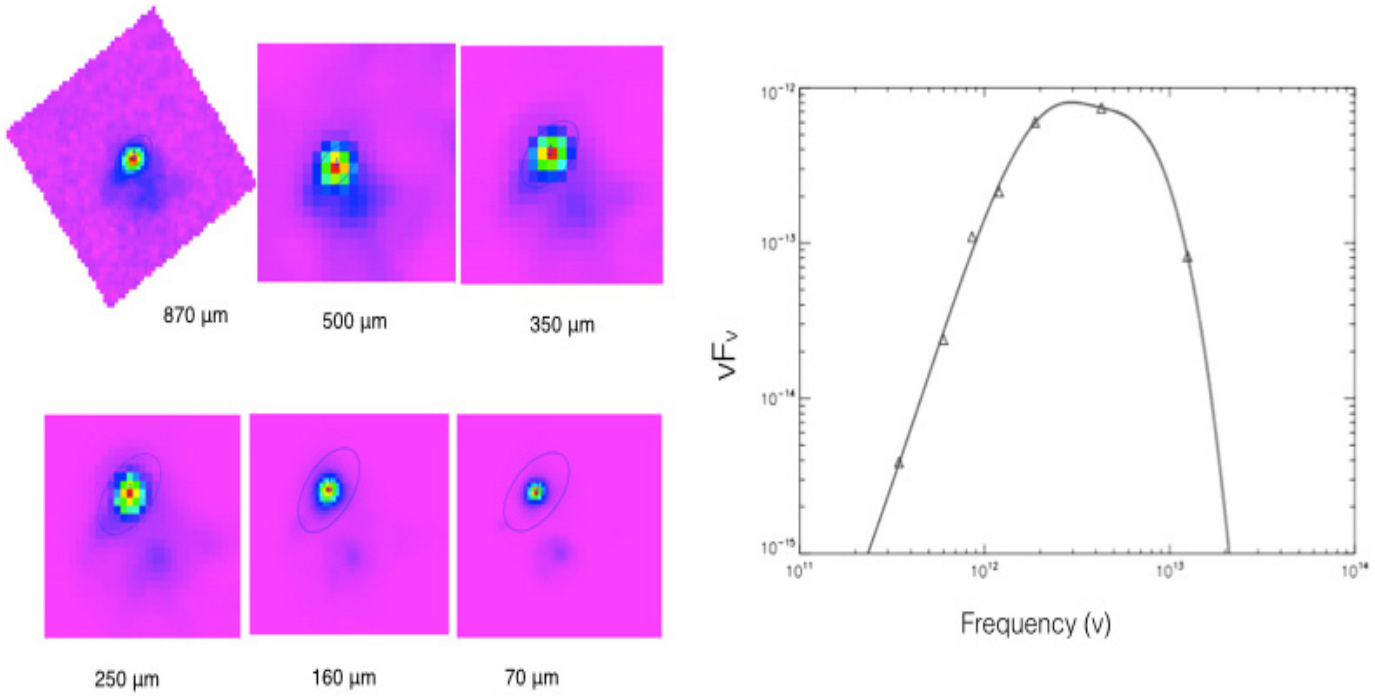
- The Astronomy & Astrophysics group at IIST has been actively involved in researchactivities in a wide spectrum of topics covering Galactic and Extragalactic areas.

  The group has been using the data from Hubble Space Telescope(HST) to study the physical conditions of gas outside of galaxies, in the intergalactic and circumgalactic space (Fig 7). These detections have added substantial useful information on the ongoing global observational campaign in extragalactic astronomy to map the distribution of baryons in the low redshift universe. As part of this work, the group has also been taking advantage of data from the newly commissioned 3.6m Devasthal Optical Telescope at Nainital, and also from large scale surveys such as the Sloan Digital Sky Survey.



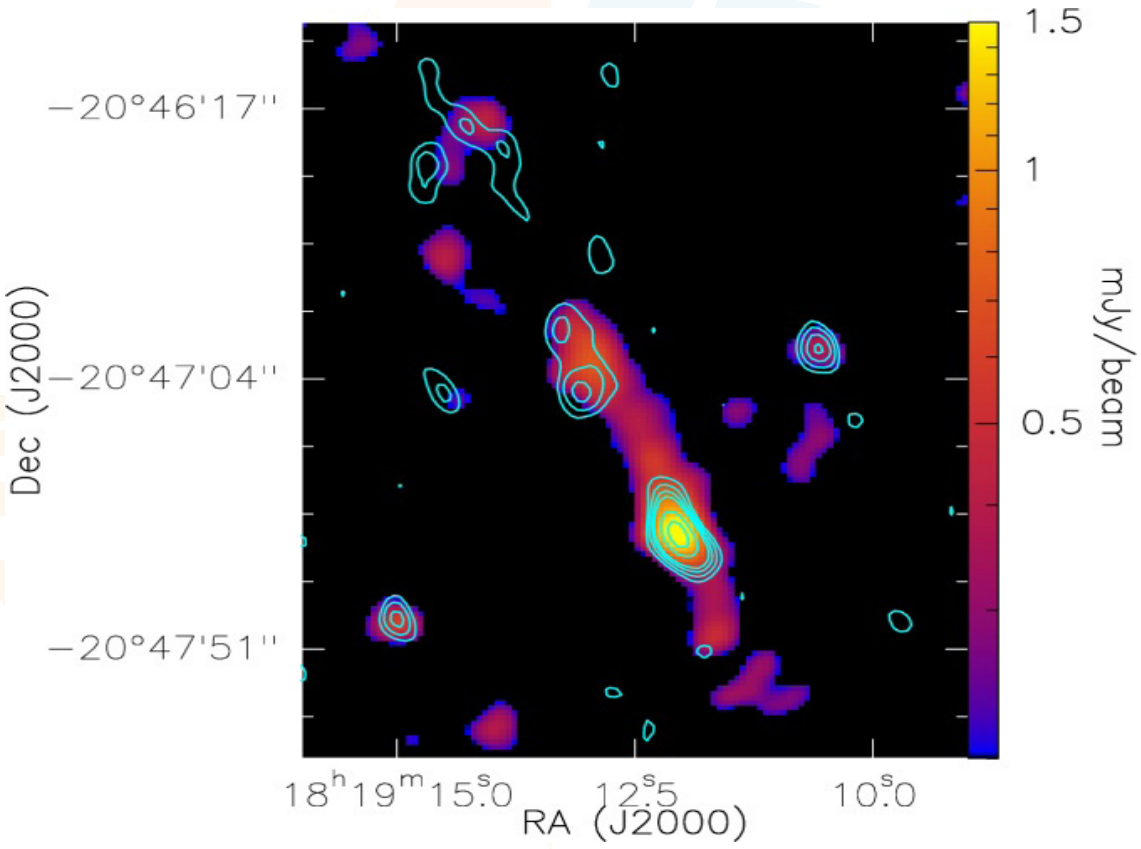
The figure is R-band mosaic image retrieved from SDSS Data Release 13, and shows foreground galaxies and the projected separation in the plane of the sky from the background quasar. The circumgalactic medium of these galaxies is being currently studied with data from the Hubble Space Telescope ultraviolet spectrograph.
Fig 7

- In addition to the extragalactic field, the group has a strong presence in the field of star formation. Methanol masers at 6.7 GHz are thought to be exclusively associated with early phases of high-mass star formation. The association of 6.7 GHz methanol masers with massive young stellar objects can be tested by determining the spectral energy distributions of the maser hosts. In addition, this will give insight on the evolutionary stage of these sources. To this effect, spectral energy distributions have been constructed towards over two hundred and fifty 6.7GHz methanol masers, from 870 μm to 24 μm using data from blind surveys of the Galactic plane (specifically, the ATLASGAL, Hi-GAL and MIPSGAL surveys) (Fig.8). Modelling the spectral energy distributions allowed determination of properties of the sources such as mass, temperature, far-infrared luminosity, etc. Over 95% of the 6.7 GHz methanol masers are associated with young stellar objects which will form massive stars, confirming earlier studies. In addition, the observed mass to luminosity ratios strongly suggest that around 80% of the sources are in an early evolutionary phase wherein matter is still being accreted onto the young stellar object.



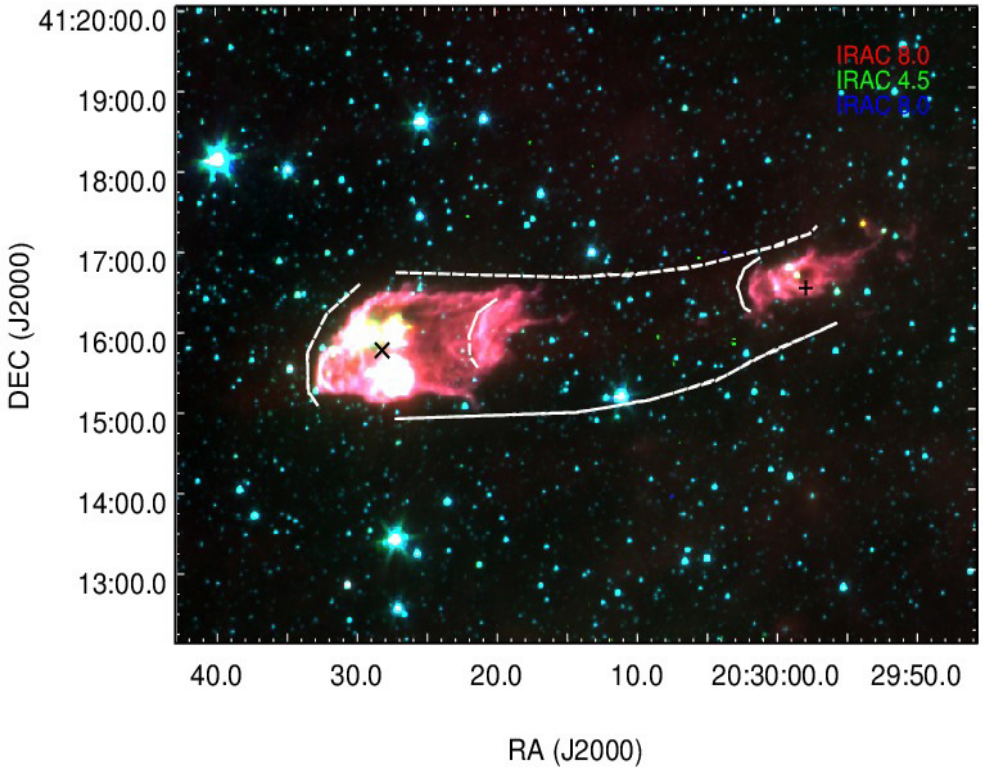
The left panel of the figure shows emission for a typical 6.7 GHz methanol maser from 870 μm to 70 μm. The blue ellipse shows the aperture used to determine the flux in each image. The resulting spectral energy distribution (data marked in triangles) along with the model fit (solid line) is shown in the right panel.
Fig.8

- One of the striking phases in the star formation process is the ejection of material at high velocities from the young accreting protostar into the enveloping cloud. High velocity jets create shocks when they impinge on the ambient interstellar medium and these shocks are regions where particles can be accelerated to relativistic energies. One example of high-velocity jet is the HH80-81 jet, associated with the protostar of IRAS 18162-2048. While the presence of non-thermal emission was known in the jet, the presence of synchrotron emission in the jet and associated radio condensations has been confirmed using low frequency (radio) observations for the first time. This clinching evidence from Giant-Metrewave Radio Telescope (GMRT), India. signifies the presence of magnetic field and is of remarkable import for high energy astrophysics, as this opens up the possibility of protostellar jets being one of the origins of cosmic rays. Radio variability has also been observed of the jet on timescales of few years. For one radio condensation, the Herbig-Haro object HH80, various models of high energy emission have been explored to reconcile the radio and X-ray observations (Fig. 9).



The inner region of the HH80-81 jet imaged at 610 MHz. The color image shows the jet as seen in 2005 while the contours depict the 2016 emission.
Fig.9

The Cygnux-X region is a dreamland for astronomers working towards understanding star formation as it covers a variety of objects in different evolutionary phases to explore. A multiwavelength study towards a star-forming globule (IRAS 20286+4105) in this region, revealed the scenario of ionization and triggered star formation by a runaway star following a supernova explosion in a nearby binary system (Fig.10).



Spitzer IRAC three-colour composite image of the region around IRAS 20286+4105. The position of the IRAS source and SNRG079.8+01.2 are marked with 'X' and '+', respectively. The figure also marks the curvatures and the northern and southern edges based on visual inspection.
Fig 10

5. REMOTE SENSING OF EARTH'S RESOURCES AND ENVIRONMENT

The research activities being undertaken at IIST pertain to the following four sub-domains of remote sensing.

- **Integration of hyperspectral imaging and 3D laser scanning for crop discrimination and biophysical modelling**

  Imaging spectroscopy coupled with evolving terrestrial hyper-spectral imaging and laser scanning provides a rapid and accurate technique to provide crop-related information at high spatial and temporal resolution which is essential to assess within-field variability and to generate training data for space-borne imagery.

  The research at IIST is aimed at the following aspects of remote sensing methods and applications.

  (i) Methods and algorithms for real-time analysis of high resolution hyperspectral imagery for various application scenarios such as onboard imaging data acquisition prioritization and transmission strategy, advanced target detection under complex environments such as the lookout for occurrence of a specific type of material/mineral/target in unmapped terrain.

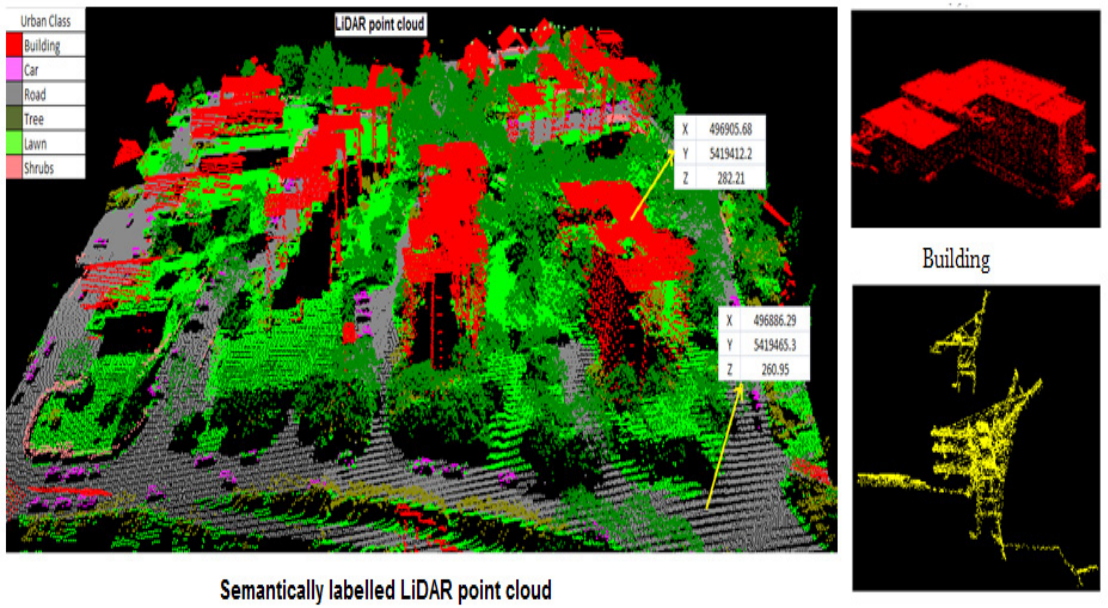
  (ii) Application of drone based hyperspectral imaging in agriculture: Biophysical modeling and crop classification at plant level for optimizing plant nutrients within the context of precision farming.

  (iii) 3D modelling of crops and fringe vegetation: applications of ground, airborne and space-borne 3D laser scanning for precision mapping and monitoring of various structural and growth parameters across space and time.

- **Methods and algorithms for 3D urban buildings and trees modelling using airborne LiDAR and multispectral data**

  Multi-sensor fusion technique has been a very active research area in recent years wherein the complementary characteristics of various sensors are exploited for improved object detection. We have been working on developing algorithms and methodologies related to automated processing of LiDAR point cloud for various applications. Some of the important research work that was carried out is as below.

  1. An efficient and reliable algorithmic framework for semantically labelling 3D coloured LiDAR point cloud acquired over an urban environment in an open source prototype system was developed (Fig.11). As part of mapping urban green space, a fully automated object based framework was developed to detect individual trees from the LiDAR point cloud.



Semantically labeled point cloud
Fig.11

2. A novel methodology was developed for classifying hyperspectral and LiDAR derived DSM image using active learning approach utilizing the knowledge of posterior information of neighbourhood and spatial connectedness.

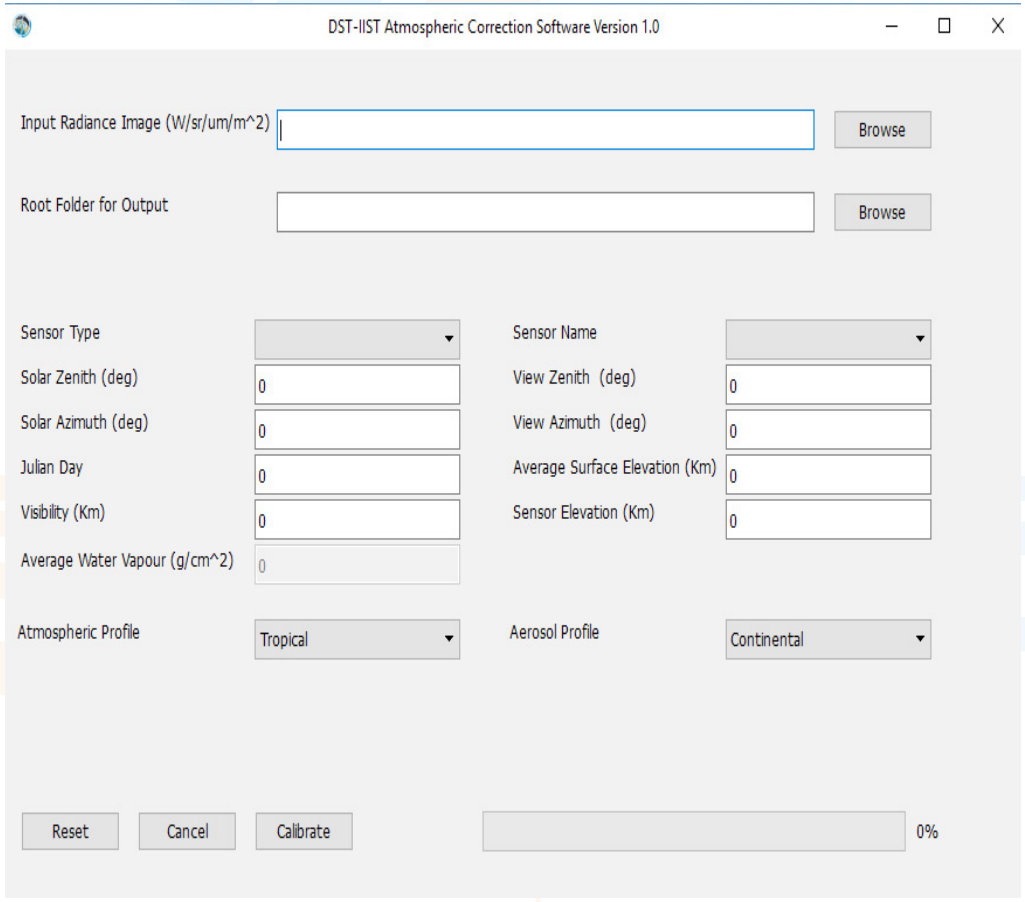
- **Remote sensing applications for mangrove vegetation and urban growth modeling**

Mangroves are one of the ecologically sensitive evergreen forests that thrive in the brackish water environment of the tropical and sub-tropical coasts. India is found to have floristically diversified mangrove types and Bhitarkanika national park is the one having maximum biodiversity among them. We studied the potential of hyperspectral (HS) and multispectral (MS) and multi temporal satellite data for Bhitarkanika national park for the following, (a) classifying the mangroves at species level, (b) developed the spectral library of about 34 mangrove species, (b) assess and compare the spectral separability of HS data – field and lab data using multiple statistical algorithms and, (c) to relate the image derivatives such as vegetation indices, textural parameters, image transformation to other biophysical parameters such as leaf area index, biomass.

We have also been developing a stand-alone model to assess the health of mangrove vegetation using freely available near real time satellite data and high resolution data, and working on urban modelling to understand the tremendous growth in the recent decades in one of the metropolitan cities of India, Chennai, using multi-temporal satellite data and Cellular automata based land cover modeling.

- **Development of a general-open source atmospheric correction module for multi-and-hyperspectral remote sensing data**

The aim is to develop a stand-alone atmospheric correction module for multispectral and hyperspectral and data sources and including local and regional level actual meteorological data. Compared to the available modules, the main scientific advantages are: (a) the ability to import real-world data to parameterise atmospheric conditions from automated weather stations, radiosonde measurements, and sun photometer measurements, (b) the ability to import spectra from ENVI Spectral Library files (allows simulations of the at-sensor radiance that would be measured for a set of field spectral measurements) (Fig12).



IIST Atmospheric Correction Module for hyperspectral and multispectral remote sensing data calibration
Fig.12

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CHAPTER - 11

METEOROLOGY FACILITY, THUMBA EQUATORIAL ROCKET LAUNCHING STATION (TERLS), THIRUVANANTHAPURAM

Thumba Equatorial Rocket Launching Station(TERLS) at 8°32´N and 76°52´E was established as an International Rocket Launching Station for conducting Meteorological and Sounding Rocket Experiments on the geomagnetic equator. The scientific and technical committee of United Nations Organisation, and COSPAR-International Committee for space research recommended that a geomagnetic equatorial launch Station to be set up for conducting electrojet and magnetic field experiments around the geomagnetic equator between 1°N and 1°S magnetic latitudes.

Hence, TERLS was set up in 1963 with the help of various UN member nations and the first rocket Nike apache was launched on November 21, 1963 at 1855 Hrs IST marking the entry of India into space age. INCOSPAR- Indian National Committee for Space Research was formed in 1963 under the chairmanship of Dr.Vikram Sarabhai, which was responsible for setting up of TERLS and also managed all the space activities of India. TERLS was dedicated to UN on Feb 2, 1968. Till the disintegration of USSR, weekly sounding rocket (M-100) launching operations were carried out by TERLS and that resulted in M100 meteorological data base from 1971 to 1991. About 1163 M100 rockets were launched from TERLS and the rich data derived on wind and temperature from 20km to 80km is used by scientific investigators all over the world for their studies on atmospheric oscillations, monsoon, stratwarm etc. RH200, the indigenous sounding rocket flights resumed from TERLS from 2002 onwards under Middle Atmosphere Dynamics Experiment (MIDAS) for wind profile experiments with Copper Chaff Payload as a monthly launch programme in addition to outreach activities of ISRO. TERLS functions under Mechanism & Vehicle Integration entity (MVIT) of VSSC.

Plate.1 C-band polarimetric Doppler weather radar

The major activities of TERLS during 2016, 2017 are listed in this chapter.

A. MAJOR FACILITIES / INSTRUMENTATION DEVELOPED

Doppler weather Radar:

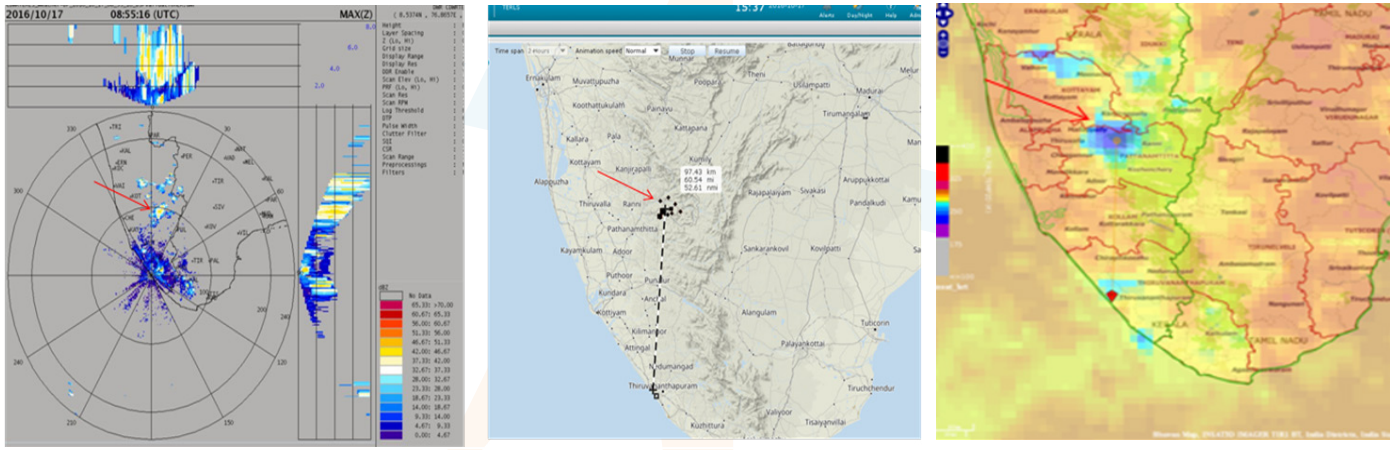
The recent inception of a polarimetric Doppler weather Radar operates at C-Band (5.60-5.65GHz). (Plate 1) and X-Band (9.3-9.5GHz) (Plate 2) Primary Surveillance Radar facilities have paved radar meteorological studies at TERLS. Generation of sixty (60) online derived radar products can be possible which includes base and weather products.

Plate.2 X-band surveillance radar

B. SCIENCE RESULTS

1. ATMOSPHERE AND CLIMATE

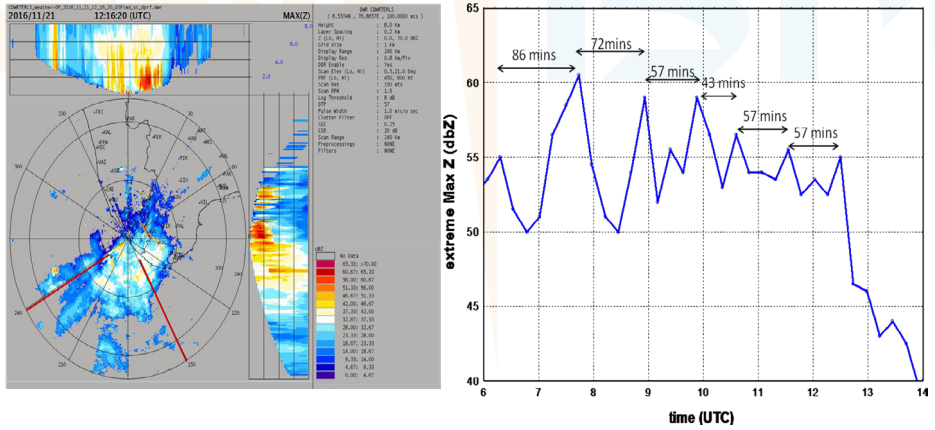
Fig.1 shows the reflectivity product during the cumulus stage of a developing thundercloud along with lightning stroke and satellite observations.



Developing stage of a thundercloud marked by red arrow on October 17, 2017, 1415 IST (DWR, lightning stroke and INSAT imagery)

Fig.1

Periodicity of cloud formation within the low pressure regime formed as a part of easterly wave circulation has been studied by using maximum reflectivity (MAXZ) product within subtended arc area of 150-240 deg. in azimuth confirms the theory of near hourly significant incidence of high and low amplitudes in cloud developments within a typical quasi-stationary low pressure system (Fig.2).

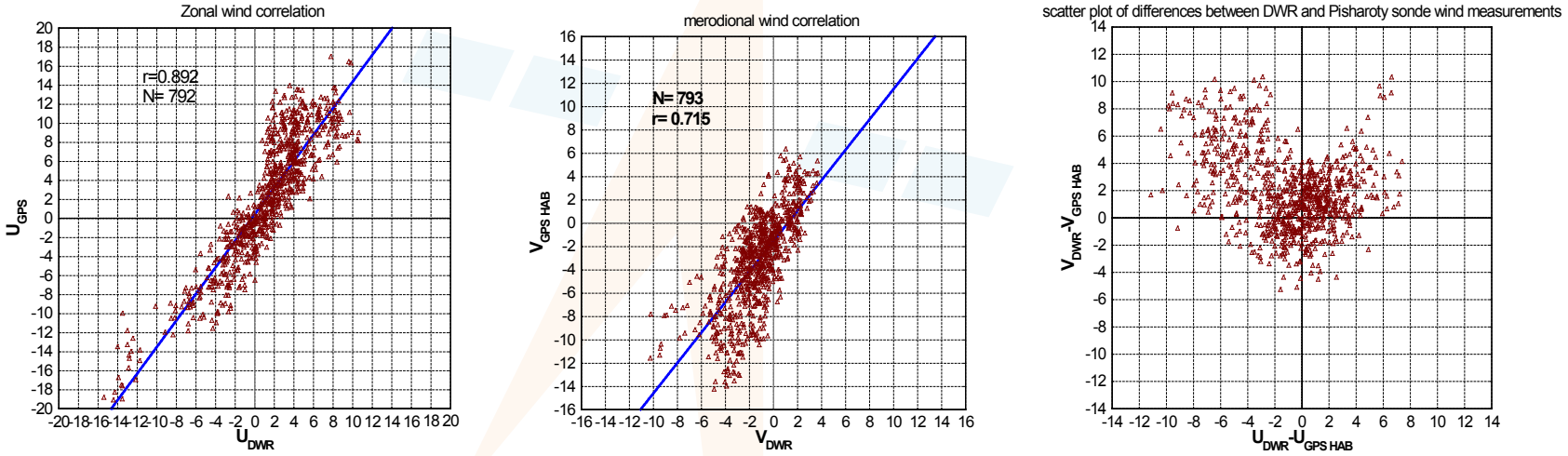


MAX during a quasi-stationary low pressure system and temporal variation of extreme MAXZ value within the regime on Nov 21, 2016.

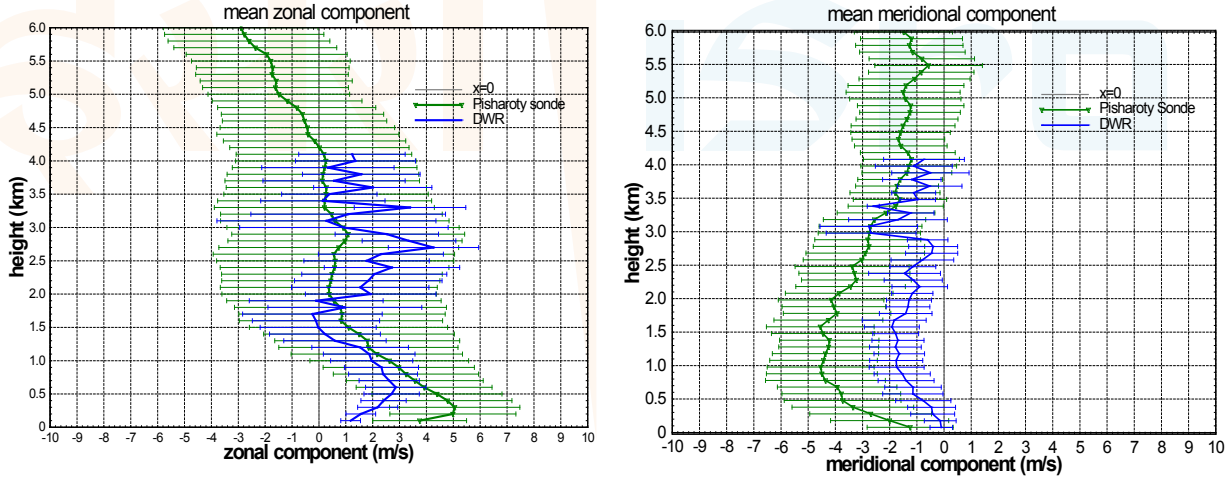
Fig. 2

- **Wind features**

Statistical comparison of horizontal wind components at 1430 hrs IST has been carried out among the DWR and GPS radiosonde-Pisharotysonde High Altitude Balloon observations. Fig.3a provides the scatter diagram for wind component profiles pertaining to various seasons and Fig.3b shows mean wind component comparison for the same data sets.

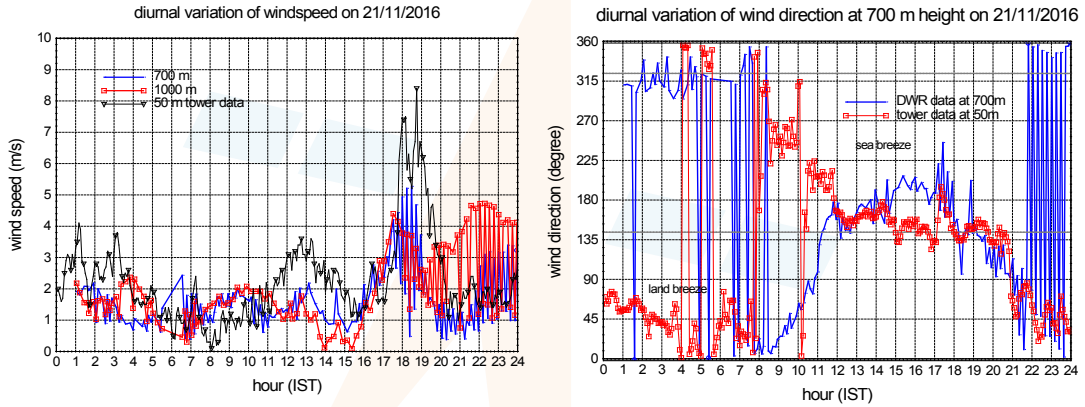


Scatter diagram of wind components at 1430 IST among DWR and GPS-Pisharotysonde HAB profiles pertain to various seasons.
Fig.3a



Comparison of mean wind components at 1430 IST between DWR and GPS-Pisharotysonde.
Fig.3b

Diurnal variation of wind speed and direction obtained from a lower surveillance level of DWR within the Atmospheric Boundary Layer is compared with the surface layer height of 50 m from the micro-meteorological tower has proven the radar capability to capture meso-scale variability in association to sea/ land breeze system (Fig.4).

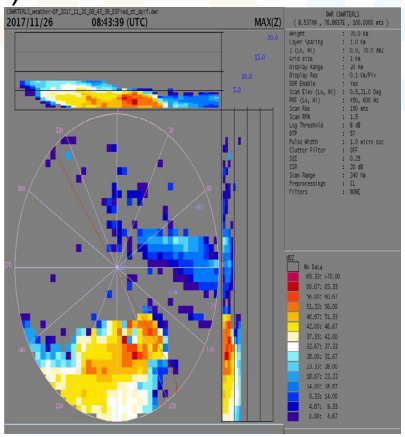


Diurnal variation of wind speed and direction between DWR and tower
Fig.4

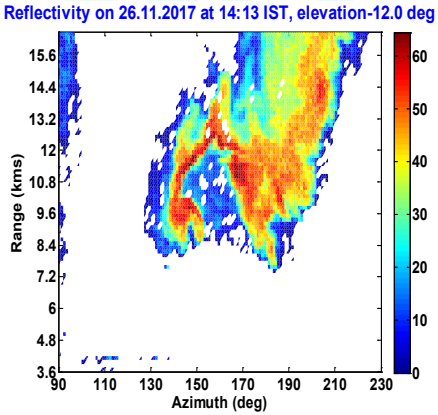
- **Tracing the micro-scale features of a waterspout**

Several investigators have documented waterspout occurrences over the SE Arabian Sea very near to the coast of Thiruvananthapuram, Kerala. The photograph of one such occurrence on Nov 26, 2017 at 1413 IST is shown in Fig.5a and the phenomenon was well within the surveillance zone of the DWR. Fig. 5b presents the reflectivity MAXZ and a prominent funnel dimension of 3.5 km in radius captured from the range-azimuth plot at an elevation of 12 deg (Fig.5c).

Waterspout occurrence
Fig 5a

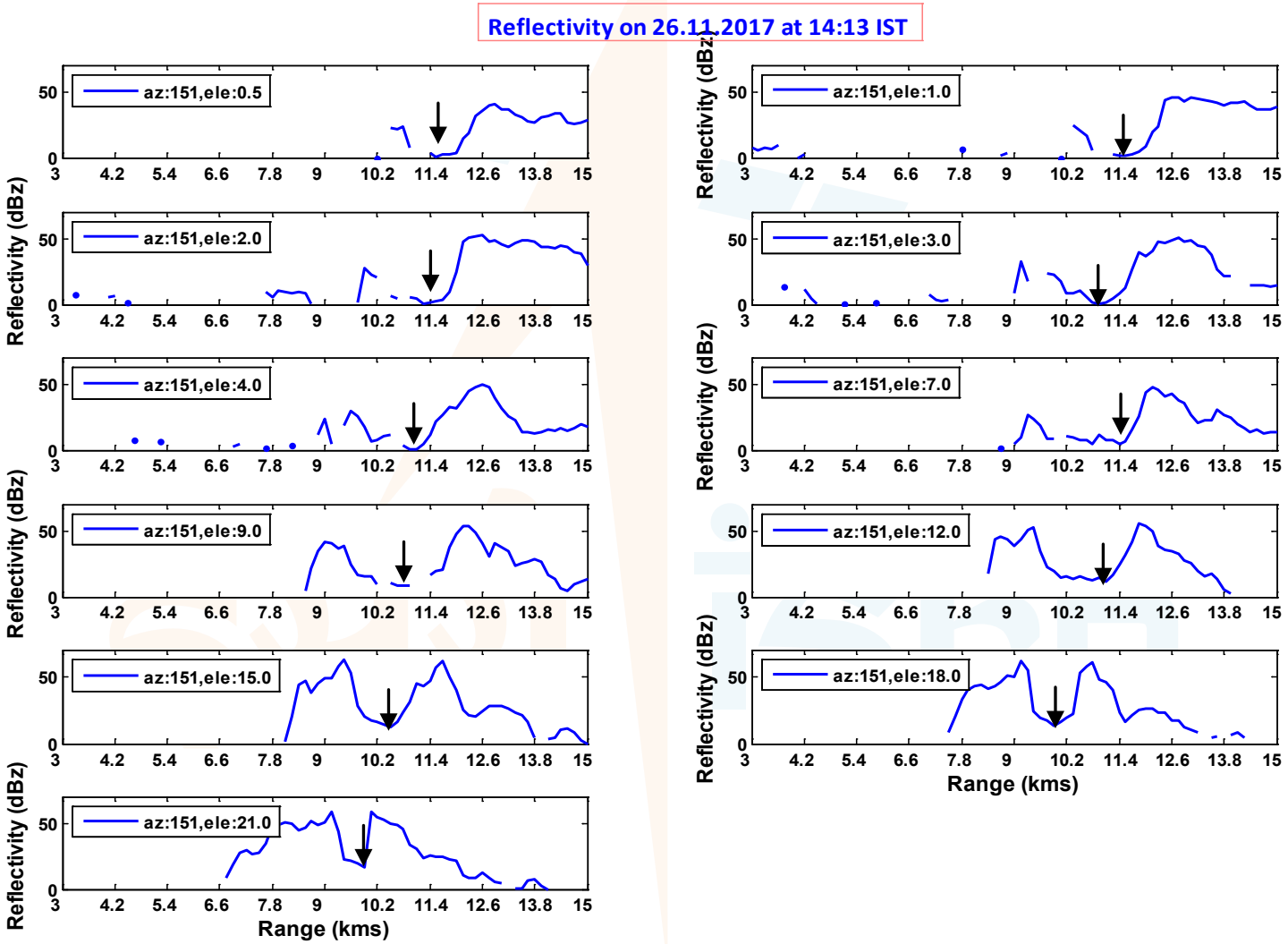


Reflectivity MAXZ
Fig 5b



Range-azimuth plot
Fig 5c

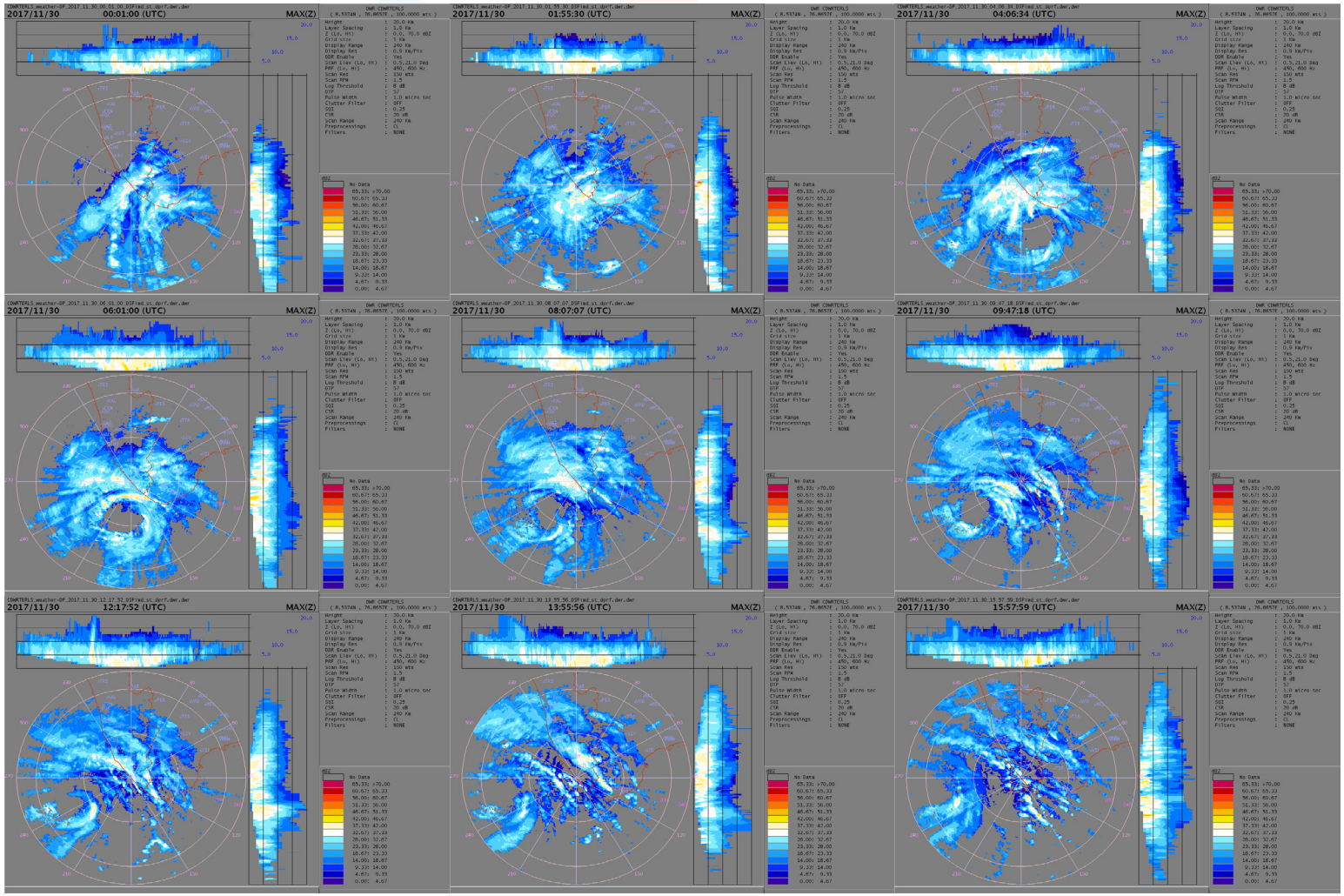
As the waterspout orientation was in the azimuth of 151 deg., range Vs reflectivity for different elevations were critically analysed for different elevations and shown in Fig.6 to study meandering funnel structure in aloft.



Range - reflectivity variation in the azimuth of 151 deg. for different elevations
Fig. 6

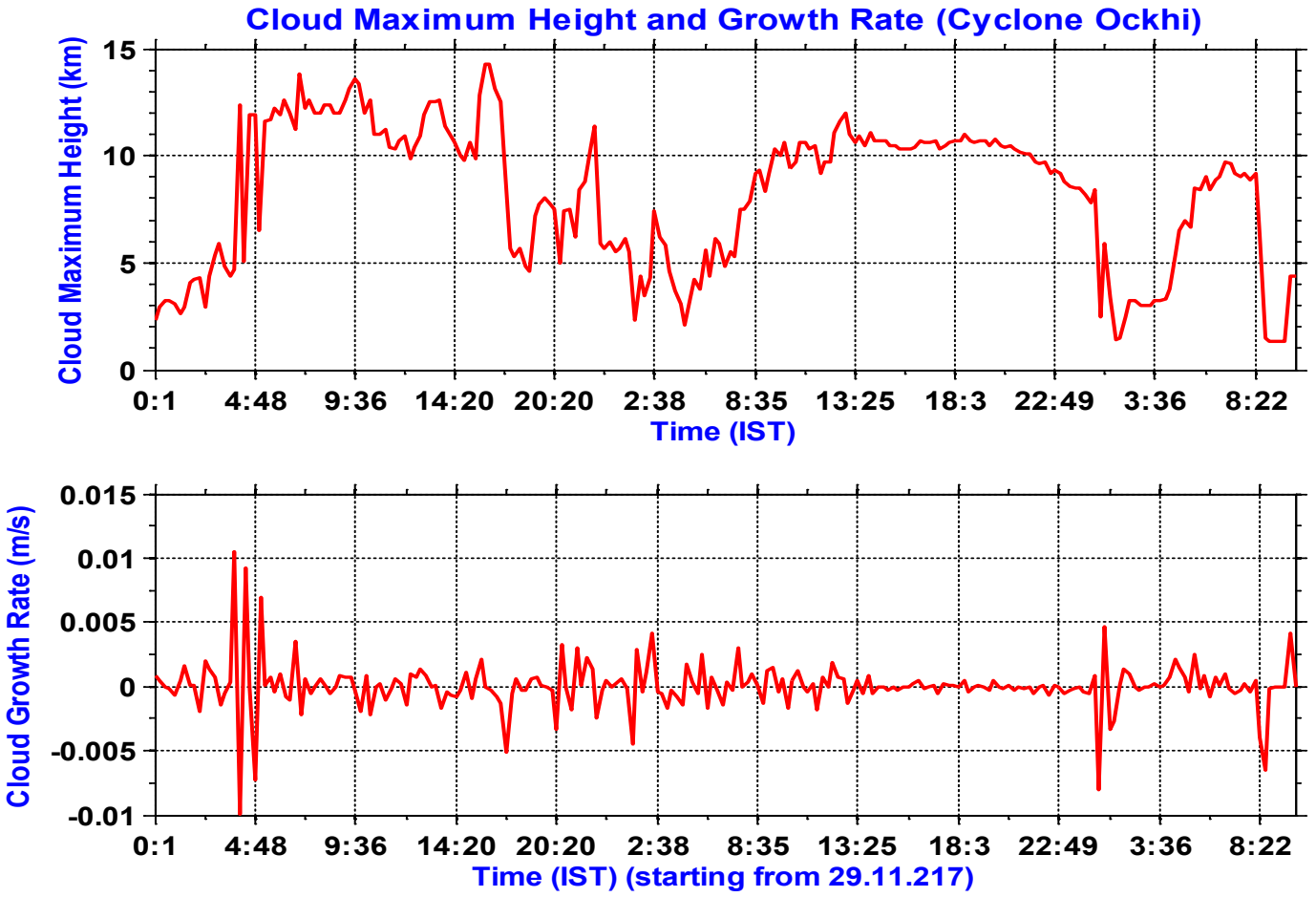
- **Surveillance during OCKHI cyclone**

The weather since Nov 28th to 30th 2017 in association with stages from low pressure to cyclonic stage during which the low pressure system was within the surveillance zone of the radar was tracked. Centrally Dense Overcast region in satellite cloud imageries seen as the cloud free zone in MAX (Z) of the system was visible as the from 0630 IST to 2130 IST on 30th Nov 2017 (Fig. 7). Around 0830 IST the system has intensified to the cyclonic storm “OCKHI” and moved WNW ward with further intensification.



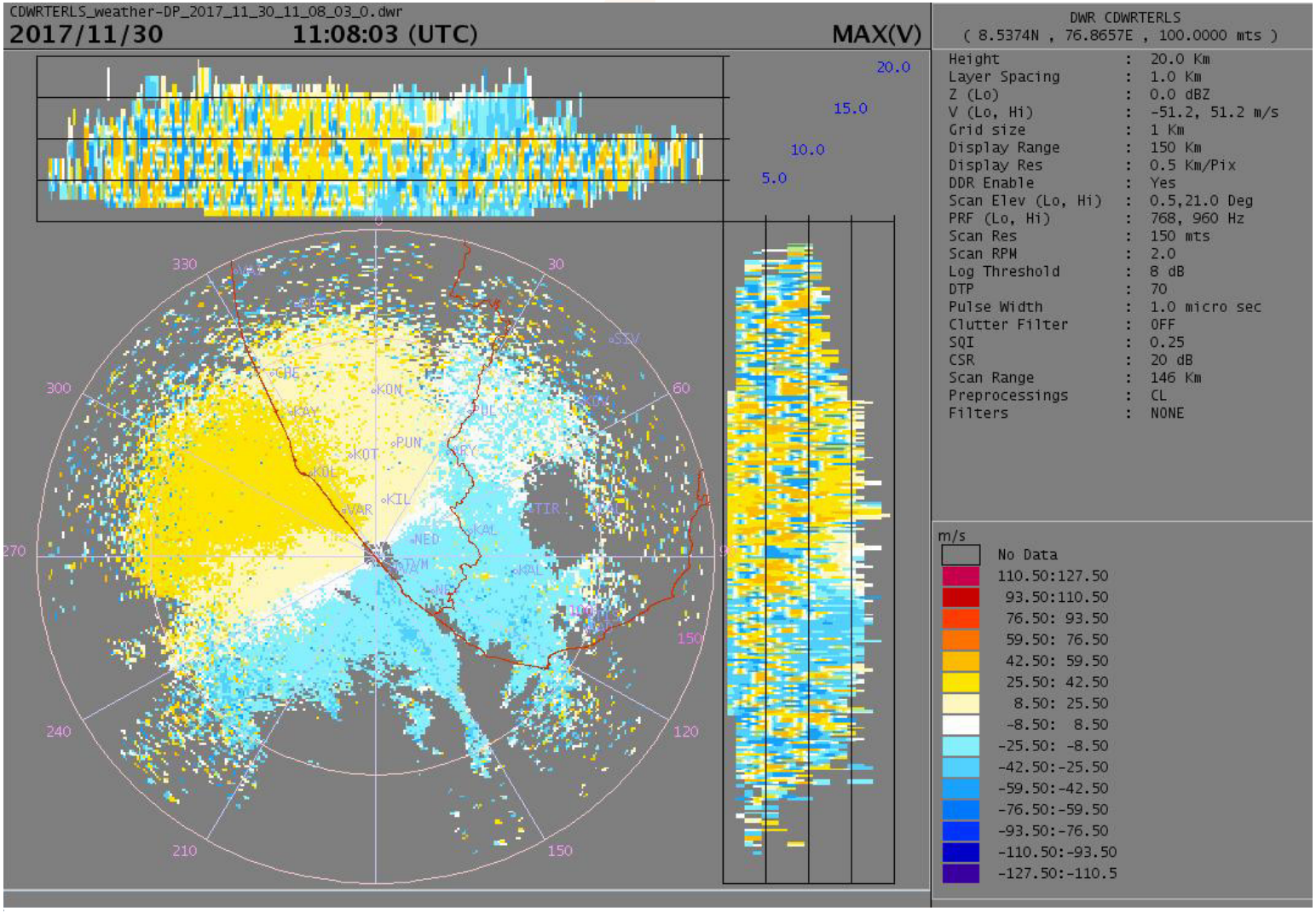
MAX(Z) product during OCKHI formation
Fig. 7

Based on the mathematical formulations of sine curve fitting over a 360 deg. azimuth circle for various ranges pertain to a specific elevation and further linear fitting for wind profile estimation within a representative range of 60 km radius resulted the Volume Velocity Processing (VVP) for wind profile generation. The maximum height at which the wind data is available shall be taken as the topmost height of clouds and from this rate of growth of topmost cloud layer are computed (Fig. 8) during “OCKHI”.

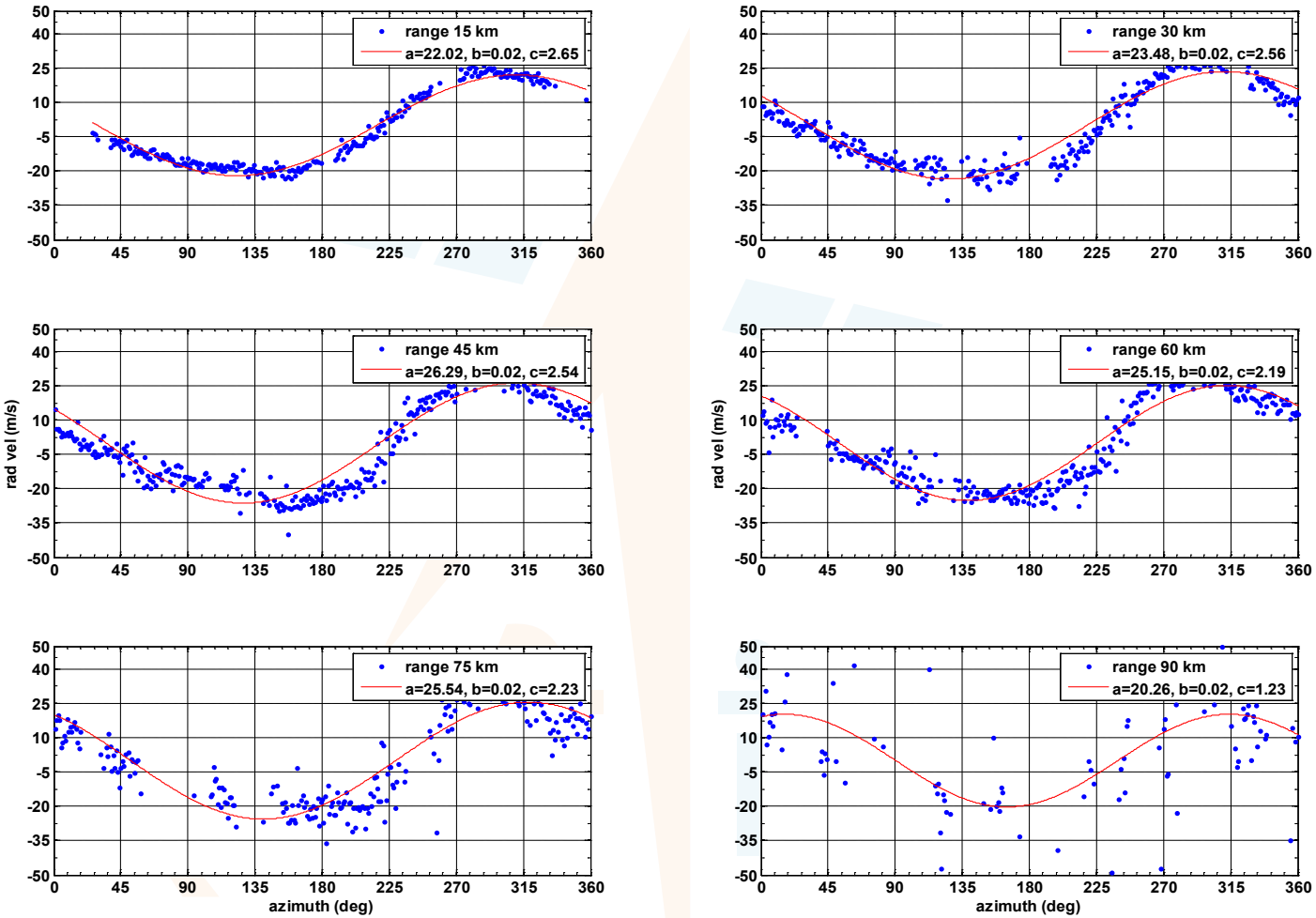


Cloud depth, rate of growth of topmost cloud layer during OCKHI
Fig. 8

Maximum radial velocity surveillance was measured at 16:38:03 IST on Nov 30, 2017 within the surveillance zone of the radar (Fig. 9). A sine curve fitting technology was adopted to check the correctness of the wind data measured and through the obtained beSt fitted sine curve certifies the accuracy of wind data measured (Fig.10).



Maximum radial velocity by DWR during OCKHI
Fig. 9

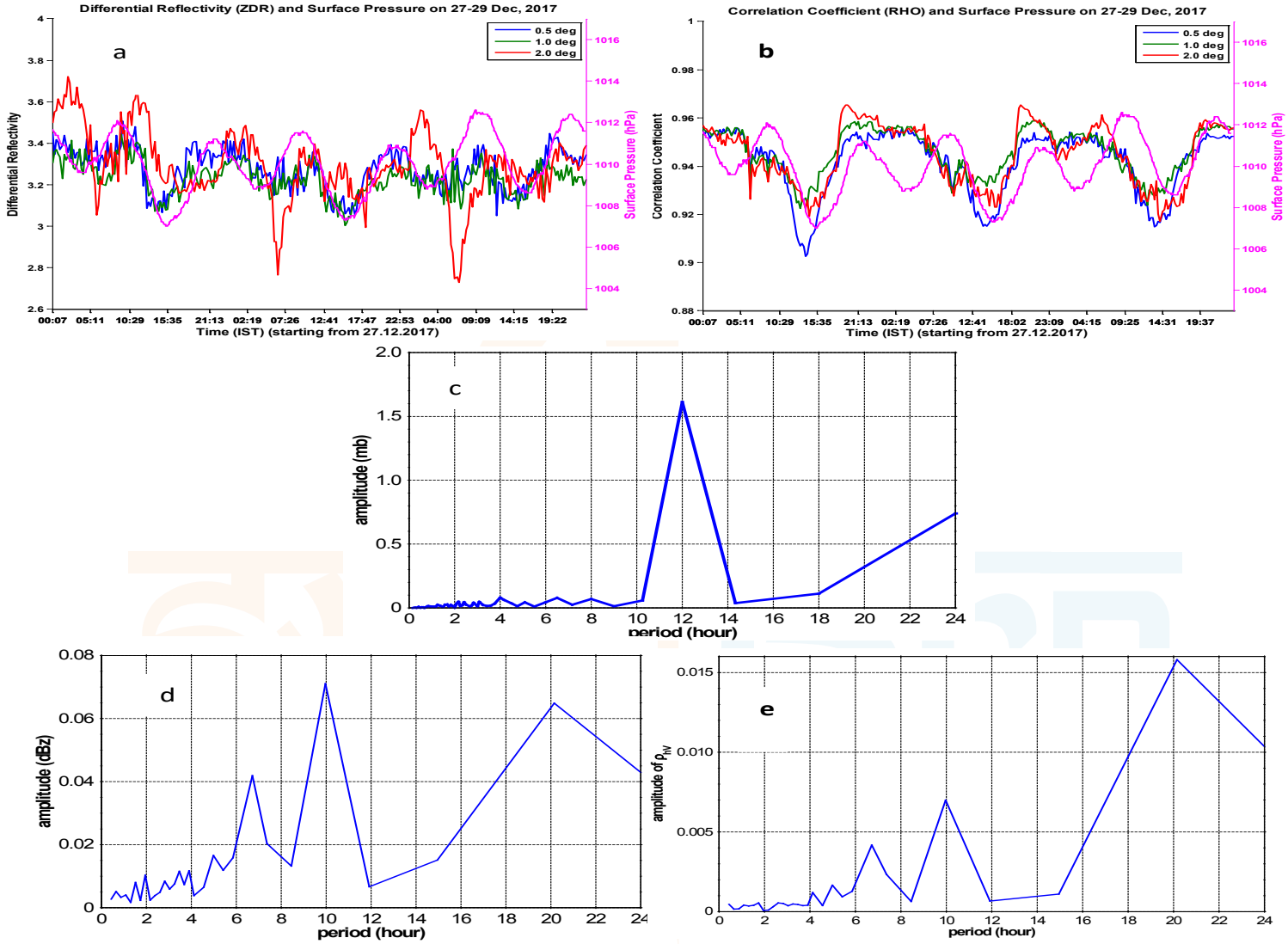


Fitted sine curves for radial velocity measured by DWR during OCKHI at 5 deg. Elevation
Fig. 10

- **Effect of atmospheric tidal oscillations in polarimetric products**

The semidiurnal oscillation and periodicity in surface pressure attributed to tidal effect is known. The polarimetric products- differential reflectivity and correlation coefficient (RHO, ρ_{hv}) averaged for a radius of 60 km for various elevation angle shows mixed-semidiurnal oscillations which indirectly indicates that the individual atmospheric scatterers undergo elongation and compression in its plane of existence due to tidal forcing.

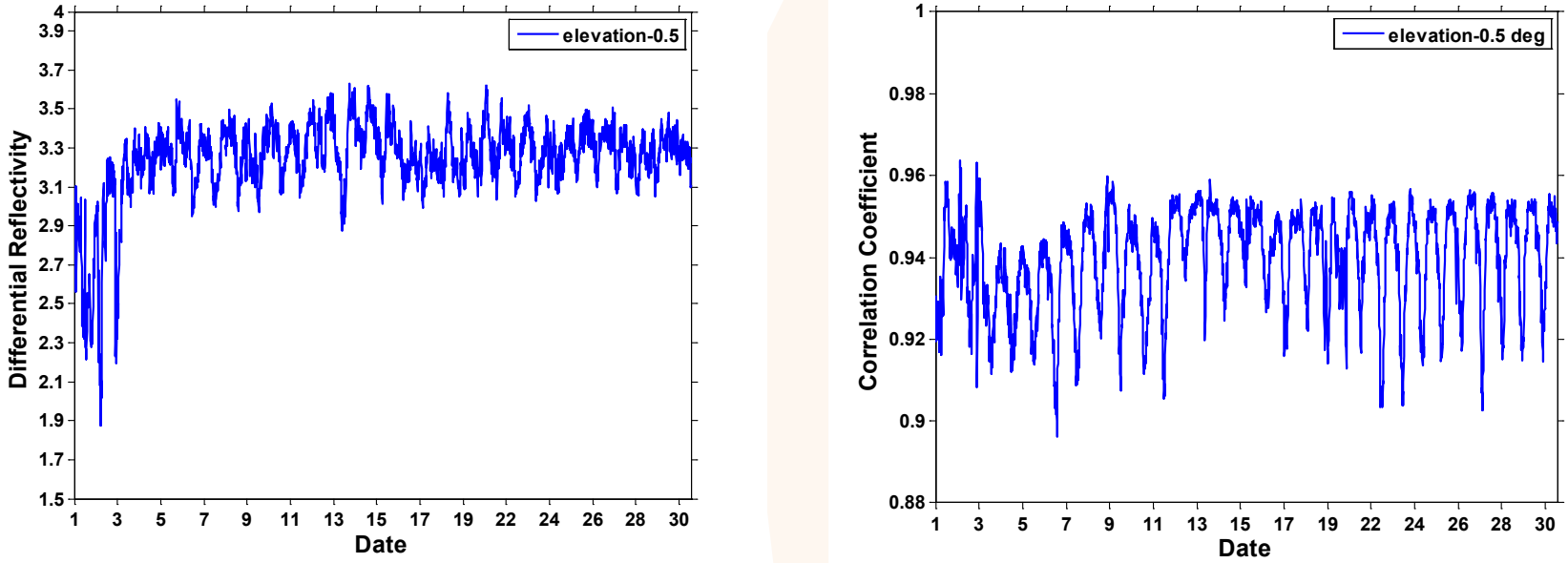
Fig.11 (a,b) show oscillation feature of differential reflectivity and RHO for various elevation angles along with surface pressure. The harmonic analysis results of surface pressure, differential reflectivity and RHO are shown in Fig. 11c, 11d and 11e respectively.



a, b Tidal oscillations in surface pressure, differential reflectivity and RHO for various elevations & Harmonic analysis for (c) surface pressure (d) differential reflectivity and (e) RHO

Fig.11

Daily Statistics of differential reflectivity and RHO for an elevation of 0.5 deg (Fig.12) for Dec 2017 clearly depicts the mixed diurnal-semi diurnal variability within the day-to-day variations.



Daily statistics of differential reflectivity and RHO for an elevation of 0.5 deg. for Dec 2017
Fig. 12

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Email: thomas_varghese@vssc.gov.in

CHAPTER - 12
SEMI-CONDUCTOR LABORATORY
CHANDIGARH

Semiconductor Laboratory (SCL) is engaged in providing end-to-end solutions for Development of Application Specific Integrated Circuits (ASICs), Opto-electronics Devices and Micro Electro Mechanical System (MEMS) Devices encompassing Design, Fabrication, Assembly, Packaging, Testing and Reliability Assurance. SCL has 180nm CMOS Technology on 8" Wafer Fab Line as per international standards and has a 6" Wafer Fab Line with CMOS/MEMS process capability. SCL strives towards creating a strong microelectronics base with activities focused on realization of critical and high reliability device requirements. Enhancements of Baseline 180nm CMOS Process have been undertaken in order to cater to wider spectrum of devices. SCL is also engaged in Fabrication of Hi-Rel Boards for DOS/ISRO Centres & Units, Assembly of Radio Sonde Systems for Atmospheric studies and indigenization of Electronic Sub Systems for other applications.

The major activities carried out by SCL during 2016-2017 are summarized in this chapter.

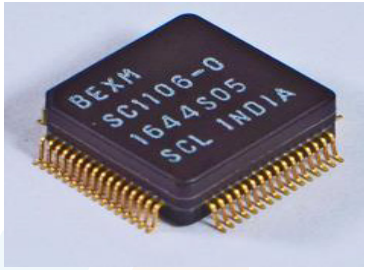
A. MAJOR DEVELOPMENTS / REALIZATION OF DEVICES / PROCESSES

Fabrication of ten Multi Project Wafer (MPW) Lots has been completed after establishment of 180nm CMOS Technology on 8" Wafer Fab with in-house designed ASICs/IPs/Test Chips. SCL has completed Design, Development and Fabrication of over one hundred and fifty devices. Fabrication of eight MPW Lots has been carried-out during 2016 & 2017. SCL has developed technology for Radiation Hardness By Design (RHBD). Devices, in RHBD Technology, have been successfully fabricated & tested for space application.

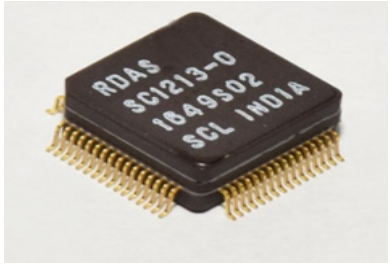
Vikram Processor, one of the key components for Launch Vehicle, has been successfully realised and test flown on PSLV-C36 flight. Also, Bus Extender Module (BEXM), Re-Configurable Data Acquisition System (RDAS) and Vikram Processor with Low Drop-out Regulator (LDO) have also been developed & delivered for Launch Vehicle applications. (Figs 1-4)

Handing-over of Vikram Processor with LDO
Fig.1

Vikram Processor
Fig. 2



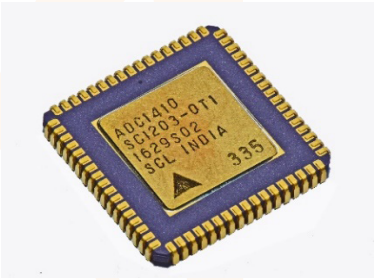
BEXM
Fig. 3



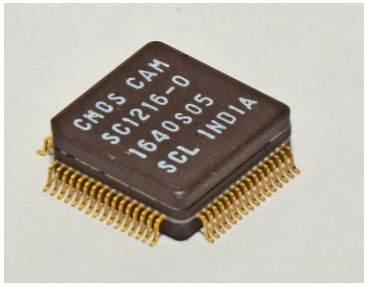
RDAS
Fig. 4

24-bit Sigma Delta Analog-to-Digital Converter (ADC) &14-bit Pipeline ADC for Satellite Payload applications and CMOS Camera Configurator for the Camera of Lander of Chandrayaan-II Mission have been delivered. (Figs 5-7)

Sigma Delta ADC
Fig.5

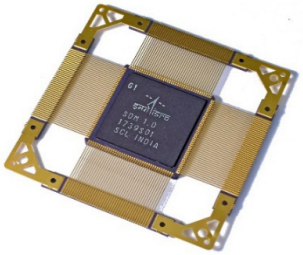


4-bit Pipeline ADC
Fig.6



CMOS Camera Configurator
Fig.7

Digital ASIC for NavIC (Indian Regional Navigation Satellite System – IRNSS) has been realised. On Board Controller 2.2 (Rad Hard) (OBC 2.2 – RH) devices have been delivered for Device Validation Model (DVM) of Radar Imaging Satellite – 1A (RISAT-1A) payload. MODEM In-Door Unit (MIDU) ASIC for Ground based Satcom Terminals has been given for use. (Figs 8-10)

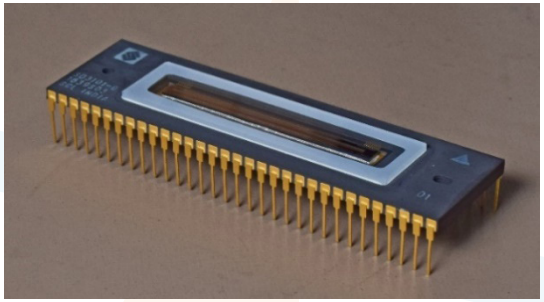


Digital ASIC for NAVIC
Fig.8

OBC 2.2 (RH)
Fig.9

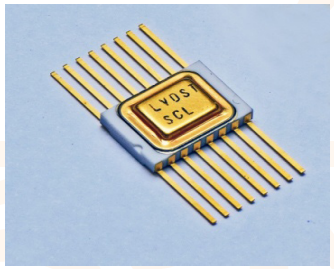
MIDU ASIC
Fig.10

Development of Frame Transfer (FT) CCD Detector Device (Fig 11) for Ocean Colour Monitor – 3 (OCM-3) Satellite Payload and 12K Time Delay Integration (TDI) CCD Device for Remote Sensing Payload is being carried-out.

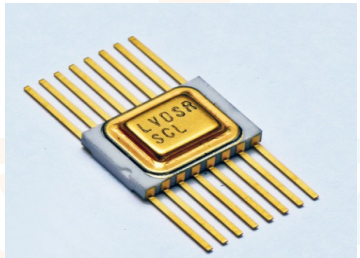


FT CCD for OCM
Fig.11

Low Voltage Differential Signal Transmitter (LVDS – Tx) and LVDS Receiver (Rx),Programmable Bias Generator (PBG),Hex Buffer and 16-bit Buffer have been developed &delivered for use. (Figs 12-16)



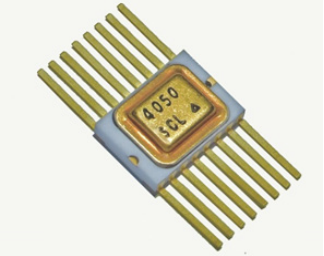
LVDS-Tx
Fig.12



LVDS-Rx
Fig.13

PBG
Fig.14

Hex Buffer
Fig.15



16- bit Buffer
Fig.16

Other major devices developed for space applications are CCD for 3D Imaging, Hyper Spectral Image Sensor (HySIS), Serializer, 8 Channel Mux Demux, Hex Schmitt Trigger Inverter, Quad 2 Input NAND Gate, Octal Buffer (5V tolerant), 16-bit Transceiver (5V tolerant), RS-422 Transceiver, RS-485 Transceiver, Low Voltage Regulator (1.8V, 150 mA), RS Encoder, Low Noise Amplifier (LNA) & Clock Driver.

Development of Silicon Photo Multiplier for Radiation Monitoring Instruments and Large Area Silicon Detector for Instrumentation application is in progress. Development of Photo Diode Detector for X-Ray System is underway. Checksum Generator and Low Drop-out Voltage Regulators for 1.8V/1.6A & 1.2V/1.6A have been realised.

SCL has completed development of Micro Electro Mechanical System (MEMS) based Acoustic Sensor for Launch Vehicle and MEMS Cantilevers for an Explosive Detector. Oil-filled Pressure Sensors (6 to 12 bar)(Fig 17), Pyro-igniter and Micro-valve have been developed for space applications.

6 to 12 bar Pressure Sensor
Fig.17

In order to cater to a wider spectrum of devices required for satellites, launch vehicles and as part of continuous development effort, enhancements of baseline 180 nm CMOS Process have been undertaken. Enhancement of existing technologies in the area of Electro-Optical Devices is focused to scale-up device performance in different wavelength regions.

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CHAPTER - 13
INDIAN INSTITUTE OF REMOTE SENSING
INDIAN SPACE RESEARCH ORGANISATION
DEPT. OF SPACE, GOVT. OF INDIA
DEHRADUN

Indian Institute of Remote Sensing (IIRS) is a premier institute with a primary aim to build capacity in Remote Sensing and Geoinformatics and their applications through education and training programmes at postgraduate level. It is a constituent Unit of Indian Space Research Organisation (ISRO), Department of Space, Govt. of India. Formerly known as Indian Photo-Interpretation Institute (IPI), founded in 1966, the Institute is first of its kind in entire South-East Asia. While nurturing its primary endeavour to build capacity among the user community by training mid-career professionals since its founding in 1966, the Institute has enhanced its capability and evolved many training and education programmes that are tuned to meet the requirements of various stake-holders, ranging from fresh graduates to policy makers including academia, industry and NGOs.

A. MAJOR FACILITIES / INSTRUMENTATION DEVELOPED

INFRASTRUCTURE UPGRADATION: New facilities made operational and capacity augmentations at IIRS during this period includes State-of-the-art EDUSAT Studio, Access Control and Video Surveillance System, High-performance Computing facility, Extension of Library Building, Central Computing Facility, Golden Jubilee Hostel, Face-lifting of Main Building.

TRAINING & EDUCATION AND OUTREACH PROGRAMMES

The Institute has trained 11,118 professionals (till January, 2018), including 1151 professionals from abroad representing 95 countries mainly from the Asia, Africa and South America. A total of 190 students in M.Sc. and 293 students in M.Tech. courses have graduated since 2002. Special tailor-made/on-demand courses are conducted at the request of the User Departments, both national and international.

In addition to aforesaid activities, IIRS also supports activities of UN-CSSTEAP which has conducted 55 PG Courses (22 in RS&GIS, 11 in SATCOM, 10 in each SATMET and SAS and 02 in GNSS). CSSTEAP has conducted 52 short courses and workshops in past 22 years. These programmes have benefited 1958 participants (PG-917 and short courses-1002) from 35 countries of Asia-Pacific region and 30 participants from 18 countries outside Asia Pacific region.Till date, 143 PG students (69 in RS&GIS; 37 in SATCOM; 18 in SATMET and 19 in SAS) from 16 different countries have been awarded M.Tech. degree. Three courses are presently ongoing, namely RS&GIS, SATCOM and GNSS.

In addition to regular training and education programmes, the Institute also conducts 'Distance Learning Programme' since 2007 which is unique in the country, complementing the education programmes of the Indian Universities. 731 institutions/ organisations in the country are currently networked with IIRS/ISRO through outreach programme and 62,143 students and professionals have been benefited so far since 2007. Under e-learning programme of IIRS outreach activity, there are currently 4187 learners wherein 943 have registered for certificates and 77 certificates are issued so far.

B. SCIENCE RESEARCH AND APPLICATIONS

1. REMOTE SENSING OF EARTH'S RESOURCES AND ENVIRONMENT

1.1 Monitoring & Assessment of Ecosystem Processes in NWH

For sustainable environmental development, making disaster resilient society and improved livelihood in North Western Himalayan (NWH) region, an interdisciplinary research project on *"Monitoring & Assessment of Ecosystem Process in NWH"* is being carried out. Project sub-themes are as follows: a) Geodynamics and Seismicity Investigation, b) Vulnerability assessment of Forest Ecosystems due to Climate change, c) Sustainable Mountain Agriculture (two sub-themes), d) Water Resources status and Availability, e) Modeling Temporal & Spatial Growth of Cities & Towns in NWH, and Rainfall Retrieval Using MW RS Data & study of Extreme Rainfall Events.

- **Geodynamics and Seismicity Investigation**: Based on CORS/IGS station data (four) and first set of campaign observations, three important findings have been obtained: Precise rate of movement of Indian plate vis-à-vis other surrounding plates; crustal shortening rate of Himalayan region and activity around Himalayan Frontal Thrust/Main Himalayan Thrust. Additionally, TEC data from other IGS/CORS analysed for several global earthquakes. Global Ionospheric Map/Model (GIM) data analysed for both point observation and spatial modelling with respect to several global earthquakes. Real time TEC data analysis revealed very good correlation between anomalies and seismic events.
- **Vulnerability assessment of Forest Ecosystems due to Climate change**: Under Impact of Global Change on Species Composition, decadal LULC (1:250k) from 1975 – 2015, change map and bioclimatic & environmental data prepared (present & IPCCARS Scenarios).
- **Climate change impacts on productivity of food and plantation crops**: Analyzed spatially climate change impact on productivity of maize, rice, and wheat crops in climate change scenarios in Doon Valley. Crop model simulation (CERES-wheat/CERES-Maize) on grid basis over HP for period of 2001-2025.
- **Assessing Soil Erosion and Nutrient Loss and its impact on Soil Quality and Crop Productivity**: Established surface runoff and sediment loss measurement sites at Chamba (Uttarakhand) and Hamirpur (Himachal Pradesh) to characterize surface runoff, sediment and nutrient loss at watershed scale. Climate change impact on soil erosion and soil quality (soil carbon sequestration) for Chamba watershed (Uttarakhand) analyzed.

- **Water resources status and availability:** Energy balance hydrological model was setup and run for entire NWH from 2014-2016 and estimated water balance including snow melt, SWE and snow depth at 5km grid scale during year 2016-17 and 2017-18. Installed 5 automatic weather stations(AWS), 2 digital water level recorder(DWLR) during 2016-17 at various sites in NWH and 11 are being installed in 2017-18 time frame, relapsed faulty data logger at Kothi snow scale and AT-RH sensor at Kothi, Manali during April 2017.
- **Modelling Temporal & Spatial Growth of Cities & Towns in NWH:** Spatio-temporal study of urban centre distribution, urban population at inter and intra state level for Uttarakhand and Himachal Pradesh and analysed growth dynamics of five (05) class-I cities in NWH using a inductive pattern based approach.
- **Rainfall Retrieval Using MW RS Data & Study of Extreme Rainfall Events:** Rainfall pattern using high resolution satellite based rainfall data set (TRMM 2B31 from 1998 -2013) and preparation of rainfall map for the monsoon season (5 km resolution) completed. Comprehensive assessment of TRMM 3B42 rainfall data set (1998-22013) over the NWH and its validation using categorical statistics with IMD data sets has been completed.
- **Snow cover products:** 8-day snow cover products from MODIS, and 15-daily snow cover fraction product from AWiFS were used to generate long-term SCA maps (2000–2017) for entire NWH region. Further, long term variability of 8-daily SCA and its current status analysed. The SCA mapped has been validated using AWiFS derived SCA. The analysis of current status (2016–17) of SCA has indicated the maximum extent of snow cover in NWH region in last 17 years. In 2nd week of February 2017, around 67% of NWH region was snow covered. The comparison of SCA during the 1st week of March and April in 2016–17 against 2015–16 indicates 7.3% and 6.5% increased SCA in current year. The difference in SCA during 1st week of March 2017 and 1st week of April 2017 was observed to be 14%, which indicates that the 14% SCA has contributed to snow melt during this period. The change in snow water equivalent retrieved using SCATSAT-1 data also validates this change in snow volume.

1.2 Remote sensing related activities

- Delineation and measurement of groundwater induced land subsidence by multi-frequency DInSAR completed including the groundwater level depletion scenario. Predictive modelling of groundwater induced land subsidence also completed.
- Development of spectral library and reflectance spectroscopy for mineral exploration in parts of mineral rich belt of Rajasthan and Odisha was conducted. Joint field investigation was carried out in Mundiyawas-Khera and Umra, Rajasthan along with GSI team leading to confirmation of indicator minerals for base mineralization. The Umra areas processing highlighted new areas for the mineralization and later verified in the field.
- Retrieval of biophysical parameters of paddy and wheat crops using RISAT-1 hybrid polarimetric SAR data completed including the crop discrimination using RISAT-1 SAR data.

- Developed a framework for automatic extraction of water at variable scales, testing of inter transferability of rule set between different sensor types (spectral and spatial resolution, temporal data) and results validated.
- Medium resolution TIR data processing for Land Surface Temperature (LST) retrieval has been carried out and attempts have been made for developing a statistics-based coal fire detection algorithm.
- Hydrological model setup and simulations are completed for Beas Basin upto Thalot using Variable Infiltration Capacity(VIC), Soil and Water Assesment (SWAT) and Snowmelt Runoff Model (SRM) models in 2016-17.Ensemble of CMIP5 climate models (5 models, 4 RCP scenarios) from CORDEX site being used to create met forcing for hydro models.
- Simulations carried out in WRF with No Urban Physics option and with urban physics options. Two urban physics options Single layer urban climate mapping (SLUCM) and building effect parameterization (BEP) were evaluated in three different seasons. It was found that Urban Heat Island could be identified in WRF simulations with Urban Physics options which was not visible in simulations with no urban physics options.
- Processed frames acquired at same altitude separately, photogrammetric processing for relative DEM and ortho-mosaic generation. Generated outputs weregiven to NIOT for validation.
- UAV aided remotely sensed data was collected in Koti area (Dehradun) and digitally processed for DEM generation with flying height: 515m, resolution: 8.9 cm, and vertical accuracy: 26 cm.
- Space-borne GRACE gravity observation and ground-based groundwater level fluctuation highlighted groundwater depletion hotspots in NW India. Satellite (Radarsat-2 and ALOS Palsar) DInSAR based spatial land subsidence areas were identified in Delhi, Chandigarh, Hissar and Mehsana with 2-5 cm/year (approx.). Ground-based DGPS observations and subsurface instrumentation (piezometer and extensor-meter) data confirms satellite derived land subsidence value.

2. Other Major In-House R&Ds

- **Lunar data analysis:** A case study over Lunar South Pole - Minimum & maximum offset between LLRI & LOLA elevation (m) over flat, moderately varying and around crater are (1.25, 132.98), (0.68, 621.59), (5.21, 724.45). Minimum & maximum offset of LLRI derived and LOLA derived terrain slope (degree) difference at crater floor, along crater wall, along crater rim are (0.08, 7.06), (0.18, 10.49), (0.17, 14.29).
- **Studies on Uttarakhand Forest Fire (April 2016):** The Uttarakhand State witnessed episodic fire incidents during last two weeks of April 2016. MODIS Terra Land surface reflectance (MOD09A1), MODIS Terra Land surface Temperature (MOD11A2) and ASTER DEM were used to map burnt areas and also to develop fire danger model. Three parameters Modified Normalized Difference Fire Index (MNDFI), Perpendicular Moisture Index (PMI) and potential surface temperature were computed from above satellite products. It was observed that the glaciers near to AWS stations are unaffected in terms of rise in temperature due to forest fire in Uttarakhand. The GFS 6 hourly forecasted wind speed and wind vectors were analyzed and wind direction wss observed as South-West which supports the logic behind the non-affecting of glaciers.

- **Study of Antarctic ice sheet/sea Ice features, glacier landforms and glacier velocity using satellite data**: Present study focuses on surrounding areas of Schirmacher Oasis, Princess Astrid Coast located in Droning Maud Land (DML) of East Antarctica. Land cover classification for part of DML and sea ice classification for part of Lazarev Sea near India bay was done using medium to high resolution optical and microwave satellite images. Various classes such as Blue ice areas (BIA), snow on BIAs, wind-blown snow, moraines, exposed hills, melt water ponds, etc. were mapped. Various ice sheet/sea ice features such as crevasses, Nunatak, Sastrugi, fast ice, floes, ice bergs etc. were also identified, mapped and monitored using these data from 2015-2017. The ice stream velocity was estimated in the range of 5 to 60 m/year and its validation was done by combined team of IIRS and GSI during 36th Indian Scientific expedition to Antarctica (ISEA)-36 summer expedition at Maitri and area south of Maitri, with highest velocity for Somovken ice stream.

Publications: 100 peer reviewed publications in 2016-17.

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CHAPTER - 14
TATA INSTITUTE OF FUNDAMENTAL RESEARCH

1. DEPARTMENT OF ASTRONOMY & ASTROPHYSICS TIFR, MUMBAI

The Department of Astronomy and Astrophysics of TIFR located in Mumbai, carries out cutting edge research in theoretical and observational astrophysics. Their research programs covers - formation, physics and evolution of a vast range of astronomical objects with equal emphasis on the building of astronomy instruments, performing observations and formulation of theoretical and computational models to explain the outcome of the observations. The highlights of the institutional activities of TIFR during 2016, 2017 are covered in this chapter.

A. MAJOR FACILITIES / INSTRUMENTATION DEVELOPED

Large Area Xray Proportional Counter(LAXPC) Payload Operation Centre (POC)

- The LAXPC payload, designed and developed at TIFR is fully operational onboard AstroSat satellite since 19thOctober 2015. The average data generated from its observations of celestial sources is of the order of ~3GB per day and additional ~800MB per day is generated for its performance monitoring and health parameters. The data is made available by ISSDC at ISRO, after each pass (once every 98 minutes) of satellite over Bengaluru and the same is to be processed by the Payload Operations Centre (POC) at TIFR with pipeline processing software tools and provide quality report as well as generate official data products that are uploaded back to ISSDC for end users.

  Design, procurement and commissioning of a powerful LAXPC POC system that meets all the requirements as, 1) To have sufficient bandwidth in data handling so as to analyse and store the data throughput volumes of upto ~4GB per day. 2) Very high reliability and adequate redundancy so as to have zero downtime of system. 3) High security for data protection. 4) To have fully compatible operating system capable of executing official data processing tools for end users. The whole system is designed to operate in normal lab environment with very high performance and reliability (Always available with 0% downtime) built in while providing high data processing capacity with minimal footprint in terms of volume, power consumption and heat generation by the system using Dual Intel Xeon processors housed in 1U rack mounted servers with dual redundant power supply. The system achieves required redundancy by having independent systems interconnected with high bandwidth networking. Each system has hardware redundancy at core level for its processors, memories, multiple storage devices configured in RAID 10 array and power supply to avoid single point failure. All the mission critical software and data are stored in two independent stand alone network attached units, each with its own hardware redundancy against single point failure and mirroring the data to assure zero downtime while providing 16TB of storage. .

- There has been lot of activities for LAXPC data analysis software development and validation. There are two software packages to analyse LAXPC data: “LaxpcSoft” which is developed at TIFR/IUCAA and LAXPClevel2 Data Pipeline which is another package to analyse LAXPC data. The “LAXPClevel2DataPipeline” is developed and validated at RRI, Bangalore, with support from SAC, Ahmedabad. Both these packages are made public and available at LAXPC website at TIFR (http://web.tifr.res.in/~astrosat_laxpc/software.html) and is updated as and when improved version or a new version of detector response is available. We have tested the LaxpcSoft extensively and has been used in recent LAXPC science publications.
- A workshop was also organised on LAXPC data analysis during January 18-21, 2017 at TIFR, Mumbai for LAXPC data analysis. About 70 participants from over 35 Institutions/Universities across India and abroad participated in this workshop.

B. SCIENCE RESULTS

1. ASTRONOMY AND ASTROPHYSICS

- **AstroSat: Indian Multi-wavelength Astronomy Mission**

AstroSat has onboard the following three main astronomy payloads for simultaneous multi-band observations:Three units of Large Area X-ray Proportional Counters (LAXPC) covering medium energy X-rays from 3 to 80 keV, a Soft X-ray Telescope (SXT) with conical foil mirrors and X-ray CCD detector, covering the energy range 0.3-8 keV,and a Cadmium-Zinc-Telluride coded-mask imager (CZTI), covering hard X-rays from 10 to 150 keV.

During 2016-2017, AstroSat has been made open for observations for astronomers across India and some portion of time reserved for international astronomers. All the three LAXPC detectors have been performing well in orbit and providing high quality data. About 400 observations of different astronomical sources in the sky were performed during 16-17. Also, routinely blank sky at different positions is being observed to study LAXPC background and the SAA model.

Since the first light, the SXT has been pointed at several different types of sources (stars, supernova remnants and quasars). It has been shown that the SXT is the most sensitive X-ray instrument on board AstroSat and would be able to detect sources as weak as 10 micro-Crab in an observation lasting a day. It is also the instrument with the highest energy resolution in X-rays.

From the first day of operation itself, hard X-ray image of the Crab Nebula was obtained with CZTI. The timing analysis of the Crab Pulsar demonstrated the very high timing accuracy (about a micro-s) of the instrument. Several gamma-ray bursts were detected by CZTI (several of them off-axis) and the utility of CZTI to localize and measure the spectra of off-axis GRBs was demonstrated. The CZTI of the AstroSat

satellite was made operational immediately after the launch of AstroSat and it is working quite well with an observing efficiency of about 55%. The observed background count rate was much higher than anticipated, resulting in large data volume. The expected background rate is about 100 counts per second per quadrant, however, the observed counts exceeded it by a factor of 10 - 20. This was understood to be due to multiple events recorded during Cosmic Ray interaction. A software patch to suppress such unwanted events was written, tested on ground model of the instrument, and uploaded successfully into the flight instrument.

The collimators and support structures of CZTI instrument are, by design, transparent above 100 keV and hence CZTI acts as an all sky monitor for gamma-ray bursts (GRB). GRB Coordination Network (GCN) circulars are regularly sent alerting the GRB community about the detection of GRBs by CZTI. Recently, CZTI is also providing sensitive upper limits for electromagnetic signals from Gravitational Wave (GW) events.

The polarisation capability of CZTI was demonstrated by regularly observing the Crab Nebula. Very significant hard X-ray polarisation has been measured for several GRBs.

- **AstroSat/LAXPC reveals the high energy variability of GRS 1915+105 in the chi class:**

The first quick look analysis of data from nine AstroSat's LAXPC observations of GRS 1915+105 was presented during March 2016 when the source had the characteristics of being in Radio-quiet chi class It was found that a simple empirical model of a disk blackbody emission, with Comptonization and a broad Gaussian Iron line can fit the time averaged 3--80 keV spectrum with a systematic uncertainty of 1.5% and a background flux uncertainty of 4%. A simple dead time-corrected Poisson noise level spectrum matches well with the observed high frequency power spectra till 50 kHz and as expected the data show no significant high frequency (> 20 Hz) features. Energy dependent power spectra reveal a strong low frequency (2 - 8 Hz) Quasi-periodic oscillation (LFQPO) and its harmonic along with broad band noise. The QPO frequency changes rapidly with flux (nearly 4 Hz in ~ 5 hours). With increasing QPO frequency, an excess noise component appears significantly in the high energy regime (8 keV). At the QPO frequencies, the time-lag as a function of energy has a non-monotonic behaviour such that the lags decrease with energy till about 15-20 keV and then increase for higher energies. These results benchmark the performance of LAXPC at high energies and confirms that its data can be used for more sophisticated analysis such as flux or frequency-resolved spectro-timing studies.

- **AstroSat LAXPC observation of Cygnus X-1 in the hard State**

The first analysis of data from AstroSat/LAXPC observations of Cygnus X-1 was reported in January 2016. LAXPC spectra reveals that the source was in the canonical hard state, represented by a prominent thermal Comptonization component having a photon index of ~ 1.8 and high temperature kT_{-e}> 60 keV along with a weak reflection and possible disk emission. The power spectrum can be characterized by two broad Lorentzian functions centered at ~ 0.4 and ~ 3 Hz. The r.m.s of the low frequency component decreases from 15 at around 4 keV to 10 at around 50 keV, while that of the high frequency one varies less rapidly from 13.5 to 11.5 in the same energy range.

The time lag between the hard (20--40 keV) and soft (5--10 keV) bands varies in a step-like manner being nearly constant at ~ 50 milli-seconds from 0.3 to 0.9 Hz, decreasing to about 8 milli-seconds for 2 - 5 Hz and finally dropping to about 2 milli-seconds for higher frequencies. The time lags increase with energy for both the low and high frequency components. The event mode LAXPC data allows for flux resolved spectral analysis on a time-scale of 1 second, which clearly shows that the photon index increased from ~ 1.72 to ~1.80 as the flux increased by nearly a factor of two. These results have been discussed in the framework of the fluctuation propagation model.

- **Spectral, timing, and polarisation property of GRB 151006A**

CZTI on its very first day of operation detected a long duration gamma-ray burst (GRB) namely GRB 151006A. Using the off-axis imaging and spectral response of the instrument, it was demonstrated that CZT Imager can localise this GRB correct to about a few degrees and it can provide, in conjunction with the Swift satellite, spectral parameters similar to that obtained from the wide band Fermi satellite.

CZTI will be most useful for the short hard GRBs by providing localisation for those detected by Fermi and spectral information for those detected only by Swift. CZTI is able to identify Compton scattered events thereby providing polarisation information for bright GRBs.

GRB 151006A, in spite of being relatively faint, shows hints of a polarisation signal at 100 - 300 keV region. CZTI should provide significant time resolved polarisation measurements for GRBs that have fluence 3 times higher than that of GRB~151006A. The number of such bright GRBs detectable by CZTI is 5 - 6 per year.

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2 TIFR BALLOON FACILITY

TIFR Balloon Facility is a facility of the Tata Institute of Fundamental Research located at Hyderabad, India for research in scientific high altitude ballooning. TIFR-BF designs, develops, fabricates and launches polyethylene balloons for high altitude studies. The facility has an in-house balloon production facility as well as ground facilities for balloon launching and recovery operations, a control room for handling the data (telemetry) and command (tele-command) operations using S-band Telemetry, and balloon tracking capabilities. Large volume balloons with heavy payloads for astronomy experiments and atmospheric science experiments up to an altitude of 43 kms have been developed and launched from this facility. The TIFR-BF also provides polyethylene balloons to other users purely for scientific and research purposes.

The major highlights of the institutional activities of the Balloon Fcaility of TIFR during 2016-17 are:

A. MAJOR FACILITIES / INSTRUMENTATION DEVELOPED

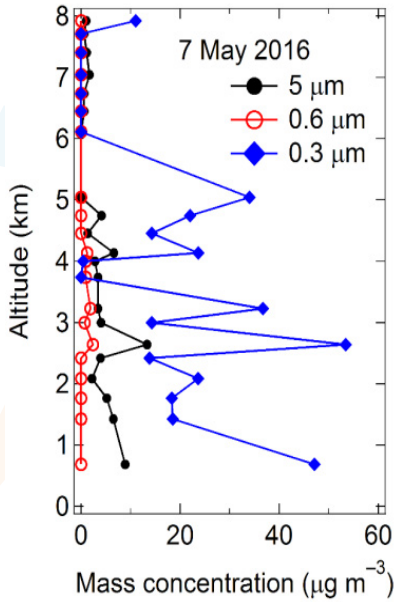
- Upgraded the mother board of existing modular integrated command and timer to achieve complete command monitoring and timer operation using single controller and modified to add two additional experimenter cards to handle additional 12 commands of 10 sec and 12 latch commands.
- To reduce size, weight and power requirements of all digital on-board electronic circuits an FPGA based Telecommand encoder / decoder has been designed and successfully implemented in a single Spartan 6 chip. Coding was done using VHDL (VHSIC hardware description language) and a Graphical User Interface (GUI) was developed to send balloon control commands from a laptop.
- New Data command board was developed to meet additional command requirement of an experimenter using small balloon flights where compact and light weight Telecommand system is desired and the new data command board will be useful for switching high current loads.
- New high bit rare telemetry encoder was developed with a 500 kpbs telemetry encoder using 8051 architecture microcontroller to handle high speed data sampling and flexibility in data sampling priorities.
- New GPS based altitude encoder was developed to interface with ATC-Transponder. This can be used with current Mode A, C and also with Mode-S transponder with ADS-B and provided with interlocks to avoid erroneous altitude data.
- Development of new high strength load tapes for design and fabrication of heavier payload capable zero pressure plastic balloons.
- Development of small plastic balloons with a spherical and oblate spheroid shapes for conducting lab tests (zero gravity and moon gravity) of satellite payloads at ISAC-ISRO.
- Design and development of sounding balloons fabricated using 5.0 microns thin antrix film for reaching 44 km altitude with GPS-radiosondes from SDSC-SHAR.

B. SCIENCE RESULTS

1. ATMOSPHERE AND CLIMATE:

- Data monitoring from various ground based instruments for atmospheric science study of several projects namely ISRO-GBP, ARFI-SPL-VSSC, ATCTM-PRL and CRABEX-SPL-VSSC have been done. The data monitored from various instruments for aerosols, trace gases and ionospheric measurements are shared between TIFR Balloon Facility and the collaborating institutes for scientific investigations.
- Balloon-borne measurement of size segregated mass concentration of aerosol: Size-segregated vertical profiles of aerosols are very critical for impact assessment of aerosols, particularly when different aerosol types co-exist in the vertical column. This will also help assessing

the size-segregated deposition and life time of aerosols. For this purpose, 6 stages (0.15–5μm) of Quartz Crystal Micro-balance (QCM) was developed and tested in balloon-borne platform during spring 2016. A raw profile of the size-segregated (0.3, 0.6 and 5.0 μm) mass concentrations of composite aerosol is shown below in fig 1.



Raw profile of the size-segregated (0.3, 0.6 and 5.0 μm) mass concentrations of composite aerosol.
Fig 1

Interestingly, mass concentrations of aerosol with particle diameter 5 μm (M_5) (super-micron) and 0.3 μm ($M_{0.3}$) (submicron) showed distinct vertical variations with former depicting a drastic decrease while the latter showed elevated concentrations with altitude up to 5 km, indicating large removal efficiency of super-micron particles than that of submicron particles.

- Tropical Tropopause Dynamics (TTD): Total 36 flights conducted for balloon borne Cryogenic Frost-point Hygrometer (CFH) observations of water vapor in the upper troposphere and lower stratosphere (UTLS) region were carried out during Indian Summer Monsoon, pre-monsoon and post monsoon times, from TIFR Balloon Facility, Hyderabad under joint collaboration with SPL-VSSC.

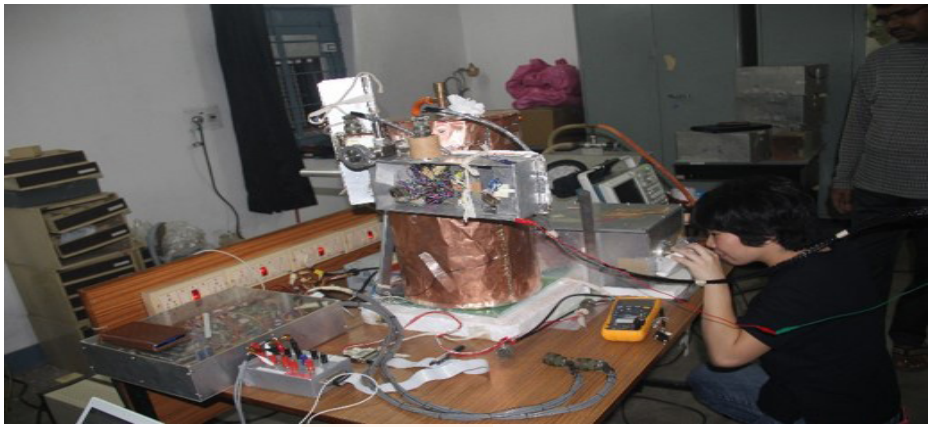
- Balloon Borne Asian Tropopause Aerosol Layer (BATAL): Series of 9 balloon flights conducted during Active Indian Summer Monsson sesonfor measuring aerosols and black carbon particles in the upper troposphere and lower stratosphere (UTLS) region during Indian summer Monsoon, comprising 5 small plastic zero pressure balloons and 4 latex balloons. All the balloon flights carried atmospheric science instruments comprising Opticle Particle Counters (OPC), Frost point Hygrometer (CFH), Boulder etc., under joint collaboration with NASA-NARL.

2. ASTRONOMY AND ASTROPHYSICS:

- Successfully conducted two zero pressure plastic balloons for carrying out far-infrared (FIR) observations using TIFR 100 cm balloon-borne telescope (T100). The telescope is an f/8 Cassegrain system with a 100 cm primary aperture. The secondary mirror is 27 cm in diameter and is vibrated at a frequency of 10 Hz in order to effect sky chopping (for online background subtraction) with an amplitude of ~4.5 arcmin. The FIR telescope is being regularly flown from TIFR Balloon Facility for studying Galactic star-forming regions at long wavelengths beyond 100 microns. The T100 is one of the largest payload to be flown by balloon world-wide and weighing about 1000 kilograms with ballast (Fig 2).

- The above two balloon flights were conducted as a part of TIFR-Japan collaboration in balloon-borne FIR astronomy. A Japanese Fabry-Perot Spectrometer (FPS) (Fig 3) has been successfully interfaced with T100 and FPS (R~1700) is tuned to the astrophysically interesting fine structure line of [C II] at 157.74 microns. [C II] line is one of the most dominant cooling lines in Photo Dissociated Regions (PDRs), especially in low gas density PDRs. The spectrometer consists of a pair of Fabry-Perot interferometers, viz., the Scanning Fabry-Perot (SFP) and the Fixed Fabry-Perot (FFP). Each interferometer consists of etalon plates which are composed of nickel mesh, suitable for FIR observations. The SFP has an order of >70 and has a finesse of ~26. The FFP has an order of only 3 and acts as an order sorting filter allowing only the desired wavelengths to pass through it and reach the detector. The detector for the FPS is a single stressed Ge:Ga photoconductor which is cooled to 1.8 k using liquid 4 He at low vapour pressure.

Balloon-borne Telescope (T100)
Fig 2



Japanese Fabry-Perot Spectrometer (FPS)
Fig 3

Telescope (T100)
Fig 4

The T100 along with the upgraded FPS tuned to astrophysically important line of [C II] at 158 microns, was last launched twice during summer (February 18 2017) and winter (November 30 2017) from the TIFR Balloon Facility, (Fig 4). The T100 performed as designed with a Japanese FPS at the focal plane. The performance of the FPS system is being investigated using the FIR data collected during the ~5.5 hours of float at 31.5 km altitude.

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CHAPTER - 15

INDIAN INSTITUTE OF ASTROPHYSICS

BENGALURU

Indian Institute of Astrophysics (IIA) is India's premier research institution devoted to studies in astronomical sciences. Its main campus is located in the southeastern part of Bengaluru. The observational facilities are spread across the country, in four major field stations - Hanle (Ladakh, Jammu and Kashmir), Gauribidanur (Karnataka), Kavalur and Kodaikanal (both in Tamilnadu). The Hosakote campus in the Bengaluru Rural District houses the Centre for Research and Education in Science and Technology (CREST). The Himalayan Chandra Telescope (HCT) in Hanle is remotely operated from this centre via a dedicated satellite link.

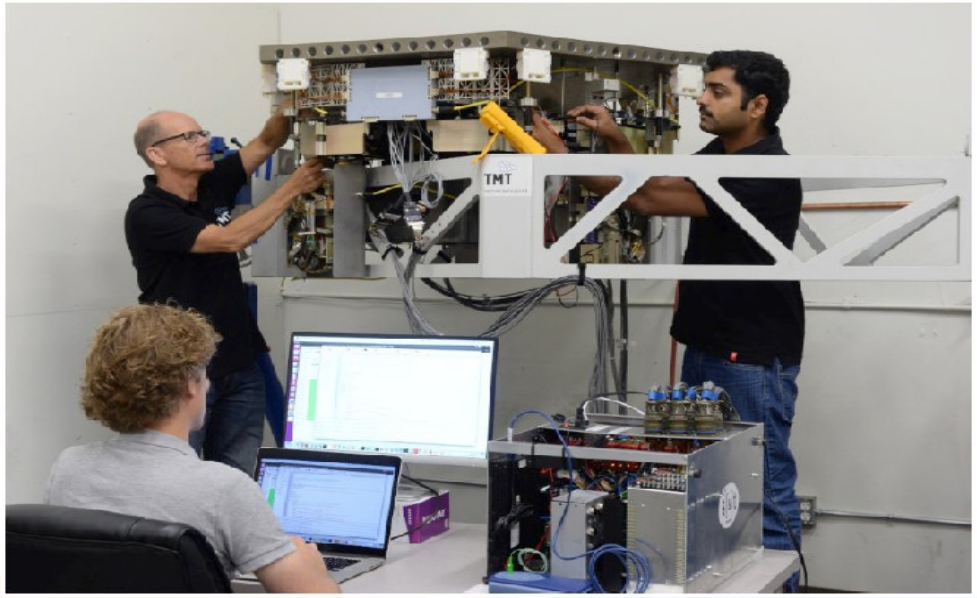
During the forty seven years of its existence, IIA's activities have grown manyfold. IIA has its own optical, infrared, radio and high altitude gamma ray array facilities. The Ultra-Violet Imaging Telescope (UVIT) on board the ASTROSAT - the first Indian space observatory launched on 28 September 2015, has been operational for the past two years. IIA was the lead institution responsible for the integration, testing and calibration of UVIT. IIA is playing a key role in India's participation in the Thirty Meter Telescope (TMT) project. TMT will be the world's most advanced ground-based observatory that will operate in optical and mid-infrared wavelengths. The Institute is actively engaged in Visible Emission Line Coronograph (VELC) payload on Aditya-L1 space mission and installation of the National Large Solar Telescope (NLST) - a multipurpose telescope to be installed at Merak village in Ladakh.

The major activities carried out by IIA during 2016-2017 are summarized in this chapter.

The year 2016 has been a most productive period during which the Institute has made significant contributions in many areas. The UVIT payload on-board ASTROSAT has been routinely carrying out excellent observations since its launch in September 28, 2015. There is no noticeable degradation in the imaging capabilities of the instrument and it has better than expected performance in the orbit. The UVIT Payload Operations Center at IIA, entrusted with the responsibilities of the routine activities (support observations, data processing, user needs and training) of UVIT is established in the main campus of the Institute and is functioning very well. Important findings from UVIT are being regularly published in leading journals. The year 2017 witnessed noteworthy developments on many fronts along with significant growth in research, academic and technical activities, human resource development and public outreach

A. MAJOR FACILITIES / INSTRUMENTATION DEVELOPED

- IIA is playing a key role in India's participation in the Thirty Meter Telescope (TMT) project. (plate 1). TMT will be the world's most advanced ground-based observatory that will operate in optical and mid-infrared wavelengths..



Assembly of M1 controls (Sensors, actuators, SSAs) and testing at TMT facility, Pasadena, USA of mirror performance against design requirements. Most of the hardware was shipped from India.
Plate 1

On the TMT Project front, the India-TMT group, led by IIA, completed the design configuration analysis for the Wide Field Optical Spectrograph (WFOS), which is one of the First Light Instruments. It made significant progress on its assigned work packages. The first prototype Segment Support Assembly (SSA) manufactured in India was assembled at a new clean room at IIA, Bengaluru. As per the work status of India-TMT, the building for segment polishing at CREST, Hosakote is progressing well and will be completed by mid June, 2018.

- The Institute is actively engaged in Visible Emission Line Coronograph (VELC) payload on Aditya-L1 space mission For this, a Near Specular Spectrometer (NSS) to measure the scattered light due to the primary mirror of the coronagraph has been developed. The design of VELC payload successfully went through major reviews at ISRO and the laboratory model assembly is underway. For assembly and testing the MGK Menon Laboratory facility was up-graded, and a clean room of class 10 areawas added.
- IIIA is engaged in the installation of the National Large Solar Telescope (NLST) – a multipurpose telescope to be installed at Merak village in Ladakh.

- The weather station, all sky camera, Solar Differential Image Motion Monitor (SDIMM) and a Shadow Band Ranging (SHABAR) instruments are deployed for measuringobserving conditions at Merak.
- The Raman Science Center at IAO, Leh is made operational. The Institute has installed an H-alpha telescope at Merak village in Ladakh.
- The Sky Radiometer at IAO, Hanle, is linked with SKYNET under a NASA collaboration. IIA is partner in the Partnership forInternational Research and Education (PIRE) Collaboration for the study of transients, “Global Relay of Observatories Watching Transients Happen – GROWTH”, funded by Science and Engineering Research Board (SERB)-DST under the Indo-US Science and Technology Forum (IUSSTF).
- MoU was signed between Space Physics Laboratory (SPL), Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram and the Indian Institute of Astrophysics for collaboration in the measurement of Carbon dioxide and Water vapour. An important development was initiated (jointly with ISRO and RRCAT) at IIA inthe area of X-ray optics. Multi-layer X-ray mirrors developed using the facility at RRCAT, were subject to performance tests and showed good promise to meet the needs of the space astronomy community.
- A novel crossed log-periodic dipole antenna for radio polarization observations at low frequencies with high isolation between the orthogonal arms of the antenna was successfully designed and developed in-house at the Gauribidanur Observatory.
- The IHY two element radio interferometer outreach kit was set up by IIA as a part of Scientific Committee on Solar Terestrial Physics (SCOSTEP) / ISWI International Space Science School conducted at Kasturbai Walchand college, Sangli, Maharashtra during November 7–17, 2016.

Plate 2

The functionality and observing capability of a basic radio interferometer was demonstrated to the participants at Kasturbai Walchand college, Sangli, Maharashtra during November, 2016. (plate 2)

B. RESEARCH CONTRIBUTIONS/ SCIENCE RESULTS:

A diverse set of research topics related to Astronomy and Astrophysics are being pursued at IIA and they are broadly classified under the following areas; Sun & Solar system, Stellar Astronomy, Galactic Astronomy, Extragalactic Astronomy & Cosmology, Theoretical Astrophysics & Physics, Techniques & Instrumentation and Space Astronomy. Among the many research findings in the last two years, a few of them are summarized here:

1. Solar Physics:

- The Kodaikanal observatory has been obtaining solar images since 1904 in broad band white light, narrow band Ca II K 393.37 nm and Hα 656.3 nm wavelengths. Many of these observations are still continuing. The collection of nearly 100- year long, daily full-disk image plate collection was fully digitized and made available to scientists around the world. This unique collection, which provides the longest, consistently calibrated data set from a single observatory, is now being used to study changes across multiple solar cycles in a systematic manner.
- Calculations related to the polarization properties of coronal emission lines were developed, and the same was applied to the Fe XIII 10747 Å line to explore its diagnostic potential of the coronal magnetic field.
- EUV observations of the Sun revealed outward propagation of jet-like features which induced transverse oscillations in the near-by coronal magnetic field lines. These are the first observations of such oscillations.
- The amount of energy released during multiple solar flares from a `delta' sunspot which accounts for nearly 95% of the solar X-ray radiation reaching the Earth was simulated. For the first time, the simulation involved the rotation of the Sun which twists the magnetic field lines inside the surface of the Sun.
- In the context of Sun-Earth connection, the near-Earth properties of a magnetic cloud ejected from the solar atmosphere, and the associated sunspot active region on the Sun were studied. The results indicate that the magnetic field lines in the cloud has a constant twist.

2. Stellar Astronomy

- Three short-period Earth-sized planets transiting an ultracool dwarf star Trappist-1, only 12 parsecs away, are discovered using TRAPPIST. Observations taken from the HCT contributed significantly in resolving the degeneracy of the orbital period of the third planet.
- Extensive monitoring of the Transitional Supernovae such as SNe iPTF13ebh and SN 2015bp during the pre-maximum, maximum and post-maximum phase was carried out using the HCT. The two objects were found to be declining faster than the normal type Ia supernova and producing less amount of ^{56}Ni.
- Early results from the Ultra-Violet Imaging Telescope (UVIT) on board the ASTROSAT observatory reported the discovery of a hot companion associated with one of the Blue Straggler Stars (BSSs) in the old open cluster, NGC 188. The discovery demonstrated the capability of UVIT to accurately estimate the parameters of binary systems, using its filter systems.

- Approximately 250 variable stars are detected in a sample of 23 selected globular clusters by using CCD time-series photometry. The absolute magnitude and [Fe/H] for each individual RR Lyrae is obtained via the Fourier decomposition of the light curve.

3. Extragalactic astronomy and Cosmology:

- One of the important cosmological parameters is the Hubble constant at the present epoch (H_0), and therefore its precise determination is very important for many aspects of cosmology. Observations of gravitationally lensed quasar systems were used to estimate H_0.
- A semi-automated quantitative method was introduced to estimate the age and reddening of 1072 star clusters in the Large Magellanic Cloud (LMC) using the Optical Gravitational Lensing Experiment III survey data. This study brings out 308 newly parametrized clusters.

4. Theoretical astrophysics:

- A dynamo model of the galaxy was constructed to explain the strength and global 3D structure of the observed magnetic field. A key result is that saturation is achieved within 1 Gyr that has implications for detection and study of its cosmic evolution through upcoming facilities such as the Square Kilometer Array.
- A model of cosmic evolution of black hole energetics was constructed that takes into account the mass and spin accreted by the hole and the angular momentum torque due to an electro-dynamical jet. An interesting result is that when the accretion stops, the jet power increases before a gradual decline if the initial spin is above a certain limit.
- A dynamical model of tidal disruption events (TDE) was constructed assuming a time dependent accretion model, to calculate the rise time, the peak bolometric luminosity in terms of physical parameters and a typical light curve of TDEs which is then compared with the detector sensitivities to obtain the duration of flare detection.

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CHAPTER - 16

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS (IUCAA)

PUNE

The Inter-University Centre for Astronomy and Astrophysics (IUCAA) is a Centre of excellence for research in astronomy and astrophysics (A & A), and related areas. The main objectives are to provide a Centre of Excellence within the university sector for teaching, research and development in A & A, as well as to promote nucleation and growth of active groups in this area in universities. Besides conducting vigorous research programmes of its own, the Centre enables workers from Indian universities, teachers as well as students, to visit the Centre to use the facilities for various durations.

A. MAJOR FACILITIES/INSTRUMENTATION DEVELOPED

- The Solar Astrophysics Group at IUCAA is leading the efforts on building the Solar Ultraviolet Imaging Telescope (SUIT) on board the Aditya-L1 mission of the Indian Space Research Organization (ISRO). The payload has gone through the preliminary design review, and currently a lab model has been assembled for testing and performance measurements. The group is also involved in studying the physical processes that are important in heating of the upper layers of the atmosphere, initiation and evolution of erupting prominences and flux ropes that eventually lead to a flare and/or coronal mass ejection.

- During 2016, the AstroSat Science Support Cell (ASSC) was established at IUCAA and has been run in collaboration with ISRO. This Cell performs the task of providing all necessary support to the users of AstroSat. ASSC hosts, maintains and develops various documents, utilities and packages required for proposal preparation, including the AstroSat Proposal Processing System (APPS), and also the software required for analysing the data of all the AstroSat instruments. ASSC regularly conducts capacity building workshops for AstroSat.

B. SCIENCE RESULTS

- **Quantum Theory and Gravity:** The deep inter-relationship between gravitational dynamics and horizon thermodynamics suggests that gravity is an emergent phenomenon, with its field equations having the same status as, say, the equations of fluid dynamics. This interpretation of gravity as an emergent phenomenon has a direct relevance to cosmology. Due to an extra symmetry present in this approach, the field equations of gravity are insensitive to the changes in the bulk vacuum energy, which does not couple to gravity. This is a necessary pre-condition for a successful solution to the cosmological constant problem.

Demanding that the amount of cosmic information ('CosmIn'), available to an eternal observer in the universe, it should be finite, and requires the universe to have a late-time accelerated expansion, exactly as observed. Combining the introduction of CosmIn with generic features of the quantum structure of spacetime (e.g., the holographic principle), a holistic model for cosmology has been developed.

- **Cosmology of the Phantom Brane, and Dark Matter and Dark Energy:** The phantom brane is a theoretically significant construction since the effective equation of state of dark energy can fall below the so-called phantom divide at w = -1. Such a braneworld, originally discovered by the IUCAA team in 2002, can provide an excellent fit to current observations of the expansion history. Further, IUCAA team has shown that new models of dark matter and dark energy can be constructed from the alpha-attractor class of models. These new models include tracker models of dark energy, which significantly alleviate the fine tuning problem faced by the cosmological constant.

- **Cosmology and Structure Formation:** Numerical simulations and semi-analytical techniques have been used to explore various facets of the formation and evolution of cosmological large scale structure and the galaxies that inhabit it. These include the assembly history of gravitationally collapsed `haloes' of dark matter (which are believed to host galaxies), and the dependence of this assembly on the external environment provided by the so-called Cosmic Web. It has been shown that the tidal environment of haloes plays a key role in shaping their present-day structure and can also affect galaxy evolution. The observed optical properties and neutral Hydrogen content of low-redshift galaxies has been modeled using analytical and Monte Carlo techniques to gain insight into how these galaxies are distributed in the Cosmic Web.

- **Observational Cosmology and Extragalactic Astronomy:** Investigations have been carried out to find the nature of accretion disk in a bare Seyfert 1 galaxy Fairall 9 using Swift monitoring observations, consisting of 165 usable pointings spanning nearly two years, and covering six ultraviolet (UV)/optical bands and X-rays. The observed optical/UV lags vary as wavelength, consistent but longer than the predicted lags for a standard accretion disc. Using a year-long Swift monitoring and four long XMM-Newton observations of a high accretion rate AGN 1H0707-495, it has been found that the reprocessing is not the dominant mechanism for the UV variability, and established that the broad emission line reported earlier is real, and not an artefact of the variability of different spectral component.

- **Discovery of Saraswati Supercluster:** Saraswati supercluster located in the stripe-82 region of Sloan Digital Sky Survey (SDSS) is the first major discovery of its kind made in India by researchers based in IUCAA and in three Indian universities. This supercluster extends over an astonishingly large physical scale of ~ 200 Mpc, and contains a minimum mass of 2 x 10^{16} suns in at least 48 massive galaxy clusters and groups at the same redshift. This is possibly one of the most massive structures observed in the Universe so far, whose existence challenges the prevailing cosmological theories.

- **Gravitational Waves:** The direct detection of gravitational waves from colliding black holes was made by the laser interferometer gravitational wave observatory (LIGO) detectors for the first time on 14th September 2015. The discovery was announced on 11th February 2016. Subsequently, several such events were detected. The Nobel prize in physics in 2017 was awarded for this discovery. Several of IUCAA members have contributed significantly to this discovery. In the wake of this discovery, the LIGO-India project was approved, which involves constructing a laser interferometric detector on Indian soil. Specifically, one of the recent works in the concerning period centred around exploring ways to discriminate against glitches (noise transients), which frequently occur in the data and give rise to false triggers in the search pipelines.

- **Stellar Spectroscopy:** Optical spectroscopy and photometry of main-belt asteroids with a high orbital inclination were carried out recently using the Wide Field Grism Spectrograph 2 (WFGS2), mounted on the University of Hawaii (UH) 2.2 m telescope, and also employed the IUCAA Faint Object Spectrograph and Camera (IFOSC) mounted on the 2 m telescope at the IUCAA Girawali Observatory (IGO). Further, Na D and Ca II high spectral resolution observations of Ca II K lines were obtained with the Vainu Bappu 2.3 m telescope and the Southern African Large Telescope (SALT) towards the three stars (HD 63578, HD 68217 and HD 76161) along with simultaneous observations of Na I D lines.

  Several million spectra have been taken by a reflecting Schmidt telescope located at Xinglong station, Hebei Province, China. Automated classification tools using Artificial Neural Network (ANN); Multi-Level Decision Tree, and Random Forest have been employed on this large spectral data base using relevant Miles spectral library as a training set.

- **AstroSat:** IUCAA continues to operate the Payload Operation Centre (POC) of the Cadmium Zinc Telluride Imager (CZTI) instrument aboard the Indian Space Astronomy Observatory AstroSat. Since the launch of AstroSat in September 2015, routine analysis of all the data received from this instrument is being carried out on a round-the-clock basis. The processed data is supplied to the Indian Space Science Data Centre (ISSDC) of ISRO, which makes it available to the users. Constant monitoring of payload health is also carried out by the POC and remedial action is taken when required. CZTI POC is a collaborative effort of IUCAA and the Tata Institute of Fundamental Research (TIFR), Mumbai, with additional involvement of the Physical Research Laboratory (PRL), Ahmedabad, and the Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram.

  The CZTI routinely detects cosmic Gamma Ray Bursts (GRB), at the rate of once a week on average. These are recorded by the POC at the CZTI GRB archive webpage, and announced via GCN circulars. Search of CZTI data is made for possible gamma ray flashes associated with gravitational wave events as well. CZTI observations were important to disprove one such claimed association, and to put localization constraints on the one true association that has so far been found. For bright GRBs, CZTI is able to detect hard X-ray polarisation. Polarimetric capability of the CZTI has been utilised also for the Crab pulsar and nebula, yielding the most sensitive measurements in this band till date, and enabling the study of the variation of polarisation across the 33-ms pulse period.

  The Ultraviolet Imaging Telescope (UVIT) is another instrument on AstroSat in which IUCAA has been involved. It provides ultraviolet imaging simultaneously in two UV bands: 130 - 180 nm and 200 - 300 nm, with a choice of filters to select part of a band, low resolution slitless spectroscopy with a spectral resolution of ~ 80. The field of view is a circle of 28' diameter and the angular resolution is ~ 1.4". This instrument started observations in December 2015. During its operation, a large number of observations have been made of a variety of objects including stellar clusters, evolved stars, galaxies, galactic clusters, extra-solar planetary systems, X-ray sources like active galactic nuclei and binary stars.

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CHAPTER - 17
RAMAN RESEARCH INSTITUTE (RRI)
BANGALORE

The Raman Research Institute (RRI) is an icon that symbolizes and represents the heritage of Indian physicist and Nobel Laureate Sir C V Raman, continuing his legacy and style of qualitatively impactful research. The Institute preserves the inspirational spirit of this stalwart of Indian scientific cultural history.

The Raman Research Institute is now an autonomous research institute engaged in research in basic sciences.The Institute carries out the mandate as defined by the Governing Council and RRI Trust to conduct basic research with focus in niche fields of

1. Astronomy & Astrophysics including theoretical astrophysics, observational astronomy, and experimental Radio and X-ray astronomy,
2. Light & Matter Physics including cold atoms, ions, molecules, quantum communications and computing, and intense laser produced plasma,
3. Soft Condensed matter including research in liquid crystals, nano-composites, colloids, chemistry and biological physics, and
4. Theoretical Physics including General Relativity, Foundational quantum mechanics, soft matter physics, and classical and quantum statistical Mechanics and Gravity.

Over the last few years, research within the Astronomy & Astrophysics (AA) group at RRI may be broadly classified into theoretical astrophysics and cosmology, observational radio and X-ray astronomy, signal processing and design, and construction of novel special purpose telescopes.

A. MAJOR FACILITIES/INSTRUMENTATION DEVELOPED

The unrelenting quest for pushing the frontiers of knowledge about the observable universe and the need to see hitherto hidden regions of space has fuelled the need for better, efficient and sensitive telescopes and associated receivers and algorithms. Additionally, new methods and modeling aimed towards extracting the signal of interest from the background is desired. Recent research at RRI over the past year has focused on both these aspects. Efforts are towards building a cm-wave imaging telescope which by use of a novel optics scheme - “efficient linear array imaging” – provides good resolution and sensitivity with 70% less reflector area and easy cum cost effective manufacturing.

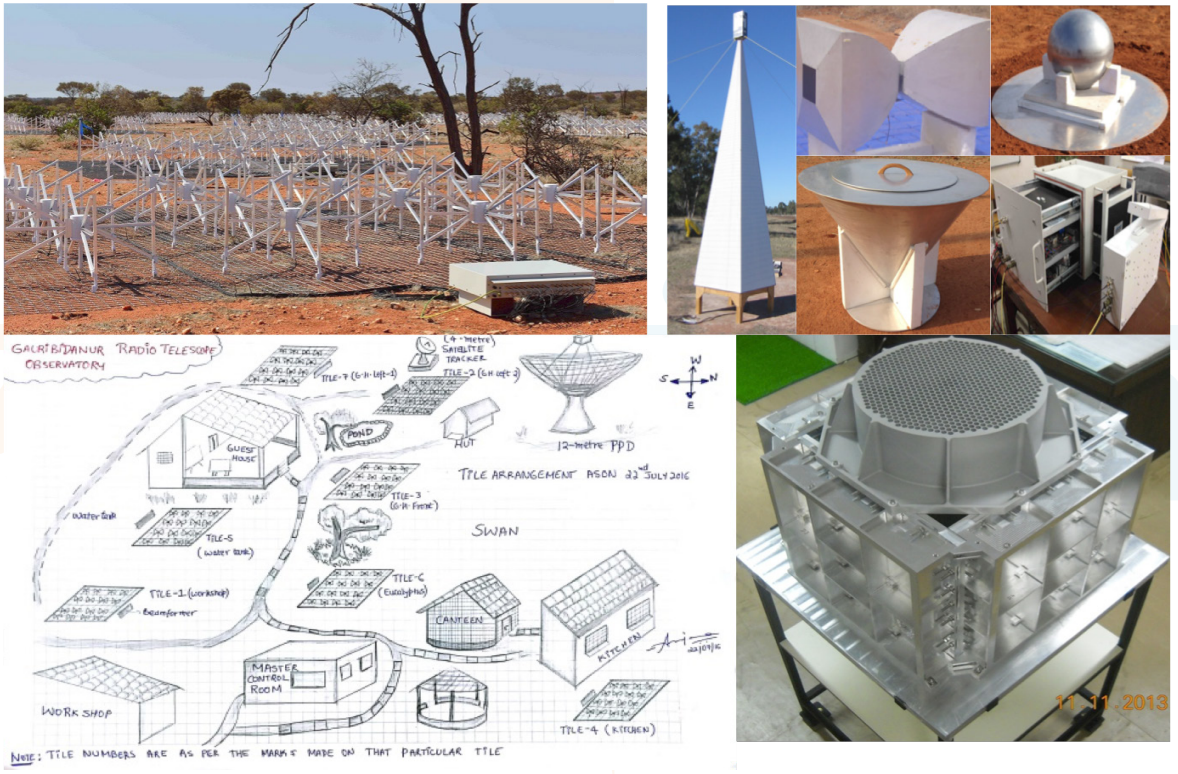
RRI is currently designing and building an Indian X-ray polarimeter (called POLIX), as a payload for a dedicated small satellite mission of ISRO called XPoSat. In this regard, an MoU was signed in September 2017 between ISRO Satellite Centre [ISAC], and Raman Research Institute (RRI).

POLIX is poised to be the first dedicated X-ray polarimeter mission in the world and to open a new window in high energy astrophysics by measuring X-ray polarization in about 50 bright X-ray sources, ahead of the NASA and ESA space mission proposals for launching X-ray polarimeters.

In recent years, Experimental Radio Astronomy at RRI is inventing, designing and building specialized spectral radiometers for studies of Cosmic Dawn and First stars via red-shifted global 21-cm from cosmological hydrogen.

Another experimental initiative is to build a Sky Watch Array Network across India, involving students from science and technology institutes and universities, for a better study on the phenomenon of radio transients and towards high angular resolution imaging at low radio frequencies.

Research in signal processing has been geared towards developing error correcting codes, methods to search/detect unpulsed emissions intrinsic to pulsars, new approaches with low data processing requirements for detecting pulses that undergo dispersion and foreground modeling and subtraction for long wavelength astronomy.



Clockwise from top left:MWA radio telescope as a precursor to the International Square kilometer array (SKA) telescope. BuildingRadio astronomy radiometers for discovering first formation of atoms, stars and galaxies in the universe, DevelopingX-ray Polarimeter (POLIX) as payload for ISRO's XPoSat, to be the world's first X-ray polarisation Mission; Cartoon of SWAN – Sky Watch Array Network - assembled at Gauribidanur field station.

B. SCIENCE RESULTS

1. ASTRONOMY AND ASTROPHYSICS

Theoretical Astrophysics

- **Intracluster medium and Galactic outflows:**

  Astronomy and Astrophysics (AA) group members and collaborators have analyzed data from a sample of galaxy clusters and shown evidence for the first time that rules out models of "preheating" in intracluster gas at the outer regions that are least affected by cooling and active galactic nuclei (AGN) feedback from the central region. With detailed analytical calculations and 1D hydrodynamic simulations, RRI researchers have found that radiation pressure is important in the early period after the onset of star formation in a cluster after which heating due to radiation becomes important. They have also studied the evolution of clustered supernovae to form a single bubble and provide observational diagnostics that will help observers to distinguish this phase of evolution of super-bubbles. Recent research has worked out the basic physical process and the parameters that can support molecule formation in starburst nuclei (the highly dense central region of a starburst galaxy). Using the recently determined OVII/OVIII line ratio RRI researchers have discriminated between bubbles driven by star formation and by black hole jets and estimate the age for the bubbles as 15-20 million years.

- **Stellar Dynamics in Galactic nuclei:**

  Recent research at RRI has developed a theory that provides firm foundations for the dynamical and statistical mechanical theory of Keplerian stellar systems (whose mass is smaller than the mass of their black holes). Over the past year, the power of this theory has been demonstrated by applying it to model problems regarding the dynamics and statistical mechanics of astrophysical disks including the response of a stellar, spherical density cusp at the galactic center, to a growing ring of gas.

- **Cosmology:**

  During the past year cosmologists at RRI have proposed a general method, based on the delay spectrum approach, to extract HI power spectra of gas in Cosmic Dawn and Reionization from tracking observations using an imaging radio interferometer. They have also investigated the possibility of using the Silk-damping induced CMB spectral distortion as a probe of small-scale power in four suggested alternative dark matter candidates and have obtained interesting results.

- **Theoretical modeling of astrophysical sources:**

  Astrophysicists at RRI have explored high energy and very high energy phenomena in the universe with gamma ray, neutrino and cosmic ray data and theoretically interpreted the observational results and provided estimates to the jet power related to synchrotron emission of electrons and protons.

Observational Astronomy

- **Radio Astronomy:**

  Recent research at RRI has been on using the Murchison Widefield Array (MWA) telescope, which was built by RRI in an international partnership, to Study the phenomenon of sub-pulse drifting, which may hold the key to understanding the pulsar emission mechanism. Pulsars are rotating neutron stars or white dwarfs that emit a beam of radiation; the rotation results in the appearance of pulsed emission and hence the name. Another work has used the MWA along with other telescopes to estimate, for the first time and over the frequency range 80-1400 MHz, spectra from radio halos and relics (enormous regions of diffuse radio emissions) in merging galaxy clusters. Use of high resolution GMRT HI mapping has allowed RRI astronomers to resolve and study in detail smaller scale features in a system of two interacting spiral galaxies, spiral debris and a tidal dwarf galaxy. This has enabled RRI astronomers to estimate their dynamics and propose formation mechanisms for the tidal dwarf galaxy. RRI astronomers have used in-house built spectral radiometers SARAS 2 to derive likelihoods for plausible redshifted 21 cm signals from neutral hydrogen, which is a key probe of “Cosmic Dawn” and the “Epoch of Reionization”. Comprised of super-massive black holes at the centers of massive elliptical galaxies powering twin-jets of synchrotron plasma, radio galaxies are manifested in a variety of morphologies arising from the deposited plasma radiating predominantly at radio frequencies. Research at RRI in this area in recent years has focused on eliciting information on central black hole behaviour from the radio emission imaged on much larger scales.

- **X-ray Astronomy:**

  By studying the X-ray mid-eclipse (time when the X-ray emitting compact star is exactly behind the companion star) and timing record of an X-ray binary (a two star system where one of the stars is a neutron star or a black hole) researchers at RRI have discovered the presence of a massive planet (approximately 8000 times the mass of Earth) around the binary. Careful analysis of variations in X-ray intensity and spectral parameters as a function of orbital period has enabled astronomers at RRI to propose a scenario, which explains the nature of the most highly absorbed X-ray binary in our Milky Way galaxy. Astronomers at RRI have measured changes in the pulse phase dependence of X-ray emission lines with a torque reversal in a unique X-ray binary 4U 1626-67, which indicates that structures in the accretion disk that produce pulse phase dependence of emission features have changed from spin-down to spin-up phase.

CHAPTER - 18

ARYABHATTA RESEARCH INSTITUTE OF OBSERVATIONAL SCIENCES (ARIES)

NAINITAL

ARIES, Nainital, one of the premier autonomous research Institute under the Department of Science and Technology (DST), Government of India, is engaged in carrying out frontline research in the fields of Astronomy & Astrophysics, Solar Physics and Atmospheric Sciences. The Institute is also involved in developing state-of-the-art backend instruments.

ARIES has recently installed a 3.6m aperture new technology optical telescope at ARIES, Devasthal which is about 60 km from Nainital and is at an altitude of about 2500 m. ARIES also operates two optical telescopes of 1.04m and 1.3m apertures at Nainital and Devasthal, respectively. Both the telescopes are equipped with large format CCDs and several optical broad and narrow band filters to carry out photometry of celestial objects. The 1.04 m telescope also has an imaging polarimeter as another back-end instrument. The main solar observing facility at ARIES, Nainital is a 15cm (f/15) Coudé Solar Tower Telescope equipped with Hα filter, and a CCD camera. It is an automatic Hα flare patrolling system, which takes fast sequence of images in the flare mode observations.

The Institute is setting up an ST Radar system (@206.5 MHz) in the Institute campus, Nainital. The Institute is also setting up a facility of 4m International Liquid Mirror Telescope (ILMT) telescope at ARIES, Devasthal.

To do the mirror coating upto 3.7m diameter, a coating plant has been established in the 3.6m telescope enclosure building at ARIES, Devasthal. In order to meet science goals of telescope, a highly-customized coating plant to coat the mirror with uniformity of about a few nm was required. The design, manufacturing and installation of the coating plant are done by M/s Hind High Vacuum (HHV), Bangalore. This is the largest mirror coating facility in India.

Astronomy and Astrophysics group members are actively involved in collaboration with scientists of national and international institutions in the fields of near earth objects, individual stars, star formation, open cluster systems, globular cluster systems, large magellanic cloud (LMC), active galactic nuclei (AGN), quasars, blazars, gamma ray bursts (GRBs), supernovae and numerical simulations.

The solar physics research group carry out the observations and modeling of the transients (e.g., flares and associated plasma processes, jets, spicules, etc.), and study space weather phenomena, and magneto-hydrodyanmic waves in the solar atmosphere. Atmospheric Science group is engaged in the investigation of aerosols, trace gases, dynamics, meteorology etc., of the lower atmosphere.

A. MAJOR FACILITIES/INSTRUMENTS DEVELOPED:

1. 3.6m Devasthal Optical Telescope (DOT):

A world-class 3.6m Devasthal Optical Telescope (DOT): was activated on 30th March 2016 to explore the deep celestial sky. (Fig 1)

3.6m DOT at Devasthal, ARIES, Nainital.
Fig 1

Characterization of 4Kx4K CCD imager as the first back-end instrument for the 3.6m Devasthal Optical Telescope (DOT) was completed by June 2016. Another back-end instrument called TIRCAM2 of TIFR was made available for observations from DOT. Routine observation from DOT as a National facility has been started from April 2017.

2. International Liquid Mirror Telescope (ILMT)

The 4m International Liquid Mirror Telescope (ILMT) project (Fig 2) is collaboration between the Institute of Astrophysics and Geophysics (Liege University), the Canadian Astronomical Institutes from Quebec (Laval University), Montreal (University of Montreal), Toronto (University of Toronto and York University), Vancouver (University of British Columbia) and Victoria (University of Victoria) and the ARIES, India.

Aerial view of the ILMT building with its roof open (right) and the 1.3m telescope (left) [Image courtesy: Prof. Jean Surdej].
The ILMT will be entirely dedicated for survey of galactic and extragalactic objects of high scientific interest. At an excellent site like Devasthal, Liquid Mirror Telescopes (LMTs) can deliver the similar performance as classical telescopes with much lower cost and greater simplicity of operation. The 4m ILMT is an instrument that will be dedicated to a photometric survey of a narrow strip of sky (about half a degree) passing through the zenith. We expect to get first light before the monsoon of 2018.
Fig 2

3. Stratosphere Troposphere (ST) Radar

The ST Radar system (@206.5 MHz) at ARIES, Nainital, is configured as an Active Aperture Distributed Phased Array using state of art Solid state TR module and Digital Signal Processing techniques. This system has array of 588 Yagis of 3 elements in a circular aperture on equilateral triangular grid arrangement. It is important to mention that entire system is developed within India and antennae array is installed on a roof top for the first time.

ST Radar antenna array on the roof-top of the building.
Fig. 3

During 2016-17, ARIES has made ready total 10 clusters (out of 12 clusters) with its own efforts. The Radar has been operated extensively till mid-August, 2017 (about 570 hours since 20 Jan, 2017) and reasonably good wind data are obtained with average height coverage of about 9 km and maximum height reaching up to ~14 km above MSL. Further improvements of the systems by ECIL, Hyderabad is in progress.

4. Network of Boundary Layer Experiments (NOBLE): Under ISRO-funded project, NOBLE Ultrasonic anemometer installed at 12 m height, has been made operational. However the tender document for the purchase of soil sensors, multilevel meteorological-sensor, radiation instruments, AWS and has been prepared and to be floated as the infrastructure development work is in progress. GNSS satellite receiver (GPS) was installed at ARIES, in collaboration with NARL Gadanki, is operational and the data for atmospheric studies is being archived.

5. Thirty Meter Telescope (TMT) Project

The activities of TMT-India are coordinated by the India TMT Coordination Centre (ITCC) set up by the DST, Government of India in Bengaluru. ARIES as one of the founder PI institutes, is involved towards the project since very beginning. During last one year, major achievement by ARIES is the successful completion of the contract with the two firms (M/s Godrej, Mumbai and Avasarala, Bangalore) to manufacture the prototypes of 6 sets of segment support assemblies (SSAs).

B. SCIENCE RESULTS:

1. ASTRONOMY AND ASTROPHYSICS

- Variable Stars: The Catacysmic Variable (CV) Paloma was found to be an object which bridges the gap of magnetic CV evolution between polar and intermediate polar. It was found that flares from LO Peg were not necessarily connected with the magnetic spots. Two super flares detected in CC Eri are the brightest, the hottest, and the shortest observed flares, thus far. Using the largest sample of active G-K dwarfs, the correlations between the degree of polarization and various activity parameters are found to be stronger in B band and weaker in I band.

- The Nainital-Cape Survey is a dedicated survey programme initiated in 1999. The high-resolution spectroscopic technique was used to perform the detailed study of some of stars discovered as Delta Scuti type pulsators for the determination of their basic parameters.

- The research on Galactic structure on the basis of large archival sample of Galactic open clusters to understand the Galactic structure in the solar neighborhood was done. Various important parameters like scale height, solar displacement and local mass density, etc to probe the Galactic disk in the immediate solar neighborhood were determined. The geometrical characteristics of a significant number of clusters enabled to understand large-scale spatial properties of the cluster systems. The determination of the solar offset from the Galactic plane in a near complete sample of open clusters up to 1.8 kpc has drawn wide attention of the astronomical community.

- Recent advancement in detectors have permitted the detection of substantial population of low mass stars in OB associations. Comprehensive multi-wavelength studies of young star forming regions are being carried out to understand the scenario of star formation in greater details. The studies indicate that in most of the cases star formation is non-coeval and massive stars in the region can trigger next generation of star formation. Initial Mass Function (IMF) of young clusters in the mass range about ~30 - 0.6 $M_\odot$ can be represented by power law with a break around 1-2 $M_\odot$. It is found that IMF varies from one cluster region to another. Mass segregation is also observed in these young clusters and it was concluded that the mass segregation may be due to star formation process itself.

- Using ARIES 1m class telescopes and other national and international facilities, high cadence observations of different classes of supernovae were carried out. During the campaigns three interesting supernovae – SN 2012aa, SN 2013hj and SN 2014G were studied. Multi-band observations enables us to cover all characteristic phases of optical light curves which indicate that SN 2012aa could be a transient between type Ibc core-collapse and superluminous supernovae. The light curve characteristics revealed that both SNe 2013hj and 2014G belong to the type IIL category showing a high plateau decline rate (greater than 1.5 mag per 100 days). Modeling of the bolometric light curve yields a progenitor mass of ~ 11 $M_\odot$ with a radius of ~ 700 $R_\odot$ for SN 2013hj while for SN 2014G model estimated progenitor mass is ~ 9 $M_\odot$ with a radius of ~ 630 $R_\odot$, both having a typical energy budget of ~ 2×10^{51} erg.

- Based on the broadband imaging polarimetry data obtained through AIMPOL attached with 1.04m telescope, the evolution of type IIP SN 2013ej indicates towards possible asymmetry in the supernova ejecta. Subtle enhancements in the percentage of polarization was also seen in SN 2013hj.

- Study of objects like GRB 160625B show that the underlying physics towards long duration GRBs could be understood better by collecting a larger sample of multi-band data. This also emphasizes the longitudinal advantage of the 3.6m DOT for such transients.

- ARIES team members are involved in the follow up observations of the electromagnetic counterparts of gravitational wave events and have contributed in the first discovery of black hole-black hole merger (GW 150914) and neutron star-neutron star merger (GW 170817). The counterpart of the first binary neutron star merger GW 170817A associated with the short GRB 170817A was observed with the GMRT at cm bands. The broadband modeling of the GMRT data in conjunction with data at other wavelengths indicates that the GRB jet was misaligned from our line of sight. This is the most conclusive detection of an off-axis GRB afterglow and the first associated with a binary neutron star merger - gravitational wave event to date.

- Several nearby galaxies with ongoing and recently triggered massive star formation, as evidenced from the detection of Wolf-Rayet (WR) emission-line features, were observed using Hanle 2m optical telescope (spectroscopy), 1.3m Devasthal telescope (imaging), and Giant Meterwave Radio Telescope (GMRT). The radio HI 21 cm-line imaging using GMRT revealed signatures of recent or ongoing tidal interactions and merger with other faint galaxies, which were not detected in optical bands. The low-mass dwarf galaxies showed that metallicity is normally uniform across the disk. It was also found that most of these galaxies have remarkable radio deficiency when compared with their star formation rates from various indicators such as far infrared and optical bands. This study indicated that the WR galaxies due to their very recent starburst do not have sufficient supernovae at present epoch, essential to power cosmic particles to relativistic speeds and to emit synchrotron radiation detected at cm-band in radio. The tidal interactions were found to be the main trigger for star formation in galaxies.

- Are Radio-quiet (RQ) weak Emission line quasars (WLQ), radio quiet (RQ) counterpart of BL Lac objects (BLOs)? This question has its origin, in the so-called radio loudness dichotomy of AGN based on AGN unification scheme, where the long-sought radio-quiet counterpart of the highly polarised BL Lac is still missing. Monitoring by 1.3m ARIES telescope for their intra-night optical variability (INOV) has been used as a tool to look for any enhancement in the INOV duty cycle (DC) for RQ counterpart of BLOs, as compared to normal radio-quiet quasars. As of now, the programme has revealed two instances of RQWLQs exhibiting an INOV amplitude > 3%, a level rarely observed in existing 2-decade-long of other INOV programme of quasars, except for BLOs and highly polarised core dominated quasars.

- Blazars show flux, polarization, and spectral variability. In an extensive search of sample of blazars, optical flux variability is detected on diverse timescales. Blazars have shown colour variation on short and long timescales, and different band optical observations were found to be well correlated. These findings give evidences of non-thermal jet as well as thermal emission from accretion disc.

- In the detailed search for flux variability properties of the blazar W2R 1926+42 for the data taken by Kepler NASA Mission. strong flux variability is noticed on diverse timescales, and the blazar show possible quasi periodic oscillations (QPO) with period ~ 6.2 hours which give the mass of the black hole of the blazar to be 1.5 - 5.9 x 10^7 $M_\odot$.

- In the multi-wavelength blazar 3C 454.3, a very peculiar and unique flaring event was discovered which show strong correlated flux variability in gamma-ray, X-ray, optical, NIR bands which has a dramatic anti-correlated variability with degree of optical polarization. In another multi-wavelength campaign of the same blazar, evidence of external Compton emission mechanism was found.

- Two-dimensional numerical simulation of matter flow around black holes in pseudo-Newtonian limit, has been conducted with a novel Lagrangian-TVD code (LTVD). The computational domain was 400 r_g in radial direction and 200 r_g in the axial direction. The steady state analytical solutions are perfectly matched. Above a critical value of viscosity the solutions became time dependent. Oscillating shocks powered the bipolar jets as well as generated all types of low frequency QPOs seen in microquasars.

- A relativistic equation of state (EoS) was used to describe the fluid which constitutes the accretion disc and jet. The jet streamline was computed by obtaining the von-Zeipel surfaces (VZS). The foot point of the jet streamline i.e., VZS was computed from the disc parameters. Solving the accretion and jet equation of motions simultaneously, a self-consistent accretion-ejection solution in general relativity was obtained. It was shown that the accretion shock moves closer to the horizon, for discs starting with same outer boundary but for increasing viscosity parameter. We also showed that the jet is stronger in general relativistic description than in pseudo-Newtonian description. For highly spinning black holes, the space-time curvature induces shock in jets too.

2. SOLAR PHYSICS AND ATMOSPHERIC SCIENCE

- Properties of Sun using jets, filaments, eruptions and magnetic fields are studied using multi-wavelength ground and space base telescopes.

- Extensive observations of surface ozone made under ISRO-ATCTM project show clear evidences of significant crop loss (wheat and rice) in India due to high levels of ozone. during September – November 2017 period. Moreover, our recent observations depict an unusual variation in VLF signals shift in the terminator time may be strongly linked with enhanced mesospheric ozone production prior to earthquake eventually leading to increase in D-region ionospheric electron density prior to April 25, 2015 Gorkha Nepal Earthquake. study of unusual enhancement in tropospheric and surface ozone due to orography induced gravity waves are carried out.

- The particulate matter (PM2.5) samples were collected over Delhi and analysed in order to examine variations in atmospheric chemistry, combustion sources and influence of long-range transport. The chemical composition of PM10 aerosols at Varanasi, in the central Indo-Gangetic Plain (IGP) was analysed to examine the contribution of elemental carbon (EC) to the estimate the direct aerosol radiative effect (DARE).

- Quantification of aerosol radiative forcing and identification of wave-like signatures in the aerosol optical depth were shown over the central Himalayan region. A link between upper tropospheric planetary-scale Rossby waves and surface meteorological parameters was shown based on the observations made in association with the Ganges Valley Aerosol Experiment (GVAX) campaign at Nainital which is an extratropical site.

- Study on aerosol hygroscopicity was carried out for the first time over the central Himalayas. The study shows slightly larger light scattering enhancement factor f(RH) values for the fine particles which increase in aerosol hygroscopicity under more turbid atmospheres.
- Extensive balloon-borne observations over Nainital show very high wind speed near the subtropical jet and highlight the discrepancy in temperature profile from space-borne sensors.

Important Output Indicators for 2016-17:

S.No.	Parameters	Output
1	Papers in refereed journals	117
2	Papers in Conferences	13
3	Number of Ph.Ds.	Awarded: 05 Submitted: 03

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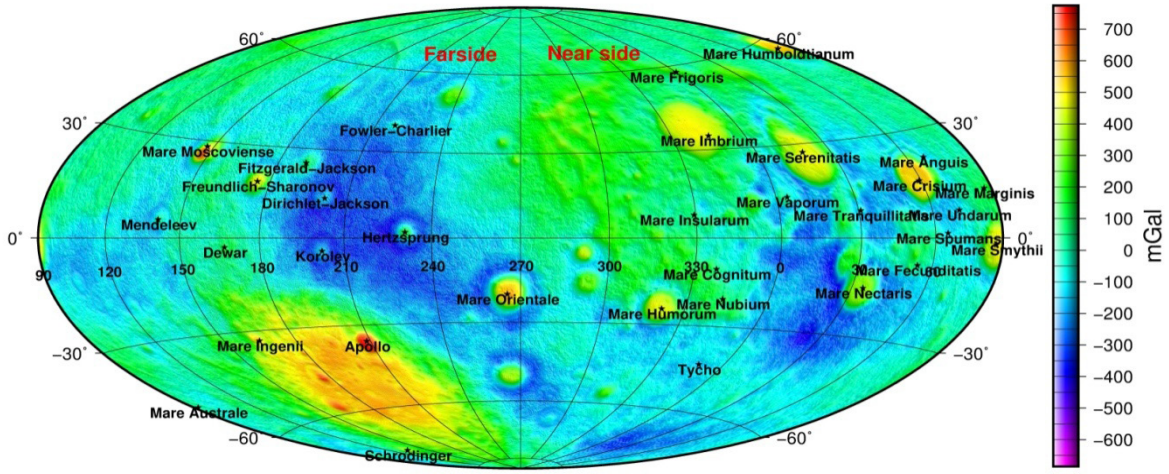
CHAPTER - 19
NATIONAL GEOPHYSICAL RESEARCH INSTITUTE
HYDERABAD

National Geophysical Research Institute (NGRI) is a constituent national laboratory of Council of Scientific & Industrial Research, under the Department of Scientific & Industrial Research (DSIR), Ministry of Science & Technology, Government of India The core research area is earth sciences, particularly solid earth geosciences that encompasses geology, geophysics and geochemistry.

1. THE SOLAR SYSTEM BODIES INCLUDING PLANETARY SCIENCE

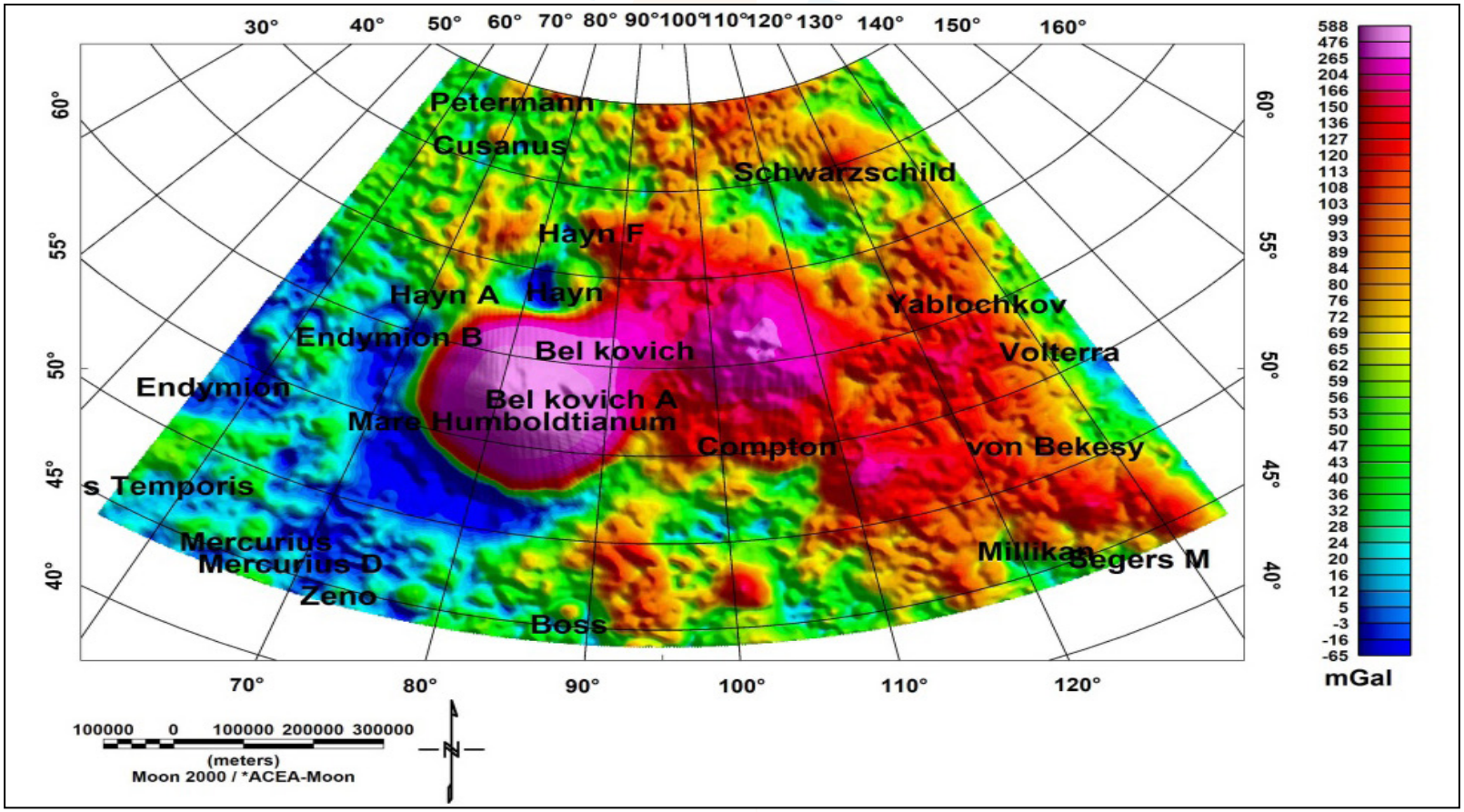
Satellite gravity: Lunar

The dedicated gravity mission to the Moon: Gravity Recovery and Interior Laboratory (GRAIL) provided the highest resolution gravity data of any planetary bodies of the solar system. The lunar gravity model: GRGM900C up to degree and order 660 derived from GRAIL mission and Lunar topography: Moontopo_2600p of degree and order 2600 derived from LOLA of Lunar Reconnaissance Orbiter are used to map the surface and subsurface structure of the moon (Fig 1). Bouguer correction density of 2.7 g/cm^3 is estimated, and transition wavelength of 270 km (from radial power spectrum) used to separation of regional and residual anomalies. The estimated crustal thickness from inversion of Bouguer gravity anomalies is varied from 0 to 70 km.



Bouguer gravity anomaly map of the moon computed using gravity model: GRAIL900C up to degree and order 6600.
Fig 1

Mare Humboldtianum, a 650km wide multi-ring impact basin on the northeastern part of the nearside of the Moon (59” N, 82” E) is hardly visible from Earth. The Galileo spacecraft has observed this Nectarian-aged basin in 1992 and the Clementine spacecraft in 1994. Humboldtianum is one of the smaller of the lunar seas. Its diameter averages about 260 km but its shape is decidedly irregular when seen in plain view. Belkovich attaches to it on the northwestern side. It is an older crater, 198 km diameter, with two large craters intruding into its walls on the west and a further flooded ring on the eastern flank. The northern part of the mare is shown on the lower left and Belkovich can be made out almost attaching to the mare’s northernmost section. Based on the spherical domain and the wavelength filtering of Humboldtianum, the long wavelength and short wavelength anomalies are separated. From the residual gravity anomaly map (high-pass with 252 km wavelength), extracted basin rings diameters are 148, 276, 435, 665 km. These rims are mapped based on gravity highs and lows of residual gravity anomaly map by keeping centroid as same.



Bouguer gravity anomaly map of Humboldtianum basin computed using gravity model: GRAIL900C up to degree and order 6600.
Fig 2

Recent shallow moonquake and impact-triggered boulder falls on the Moon

Though the origin of moonquakes is debated, a recent study reported possible sites where moonquakes occurred along young lobate scarps in the Schrödinger basin. An analysis of Lunar Reconnaissance Orbiter and Chandrayaan-1 images revealed four lobate scarps crosscut small fresh impact craters suggesting a young age for the scarps. A 28km long Scarp 1 yields a minimum age of 11 Ma based on buffered crater counting and a horizontal shortening of 10–30 m across the fault, while others are 35–82 Ma old. Two scarps are associated with boulder falls/rolled/bounced on the slopes with a low runout efficiency (~2.5) indicates low to moderate levels of ground shaking, which is interpreted as low-magnitude moonquakes. The other boulder falls (>1500) and associated with trails and bouncing marks are also observed and possibly controlled by recent impact event that produced ejecta rays and secondary crater chains traversed Schrödinger ~ 17 Ma ago. The study suggests that the Schrödinger basin may be seismically active and therefore seismometer networks can be placed there for effective detection of shallow moonquakes and continuous monitoring during future Chandrayan-II mission.

Evidence for recent seismicity in Valles Marineris, Mars

The geomorphologic observations and crater size-frequency age determinations have been gleaned from high-resolution orbiter data to demonstrate that the Valles Marineris region of Mars was seismo-tectonically active. The chasmata interior shows evidence of reactivated dip-slip faults that cross-cut the chasmata walls and floor with <8-10 km of total vertical displacement. In addition, the presence of young (<100 Ma) landslides proximal to the reactivated faults, >16000 boulder fall, and thousands of pitted mud cones on the chasmata floor suggest marsquake-triggered shaking. Fault-displacement measurements along the 250-km-long trough bounding faults indicate a cumulative seismic moment release of 10^{24} Nm, suggesting possibility of ٩-٤ moment magnitudes marsquakes. Therefore, Valles Marineris is an important locale of mars quake study that are readily detectable by the upcoming InSight seismometers.

Impact spallation processes on the Moon and Mars

Impact spallation is a fundamental process responsible for formation of ejecta boulders from impact craters but there exist limited geological observations, so far, to test these models. The 3.8 km Censorinus crater on the Moon is being explored using the Lunar Reconnaissance Orbiter Narrow Angle Camera images. The ejecta boulder distribution map with about 242,000 ejecta boulders of different size distribution (both radial and concentric) is prepared. The radial asymmetry of boulder distribution, general decrease of axial ratios away from the crater rim, edge angle and cumulative size–frequency distribution (CSFD) suggests origin in response to the oblique impact and a highly variable fragmentation history. The characteristics of Censorinus boulders are compared positively with the theoretical spallation models sensitive to the lunar target but unable to explain fragmentation and asymmetric distribution in response to the oblique impact. Since, the spallation models accounting oblique impacts have not yet developed, our observations at Censorinus crater can be used to develop and validate the new theoretical spallation models for the effects of oblique impacts.

Identification of new volcanic features on Crisium basin, Moon

Using the LROC/Chandrayaan-1 orbiter data, a dozen areas containing volcanic cones and domes are identified in Crisium basin. The features like volcanic cones, domes, rills, volcanic pits, floor-fractured craters, and concentric craters are catalogued and the morphometric parameters are measured in order to understand their formation mechanism.The work is in progress to understand complete picture on the volcanic history including age determination of Crisium basin.

2. REMOTE SENSING OF EARTH'S RESOURCES AND ENVIRONMENTS

Soil moisture monitoring using RISAT-1 data

Soil moisture is a crucial parameter in the estimation of crop yield, drought forecast, hydrological and climatic studies. Soil moisture retrieval from Synthetic Aperture Radar data is difficult owing to influence of vegetation and roughness in the backscattering signal. An algorithm was developed to eliminate these effects by integrating SAR and optical data and the algorithm was evaluated at Vidharba region, Central India using RISAT-1 (ISRO) Synthetic Aperture Radar (SAR) data at a frequency of 5.35 GHz. The derived soil moisture validated using in-situ soil moisture and compared with the standard Soil Moisture and Ocean Salinity (SMOS) soil moisture product. The soil moisture derived from RISAT-1 correlate well with the ground truth with the correlation of R^2=0.65 and RMSE of 5% (Volumetric). The developed method will be useful to estimate available water content for vegetation continuously.

Hydrological modelling Studies over Ganga River Basin

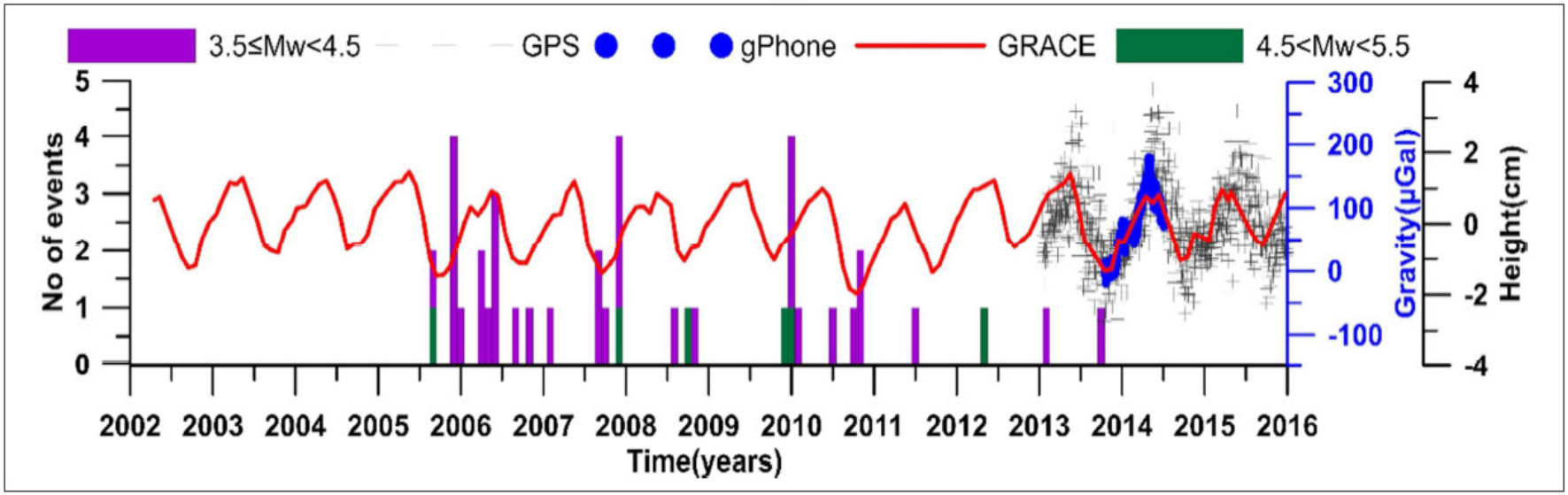
Hydrological modelling addresses the quantification of variables in the Hydrological cycle through a model to understand water budget scenario. Two decades of hydrological data from conventional observation i.e. flow data and water level, and space observations (i.e. Gravity Recovery and Climate Experiment (GRACE), Tropical Rainfall Measuring Mission (TRMM), land imageries and GPS) is being used to model the Hydrological budget of Ganga River Basin (GRB), India. The model considers topography, land use, land cover, soil, and precipitation. The quantification of individual variables in the water cycle using Soil and Water Assesment (SWAT) based distributed approach is carried out, besides addressing the impact of water budgeting at large basin scale. The accuracy of the model is improved by adopting the Total Water Storage (TWS) derived from GRACE, which is difficult to monitor in field conditions.

Satellite-geodesy

a) Koyna-Warna Region (KWR)

Koyna-Warna Region (KWR) is one of the known sites for reservoir triggered seismicity. The continued triggered seismicity over the five decades is restricted to a region of about 600-700 sq. km, which provides a unique opportunity to monitor geophysical anomalies associated with seismicity of the area. Temporal gravity changes recorded by gPhone and GRACE satellite is interpreted in conjunction with seismological,

geodetic (cGPS) observations and groundwater level measurements. GRACE data imply that seasonal vertical deformation due to hydrological loading is ~ 2 cm, which corroborates with continuous GPS observations. Seasonal hydrological loading of the region, which is in a phase of reservoir loading, might be influencing the critically stressed KWR leading to the seasonal seismicity of the region.



Vertical height derived from GRACE during 2002-2015. '+' represents the vertical height obtained from the cGPS data during the period coinciding with the observed gPhone gravity data along with the histogram of some earthquakes with time whose magnitudes are greater than 3.5.

b) Himalaya region

Satellite observations of Earth's time-variable gravity field from the GRACE Satellite Mission represent a new opportunity to explore the feasibility of monitoring Total Water storage variations from space (Rodell and Famiglietti, 2001; Wahr et al., 2004). Short-term variations in gravity on land are mainly due to corresponding changes in vertically integrated terrestrial water Storage (Whar, 1998). GRACE, for the first time, provide insight into mass changes at smaller time scales, i.e. monthly to decadal. The data enable us to monitor the fluxes of water mass changes and exchange of water masses. We use this to our advantage in investigating the glacier mass change monitoring in a highly undulating terrain like the Himalayas. Empirical Orthogonal Function (EOF) analysis is carried out to understand the accumulation mechanism in the Himalayan glaciated region. These results show that east to west accumulation and ablation seasons and mechanism are different. This Study has put boundaries where a particular mechanism stops and another starts, i.e. we have made a hydro-climatic division of Himalaya based on accumulation and ablation during the western disturbance and monsoon seasons. The westerly winter snowfall and late summer accumulation dominate the western region of the Himalaya, whereas the monsoon accumulation dominates the eastern region, and the central Himalaya is a transition zone.

CHAPTER - 20

INDIAN INSTITUTE OF GEOMAGNETISM

NAVI MUMBAI

The Indian Institute of Geomagnetism (IIG) is engaged in research in geomagnetism and allied fields such as aeronomy and several areas of geophysics. The Institute currently operates twelve magnetic observatories across the length and breadth of the country besides the magnetometers at the Indian Antarctic stations, Maitri and Bharati. The magnetic records from these observatories serve as useful tools for the study of ionospheric and magnetospheric current systems under a variety of solar-interplanetary and geomagnetic activity conditions. Near-real time transmission of digital data at one-minute resolution from all these observatories continues to be an important activity that enables continuous real-time monitoring of the space environment of the Earth from a number of locations. Apart from the two regional centres at Tirunelveli and Allahabad, a new regional centre at Shillong took birth on January 18, 2016 with its inauguration by the Honourable Union Minister of Science and Technology & Earth Sciences. This centre will host research activities focused on the seismically vulnerable North-East India with the ultimate objective to build a precursor hierarchy related to large magnitude earthquakes through in-depth understanding of the coupled nature of the dynamic Lithosphere-Atmosphere-Ionosphere system. During the academic year 2016-2017, IIG celebrated 175 years of continuous geomagnetic field observations marked by a series of workshops, seminars training programs and science outreach activities. The year-long celebrations culminated with a valedictory function on February 24, 2017 at the Colaba Observatory complex.

A. MAJOR FACILITIES

Ground geomagnetic measurements provide a unique data base for understanding the phenomena occurring in the geospace. Colaba and Alibag observatories together have the long history of geomagnetic observations from 1841 till date. This historic milestone of 175 years of uninterrupted data from the Colaba-Alibag observatories pair had enabled IIG to compile a data base for the intense and super-intense geomagnetic storms which will be useful in the studies of Sun-Earth connection with significant value to understand and assess their impact on the technologies relevant to the modern hi-tech society.

IIG supports a World Data Centre of Geomagnetism (WDC-Mumbai), which is the only international centre for geomagnetic data in South Asia, and caters to the need of space and Earth scientists, making available worldwide magnetic data in computer readable form. WDC-Mumbai is now a member of the World Data System (WDS) of the International Council for Science. Alibag and Jaipur continue to be part of the International Real time Magnetic Observatory Network (INTERMAGNET).

To understand the Lithosphere-Atmosphere-Ionosphere coupling in terms of the myriad pathways the seismic signals can take and to detect possible precursory signatures of major earthquakes in various geophysical parameters, a suite of instruments like the radon gas monitor, atmospheric electric field mills and Global Navigation Satellite System (GNSS) receivers were deployed in the North-East India and in Andaman region. As part of this study, a new all-sky airglow imager was installed at Silchar, one of the IIG's observatories in the North-East.

For upper atmospheric studies, IIG continues to operate its suite of remote sensing instruments deployed at various sites; the two digital ionosondes (one at Tirunelveli (8.7°E, 77.8°E), the dip equatorial station of IIG, and the other at Allahabad (25.5°N, 81.7°E)), the MF radar at Kolhapur (16.7°N, 74.2°E), all-sky airglow imagers at Tirunelveli, Kolhapur and Silchar and a network of GNSS receivers located at several sites.

The modernization of the in-house built proton precession magnetometer capable of making high quality total magnetic field measurements at an accuracy of 0.1 nT is now complete. A tri-axial Helmoltz coil facility, which was built in-house, was commissioned during this period of report for calibrating magnetometer sensors.

B. SCIENCE RESULTS:

1. ATMOSPHERE AND CLIMATE

A novel information theory technique, namely, the Transfer Entropy, was developed for an assessment of possible drivers of the global temperature variability. Making use of a variety of parameters like measurements of greenhouse gases, volcanic aerosols, solar activity, UV radiation, total solar irradiance, cosmic ray flux, El Nino Southern Oscillation and global temperatures, the primary drivers of the observed temperature anomaly were quantified in terms of their contributions to the observed variations.

A new prediction model was developed to forecast the peak sunspot number of the upcoming sunspot cycle (SC). By using the estimates of Shannon entropy related to the ending phase of the preceding cycle, the model suggests a weaker SC25 with a peak SSN of 63 ± 11.

In an attempt to detect electrical discharge events above thunderstorms, an experiment onboard the International Space station was performed by DTU space through international collaboration that includes IIG scientists. The analysis of the first of their kind observations during the thunderstorm event on September 8, 2015 over the Bay of Bengal showed a multitude of blue, km-scale, discharges at the cloud top layer at ~18 km altitude and a pulsating blue discharge propagating into the stratosphere reaching ~40 km altitude. These optical emissions are related to the so-called blue jets, blue starters and possibly pixies.

Analysis of the satellite data (from the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) and the TIMED Doppler Interferometer (TIDI) on board the Thermosphere Ionosphere Mesosphere Energetics Dynamics (TIMED) satellite) provided several insights of atmospheric tides and their variabilities at altitudes between 80 and 100 km besides yielding a global perspective of the dominant tidal components.

A consistency study with the long-term MF radar observations of winds from Tirunelveli reveals that the diurnal tide in meridional wind as observed from the ground-based platform closely resembles the diurnal migrating tide observed from the satellite platform, whereas the zonal component observed by the radar carries the signatures of both migrating and non-migrating tides.

2. LITHOSPHERE-ATMOSPHERE-IONOSPHERE COUPLING

IIG is now pursuing frontline research in the area of ionospheric seismology making use of InSAR and GPS-TEC data. The post-seismic response of the ionosphere to the Indian Ocean doublet earthquake that occurred on April 11, 2012 was examined. Another case study carried out was for the April 25, 2015 Nepal earthquake from the viewpoints of source directivity, rupture propagation and associated surface deformation over and near the fault plane. The azimuthal directivity of near field-co-seismic ionospheric perturbations was shown to exhibit excellent correlation with east-southeast propagation of earthquake rupture and associated surface deformation. Another study on this earthquake event had led to the inference that the shallow portion of the Main Himalayan Thrust (MHT) towards south neither ruptured during the earthquake, nor did it slip aseismically after the earthquake suggesting the possibility of MHT playing host to future large events.

In another study, an earthquake ionospheric response was inferred from the measurements of VLF signal amplitude propagating in the Earth-ionosphere waveguide during the April 25, 2015 Nepal earthquake. The VLF amplitude anomalies in the data were identified using the terminator time and nighttime fluctuation methods

3. THE IONOSPHERE, MAGNETOSPHERE AND SOLAR-TERRESTRIAL RELATIONSHIP

Theoretical and numerical simulation studies of space plasma processes pursued by IIG scientists provide clues to identify particle acceleration processes in the Earth's magnetosphere. The Cassini spacecraft during an Earth flyby detected electromagnetic ion cyclotron (EMIC) waves and whistler mode chorus in the outer magnetosphere. A study carried out for a specific data set on these waves show that the EMIC waves and to some extent the chorus can resonantly scatter relativistic electrons pushing them into their loss cone and thereby accounting for their loss.

A rare observation of slow electrostatic solitary waves in the Earth's plasma sheet boundary layer (PSBL) by Cluster satellite was successfully modelled using a nonlinear fluid model. The fluid simulations for the observed parameters showed the generation of slow and fast ion acoustic waves, electron acoustic waves and Buneman mode in the PSBL region.

The ionospheric winter and annual anomalies were revisited using the Formosat-3/COSMIC satellite observations during the ascending phase of solar cycle 24.

A new scenario of heliospheric plasma sheet impingement onto the magnetosphere giving rise to relativistic electron dropouts (RED) with possible consequences for climate change was presented. For relativistic electrons with energies greater than 0.6 MeV, a considerable amount of energy is deposited down to altitudes below 30 km. This energy deposition is greater than that of cosmic rays or solar flare particles because of the higher RED flux and also because the deposition takes place in a limited region of space.

A mechanism for the occurrence of a daytime cosmic noise absorption (CNA) event detected using the imaging riometer operated from the Indian Antarctic station, Maitri, was sought in a recent study. In the absence of westward electrojet, this event was suggested to be caused due to the gradient curvature drift of trapped nonrelativistic electrons in the equatorial plane of the Earth's magnetosphere.

Space weather is generally referred to the disturbed weather conditions in the Earth's upper atmosphere and outer space due to energetic phenomena on the Sun such as coronal mass ejections (CME), solar flares, etc. which can have potential effects on satellite orbital position, payload electronics, radiation safety of astronauts, satellite communication and navigation systems, electrical power grids and long distance pipelines on Earth. Due to increasing dependency of the society on technological systems, severe space weather (SvSW) can cause extensive social and economic disruptions in the modern high-technology society. It is therefore important to develop space weather forecasting models that can alert the users ahead about the severity of space weather.

Towards the objective stated above, a scheme for forecasting severe space weather using solar wind velocity (V) and the north-south component of interplanetary magnetic field (IMF B_z) was proposed. A high CME front velocity (sudden increase in V (ΔV) over the background by over 275 km/s) and sufficiently large B_z southward at the time of the increase in V is found to be associated with SvSW (a large negative spike in the product $\Delta V \times B_z$). What is required for triggering a space weather event is an impulsive action of large B_z southward and high ΔV (not merely high V) occurring together.

The March 17, 2015 St. Patrick's day geomagnetic storm event continued to attract interest. The results had revealed that the disturbed electric fields, which comprised of penetration electric fields (PEF) and disturbance dynamo electric fields (DDEF), played a decisive role in the ionospheric storm effects at low latitudes. Comparison of the ionospheric responses in the Asian-Australian and American sectors further reveals that negative storm effects caused by DDEF are intense over the Asian-Australian sector, while the PEFs were more effective in the American sector with their characteristic elevations of hmF2 and EIA intensifications.

The structuring of equatorial spread F (ESF) irregularities during the St. Patrick's day storm was examined using spatial receiver scintillation observations on a 251 MHz radio signal. The study suggests intermediate scale (100 m to few km) irregularities to occur at unusually higher altitudes (>800 km) covering wider longitudinal-latitudinal belt over the Indian region. All-sky imaging observations of OI 630.0 nm from Tirunelveli and Kolhapur during this night provided a glimpse of a peculiar asymmetry in the tilt of the equatorial plasma bubbles (EPBs) with respect to the geomagnetic equator.

Characteristics of ESF irregularities or EPBs and their occurrence pattern over various latitudes (or altitudes) were brought using VHF and L-band scintillations. Theoretical modelling shows that while S4 index for scintillations on a VHF signal recorded at an equatorial station may be greater than 1, the S4 index for scintillations on a VHF signal recorded near the crest of the equatorial ionization anomaly generally does not exceed the value of 1 because the intermediate scale irregularity spectrum at F layer peak near the EIA crest is shallower than that found in the equatorial F layer peak. This also explains the latitudinal distribution of L-band scintillations.

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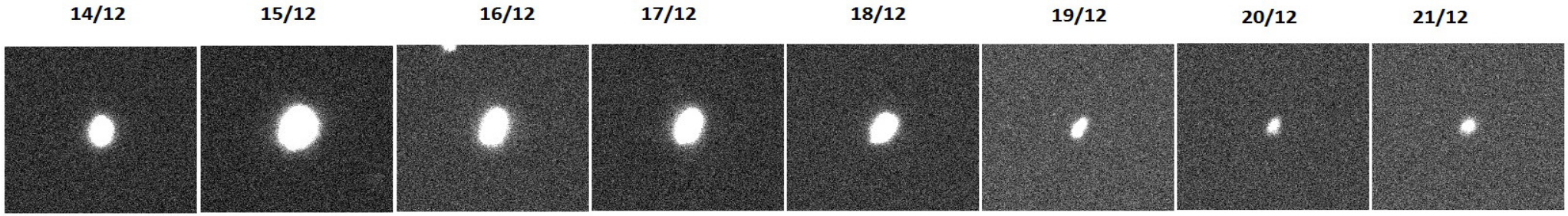
CHAPTER - 21
INDIAN CENTRE FOR SPACE PHYSICS (ICSP)
KOLKATA

Indian Centre for Space Physics is a Government Aided Autonomous Institute established in 1999 and is a Sister Organization of Calcutta University. The fields of research include Optical Astronomy, Ionospheric Science, Earthquake precursors, Astro-chemistry, sources of high energy radiation and their effects on Earth's atmosphere, low cost balloon borne science experiments from near space (~ 42km).

A. MAJOR FACILITY AND INSTRUMENTATION DEVELOPED

Optical astronomy

The Optical Astronomy group recently procured a 0.61m Planewave telescope with several CCD cameras and spectrometer to study exo-planets and GRB afterglows among others. This facility is built at West Medinipur Dist. of West Bengal in the same campus as the Ionospheric and Earthquake research Centre. Recently, the rare proximity of Asteroid Phaethon-3200 was tracked. (Fig. 1).

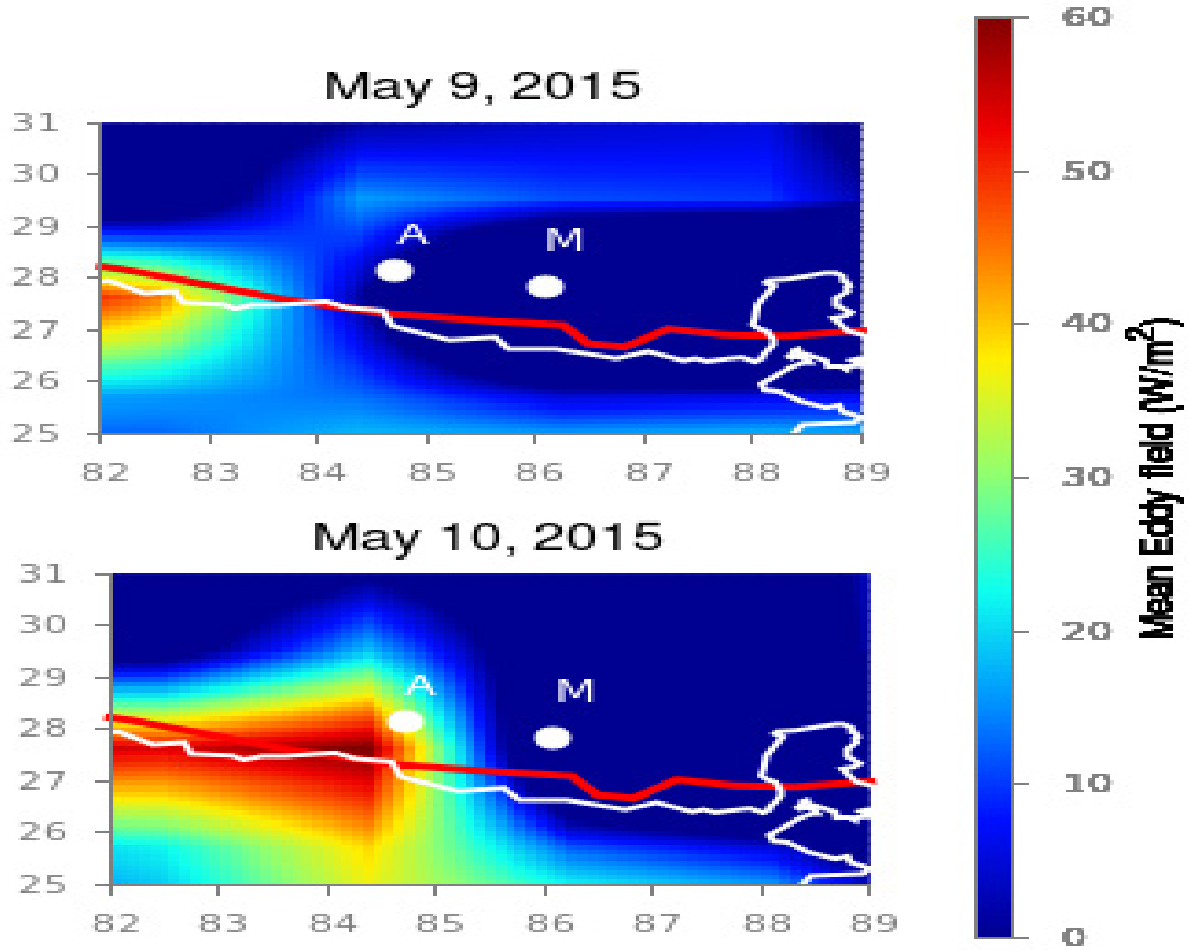


Vasistha (0.61m, L) and Arundhuti (0.25m, R) preparing to look into the sky (above). Phaethon-3200 approaching the earth on Dec. 2017, and returning back (below) in this 10s exposure
Fig 1

B. SCIENCE RESULTS

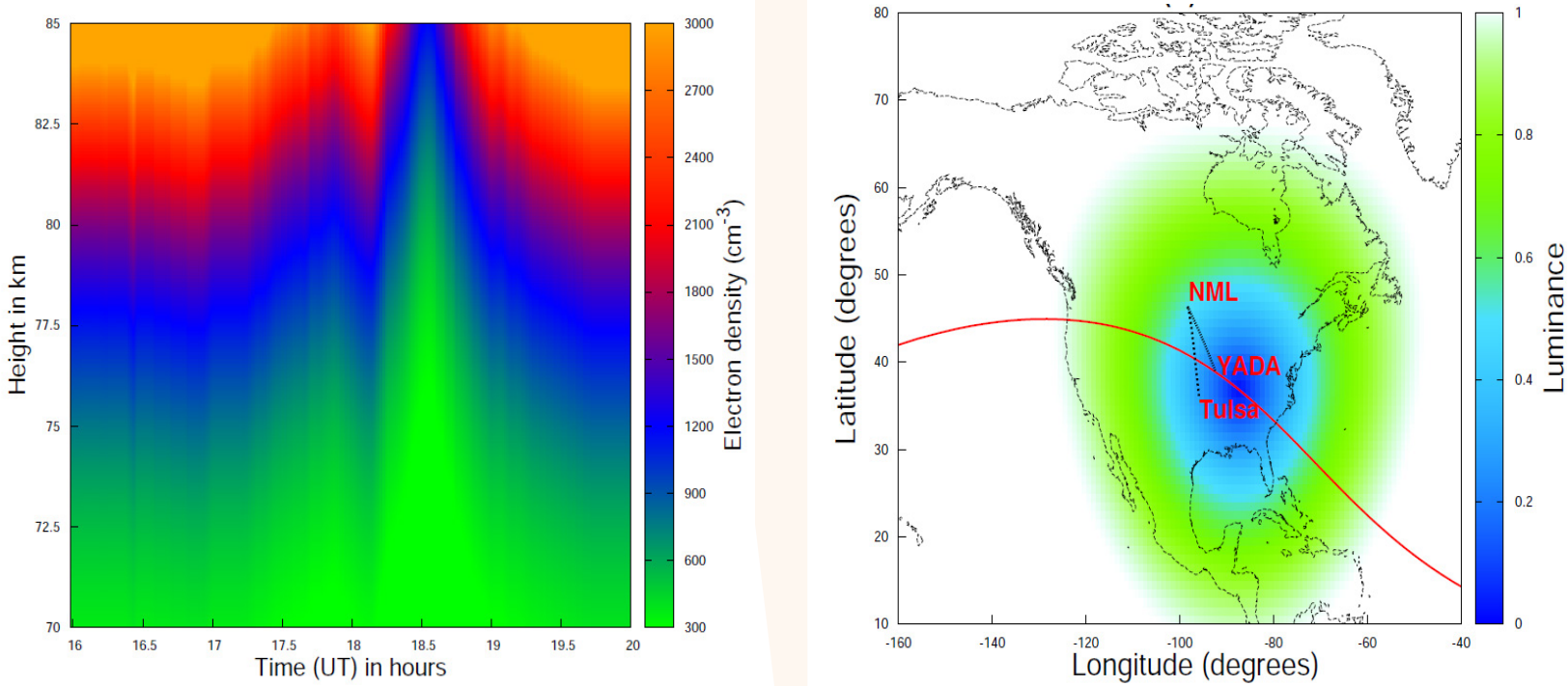
1. IONOSPHERE, MAGNETOSPHERE AND SOLAR-TERRESTRIAL RELATIONSHIP

This study includes study of earthquake precursors using anomalies in Very Low Frequency (VLF) data and other data from satellites. For example, various types of anomalies prior to the great earthquake of Nepal in April, 2015 and May, 2015 were observed. Figure 2 shows the daily Eddy field around the earthquake epicenters marked by A (for April earthquake) and M (for May earthquake). Red curve is the tectonic boundary.



Enhancement of Eddy field on May 10th just two days before the earthquake at Kathmandu in 2015.
Fig 2

During the Total Solar Eclipse of August, 2017 in USA, a solar flare occurred during the totality. The VLF data along various paths (Fig 3a) were analyzed and after computation of electron number density at various heights, the disturbance in the signal due to combined (Eclipse and flare) effects was reproduced (Fig 3b).

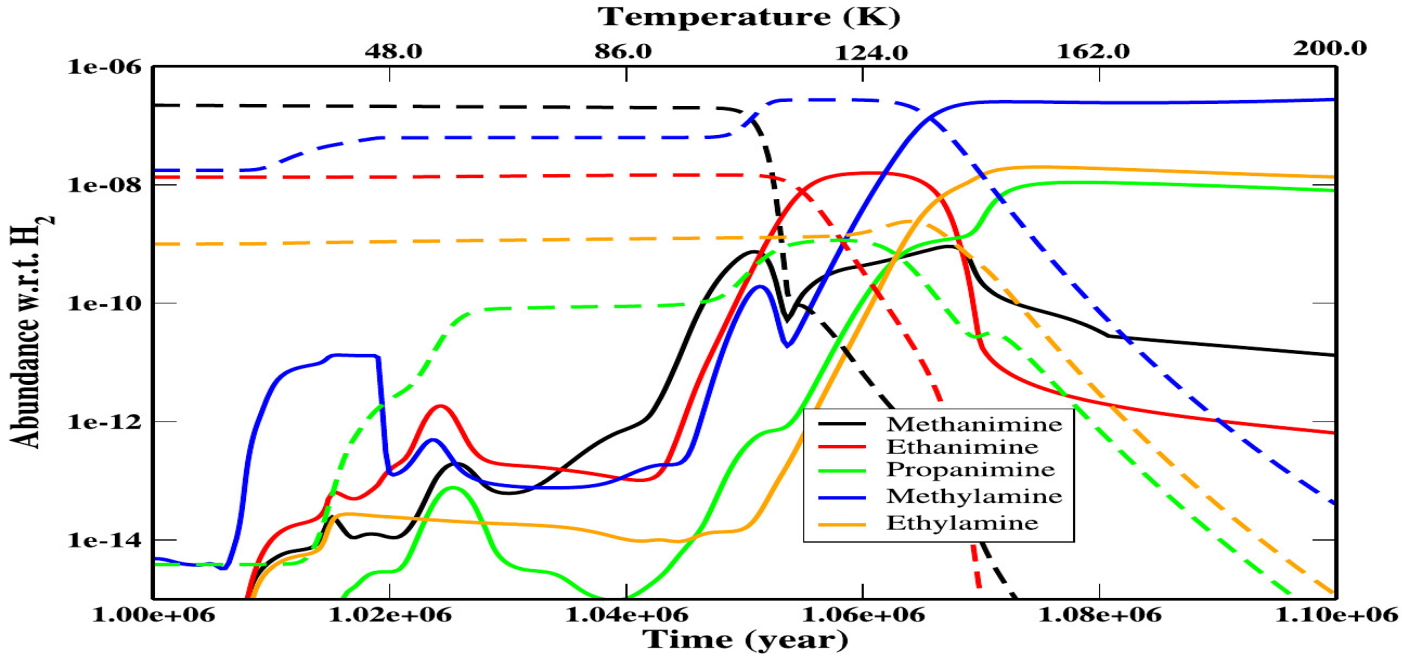


(a) Path of totality of August 2017 in USA along with VLF signal propagation studied. In (b) the electron number density is shown as a function of time (UT) during the eclipse.
Fig 3

2. ASTRONOMY AND ASTROPHYSICS

- **Astrochemistry:**

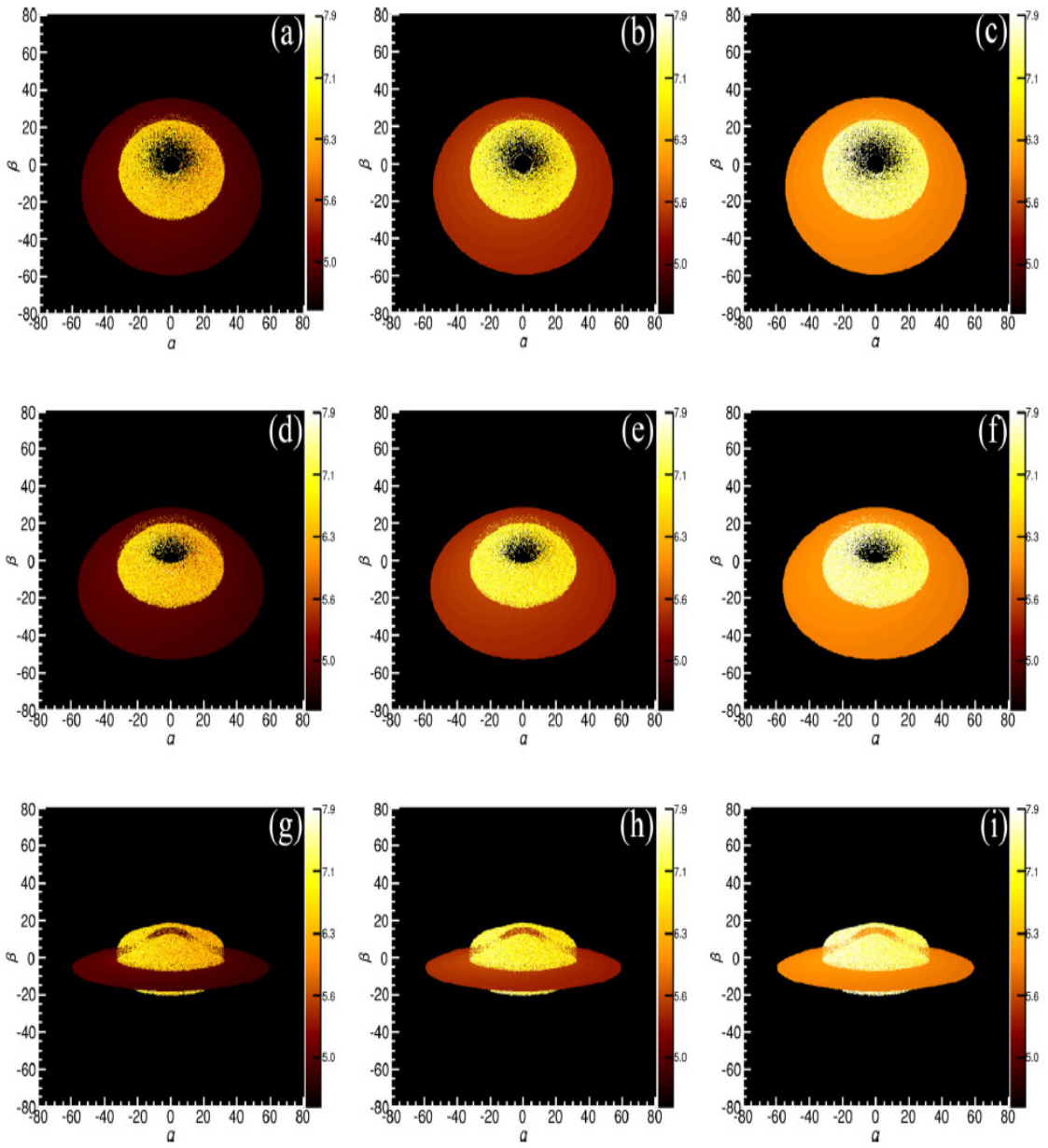
Study the formation of stars is immensely important as this holds the clue to the origin of our presence in the Universe. Various evolutionary stages of the star formation could well be probed with the observation of various molecules. It is a long-standing aspiration to use chemical properties of interstellar species to measure physical properties of the ISM. At ICSP, scientists are engaged in these studies to answer the evolutionary history of the complex bio-molecules in the Interstellar medium and circumstellar disks. Isomeric group investigation is an effective tool to find out the most probable candidate for astronomical detection. We have investigated chemical abundances, spectroscopic details along with LTE and non LTE line parameters of certain amines and aldimines from six isomeric groups (CH3N, CH5N, C2H5N, C2H7N, C3H7N, and C3H9N) to review their presence within the interstellar medium (ISM). (Fig 4) The study finds that 80% of the astronomically observed species have the C-C-O backbone while only 20% have the C-O-C backbone where most of the cases CCO backbone molecules are more stable than COC backbone molecules for a specific isomeric group. Very recently the presence of deuterated formaldehyde (HDCO) in the low mass protostar, HH212 has been reported by ICSP workers.



Chemical evolution of aldimines and amines in warm-up phase for $n_H = 10^7$ cm^{-3}.
Solid lines represent gas phase species, whereas corresponding dashed lines represent ice phase species.
Fig 4

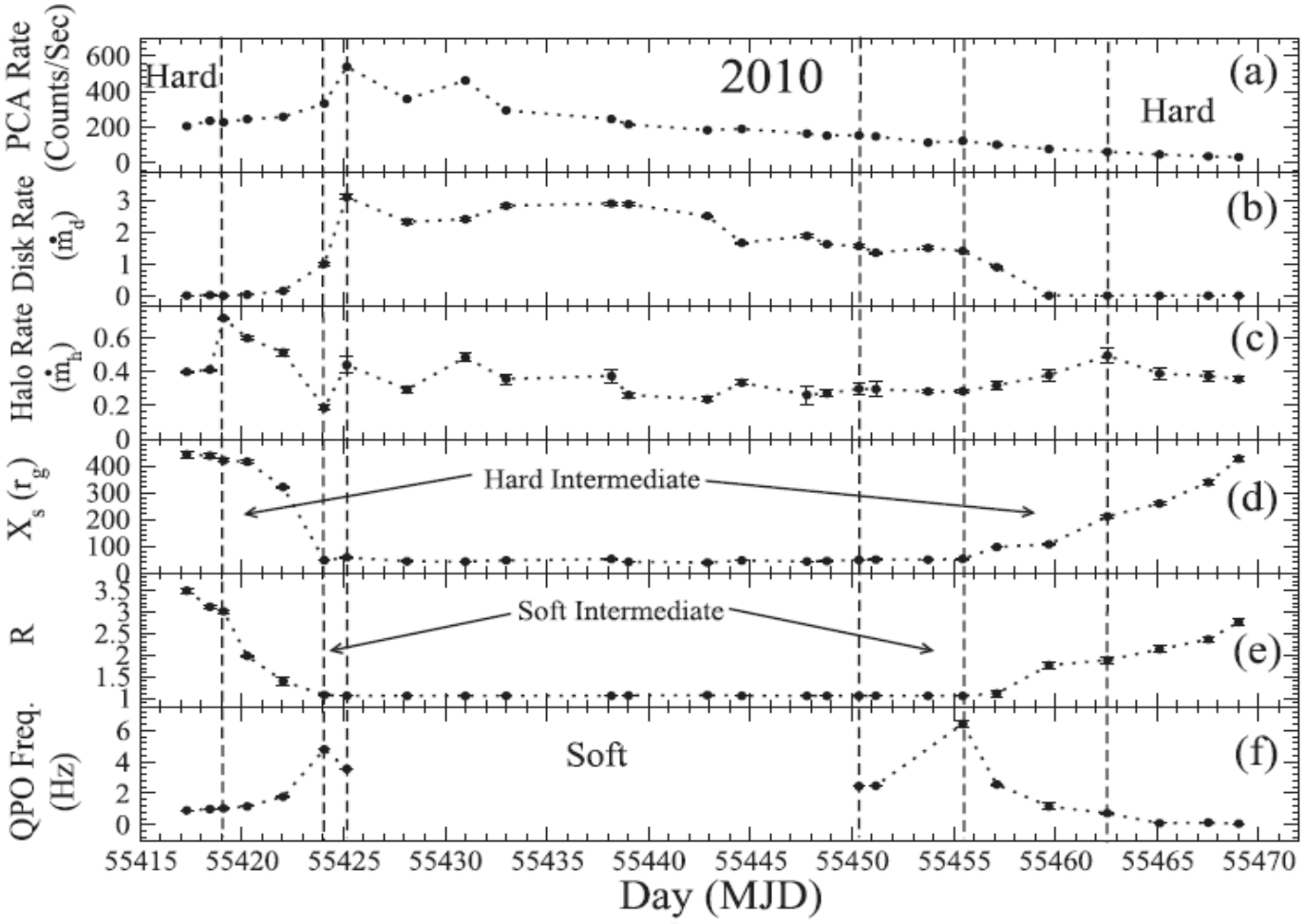
- **Black hole astrophysics:** Model images of accreting black holes using gravitaitonal bending of light

ICSP workers are contributing to the detection of black hole horizon by computing expected images of invisible black holes surrounded by accretion disks. They have successfully computed images of two component advective flows (TCAF). This gives the most accurate description of black hole accretion process to date. In Fig. 5, the expected images are shown. Images of disks along with jets were obtained. Results indicate that disks in soft states when viewed at low inclination angle may allow one to resolve the horizon if the beam width is small enough.



Keplerian disk with a CENBOL surface at the inner edge being viewed in X-rays at 36deg, 50deg and 80deg respectively. At the bottom-left, one can see the Keplerian component through CENBOL.
Fig 5

Two component advective flows (TCAF) model allows successful fitting of X-ray data from satellites. ICSP has implemented this model for usage with NASA software and has fitted several black hole candidate data, especially during outbursts (Fig 6). It gives the accretion rates in Keplerian and sub-Keplerian components as well as the size and optical depth of the hot electron cloud responsible for power-law component. Using TCAF, it has been possible to estimate the mass of the black hole as well as emissions from jets and outflow.



Fits of 2010 outburst of H1743-322 using TCAF solution. Rows from top to bottom are for (a) PCA count rate from RXTE satellite, (b-c) disk and halo rates obtained from TCAF, (d) CENBOL size or shock location, (e) Compression ratio R of the shock. In (f), quasi periodic oscillation frequencies are seen.
Fig 6

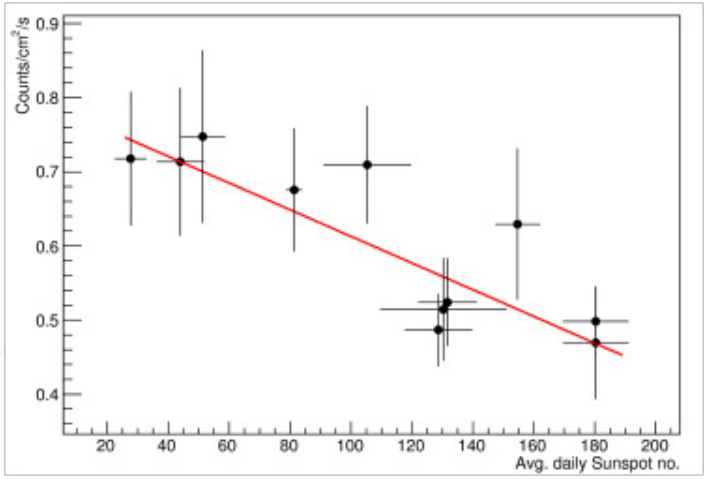
- **Balloon borne studies from Near Space (~ 42km)**

ICSP has completed 109 balloon missions to study cosmic rays, solar flares and occasionally pulsar and gamma ray bursts. Fig 7a shows one of our balloon program related photos.

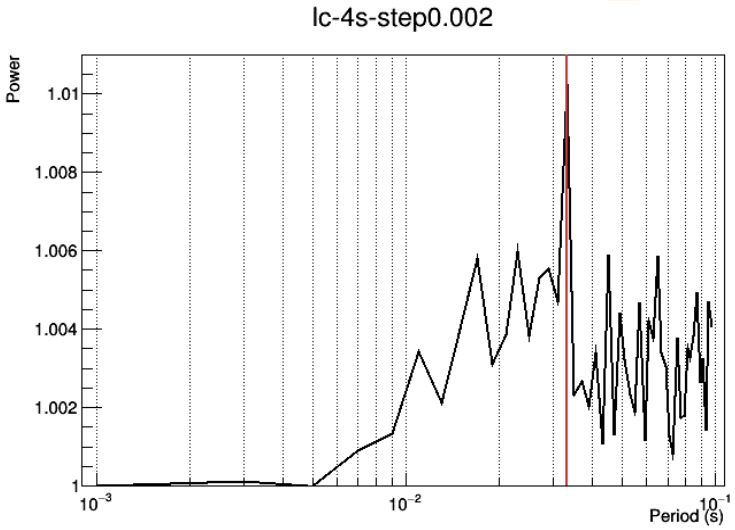
The fully recoverable payload mass is less than 5kg which includes GPS, scintillator detector for X-rays, attitude measurement unit, video cameras and other accessories. Double rubber balloons are preferred for longer flights. The cost of each flight is less than $500 due to recoverability and innovativeness. Light weight TIFR (Hyderabad balloon facility) made 4000 cu.m. balloons have also been used for higher altitudes. So far, equipments have reached to a maximum height of 42 km. ICSP uses 5” phoswich detector, (Fig 7b), 3” (3X3) and 2” (2x3) Scintillator detectors and is compiling cosmic ray spectra and intensity over the years. Fig. 7d shows pulsar localization using our dynamic Degree of freedom (DOF) technique which does not require any pointing device. We have filed applications for three patents on the multi-balloon flying technologies, radio tracking of flying balloons and their recovery, and detection of cosmic sources without pointing device.

Balloons are launched with high school participation
Fig 7a

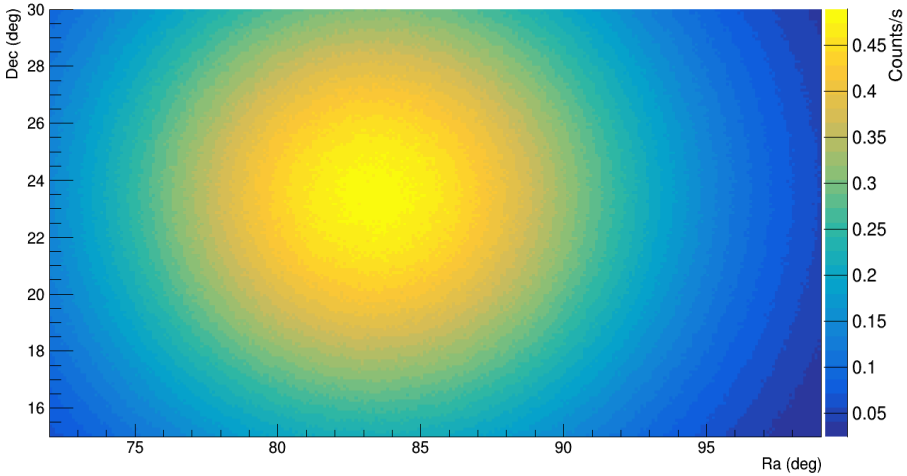
5" dia phoswich detector being tested
Fig 7b



Anticorrelation of cosmicray intensity with solar activity
Fig 7c



Localization of crab pulsar in the sky
Fig 7d



Pulsar period obtained from our data
Fig 7e

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CHAPTER - 22

S.N. BOSE NATIONAL CENTRE FOR BASIC SCIENCES

KOLKATA

S. N. Bose National Centre for Basic Sciences is an Autonomous Institute funded by Department of Science and Technology (DST). The Astrophysics and Cosmology group is engaged in research work on accretion processes on black holes and neutron stars; Satellite Orbit decay; astronomical observations including novae outbursts; Mira variables, and various cosmological problems including origin of dark energy and early universe dynamics.

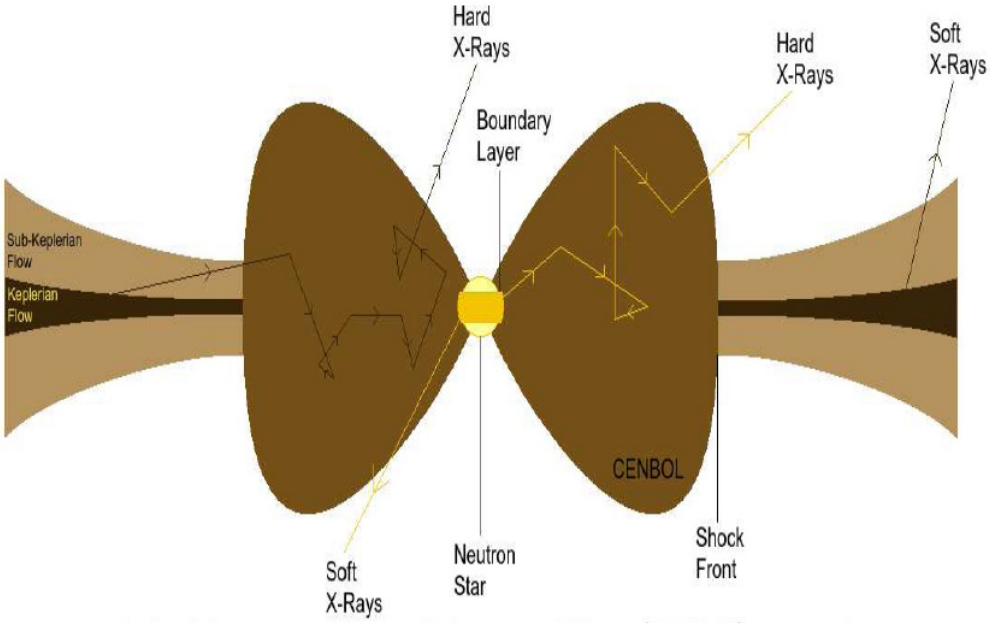
1. ASTRONOMY AND ASTROPHYSICS

ACCRETION PROCESSES ON BLACK HOLES AND NEUTRON STARS

Numerical simulations of accreting matter falling onto a black hole is continued to include the study of the motion of the toroidal flux tubes and their effects on outflow rates and collimation.

In another work, it was shown that when the viscosity is suddenly increased at the outer edge above critical value and then decreased exponentially, the Keplerian disk quickly formed on the equatorial plane, takes a much longer time to dissipate. This is presumably the cause of the hysteresis effect seen in an outburst source.

In neutron stars, the two component advective flow model of Chakrabarti & Titarchuk can be used equally successfully.(Fig 1). Only change required is that one must introduce a normal boundary layer (NBOL) also on the top of the Centrifugal pressure supported boundary layer or CENBOL which is the Compton cloud processing soft photons from the Keplerian disk and NBOL. The computed spectral and timing properties generally match with observational data

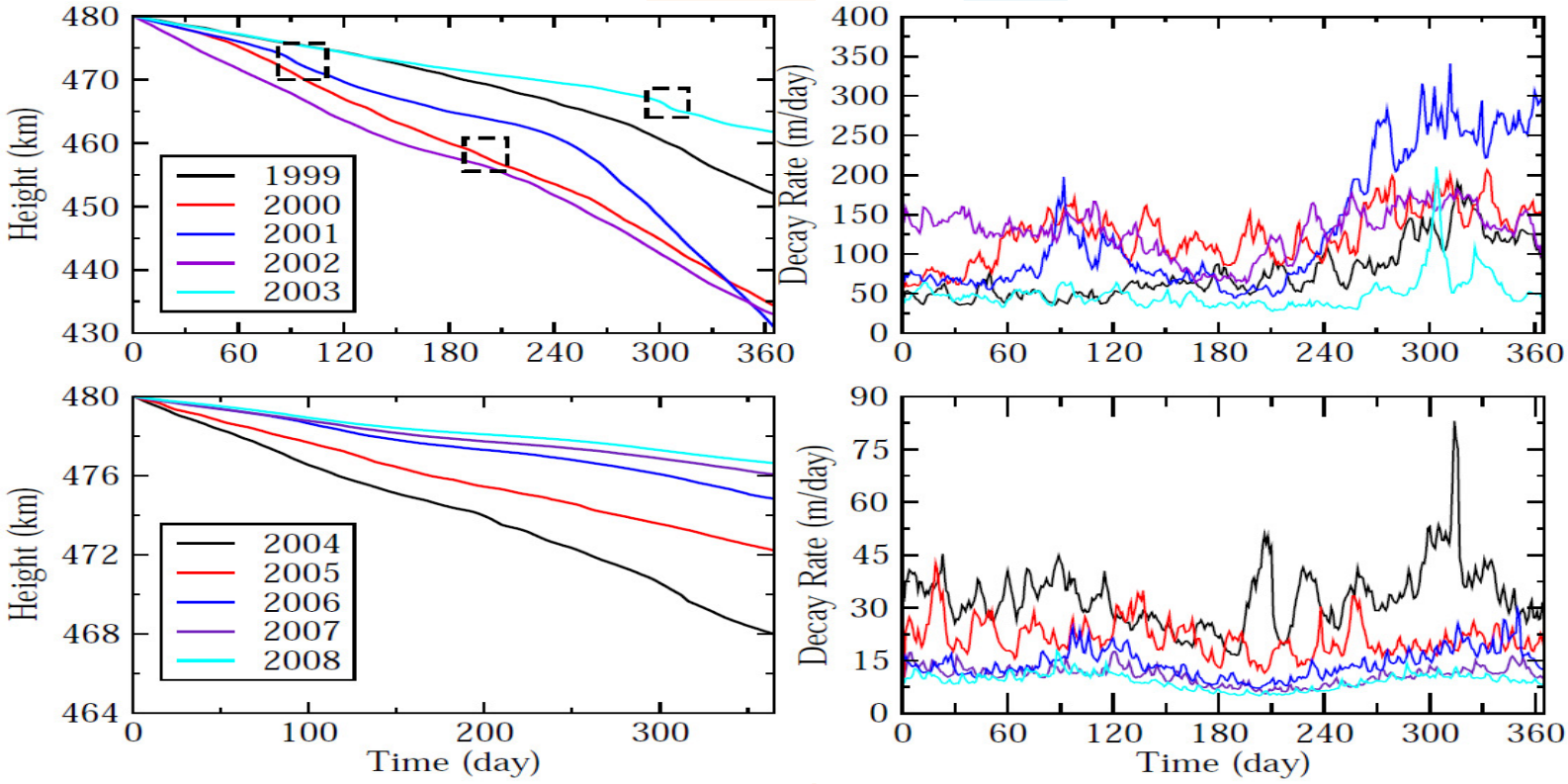


Components of accreting matter on a neutron Star. The dark, thin disk truncated at a shock on the equatorial plane is the high viscosity Keplerian disk, the pale brown advective flow of low angular momentum passes through a shock and behaves as a dynamic corona. For weak magnetic fields, matter touches the neutron Star surface and forms a boundary layer.
Fig 1

2. SOLAR SYSTEM BODIES

- **Effects Of Solar Activity On Satellite Orbits**

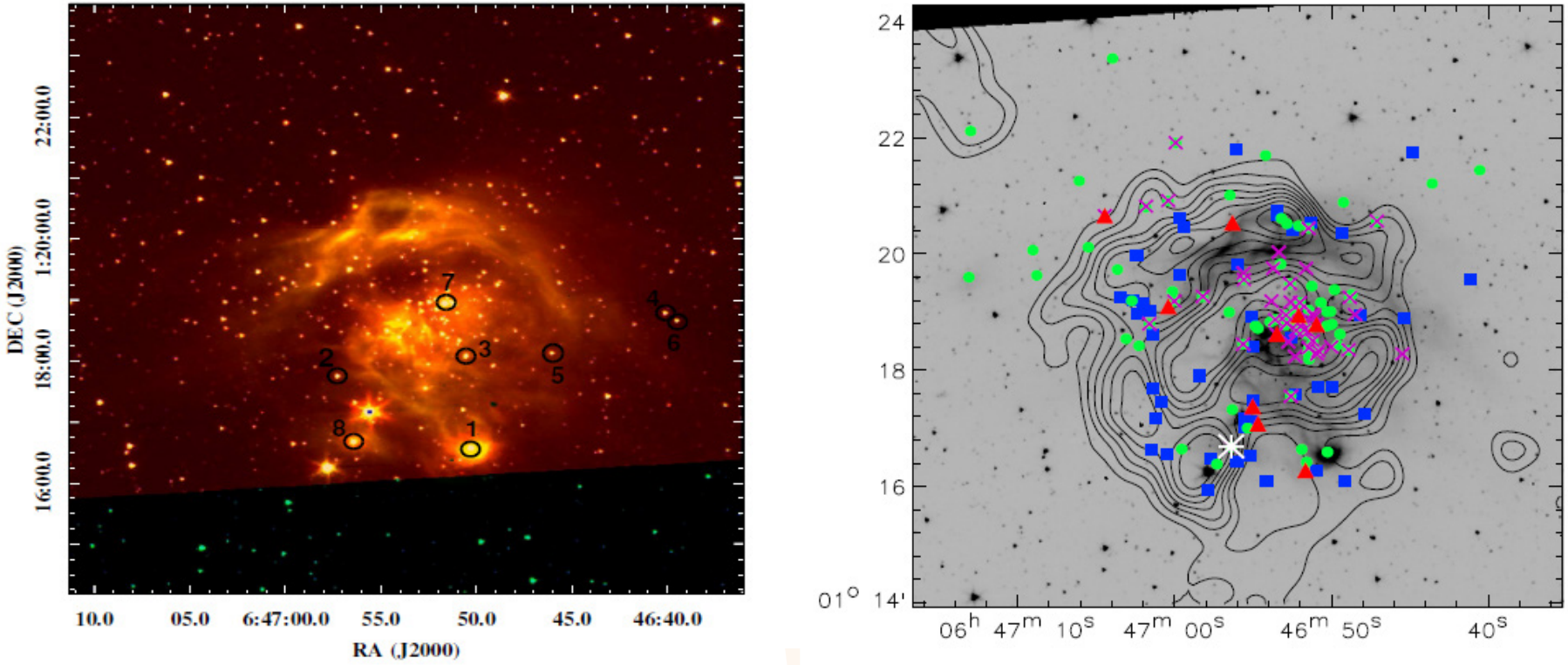
During solar maximum the number of CMEs and other effects reduce the angular momentum of a satellite and cause its orbit to decay rapidly. This is not the case during a solar minimum. We compute daily decay rate of a model LEO satellite for several years, encompassing both the solar maximum and minimum (Fig 2). We also studied how the Mangalyaan mission of ISRO orbit is affected by the atmospheres of the Earth, Mars and during interplanetary passage.



Daily and yearly variation orbital decay of a LEOS due to drags in presence of solar activities. Heights and decay rays are shown.
Fig 2

- **The Young Cluster Ngc 2282 : A Multi-Wavelength Perspective**

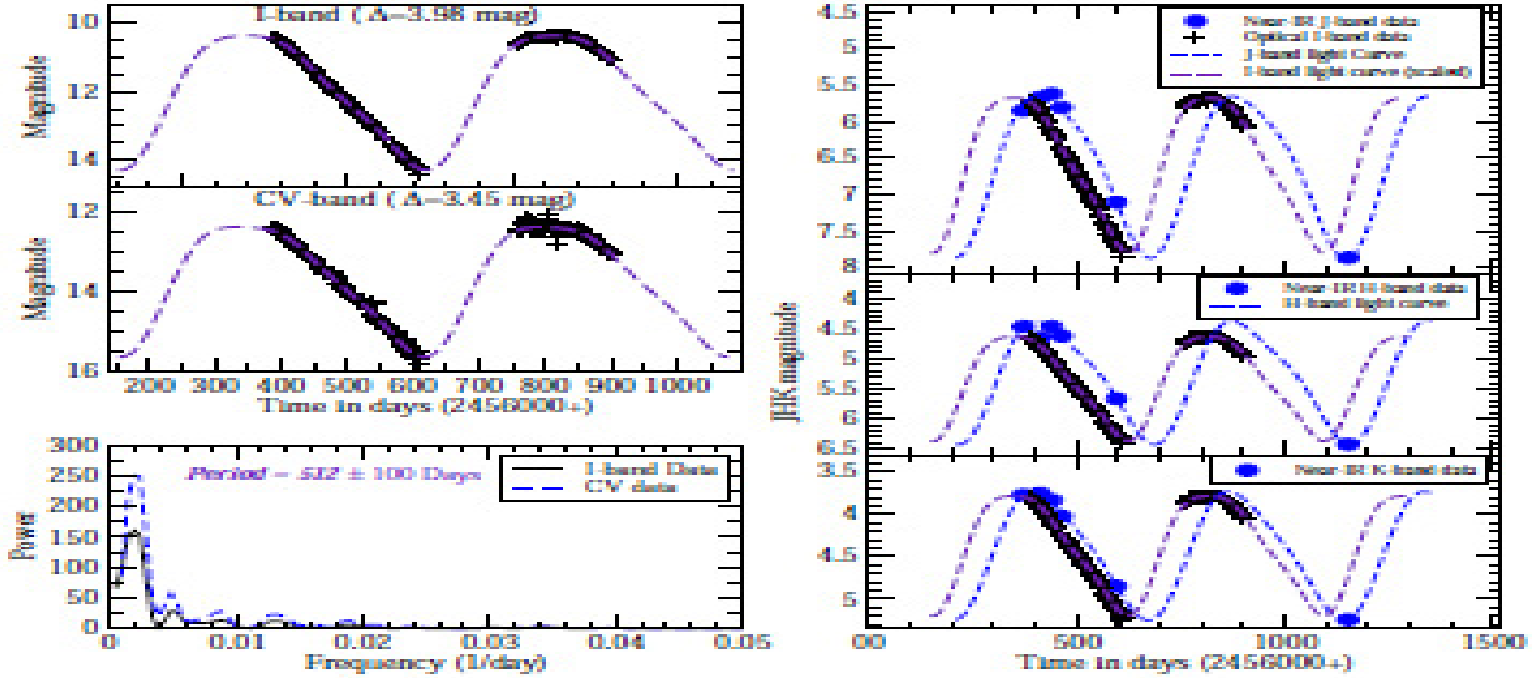
Presentation was made of the stellar content of a young cluster NGC 2282, a young star-forming in *Monoceros* constellation from deep optical to mid-infrared (IR) data from our observations using 1m ARIES telescope and 2m HCT, archival data of 3.8m UKIRT, and space-based mid-IR instrument IRAC on *Spitzer.* From optical spectroscopic analysis of few bright sources, we have identified three early B-type members in the cluster, which help us to constrain the distance to the region. Using IR colour-colour, colour-magnitude diagrams and H-alpha emission properties, we have identified a total of 152 candidate young stellar objects (YSOs) in the region, of which, 75 are classified as class II, and 9 are class I YSOs (Fig 3). The cluster parameters e.g. radial extension, extinction, age including masses and ages of individual YSOs are estimated.



[L] Near-IR Colour composite image of NGC 2282 (blue: K band; green: 3.6 μm; red: 4.5 μm). [R] the spatial distribution of Class I (red triangles), Class II (green circles), candidate YSOs from JHK colours (blue squares) overlaid on IRAC 3.6 μm image. The contours of K-band (2.2 μm) extinction map are over-plotted.
Fig 3

- **Phase Dependent Spectroscopic Studies Of A New Oxygen-Rich Mira Variable From Master Optical Transient J212444.87+321738.3**

A new Mira variable from MASTER Optical Transient (OT) alert on J212444.87+321738.3 (J2124+32) toward the Cygnus is studied. Long-term optical/near-infrared (NIR) photometric and spectroscopic observations to characterize the object was performed. (Fig 4) From the best-fit of optical/NIR light curves, an estimate of the variability period of 465±30 days was found. The strong wavelength-dependent variability amplitudes in the optical to NIR K-band are observed in the range of 4 to 1.5 mag. Interestingly, a phase lag of ~ 60 days between optical and NIR light curves like a Mira variable is also seen. A large NIR (J-K) color-index varies between 1.78 - 2.62 mag over phases, indicates a red object like a cool M-type star. Our optical/NIR spectra show molecular features of TiO, VO, CO overtone and strong water bands, which is a signature of typical oxygen-rich Mira. S- or C-type nature as ZrO bands at 1.03 and 1.06 μm and C_2 band at 1.77 μm are found to be absent. The effective temperature of the object from the SED fit, and distance and luminosity from the Period-Luminosity relations was estimated. A rare data of the phase-dependent optical/NIR spectral studies over several phases show several notable variable features in atomic and molecular lines (e.g., TiO, NaI, Ca I, H_2O and CO bands) as is commonly observed in Miras.

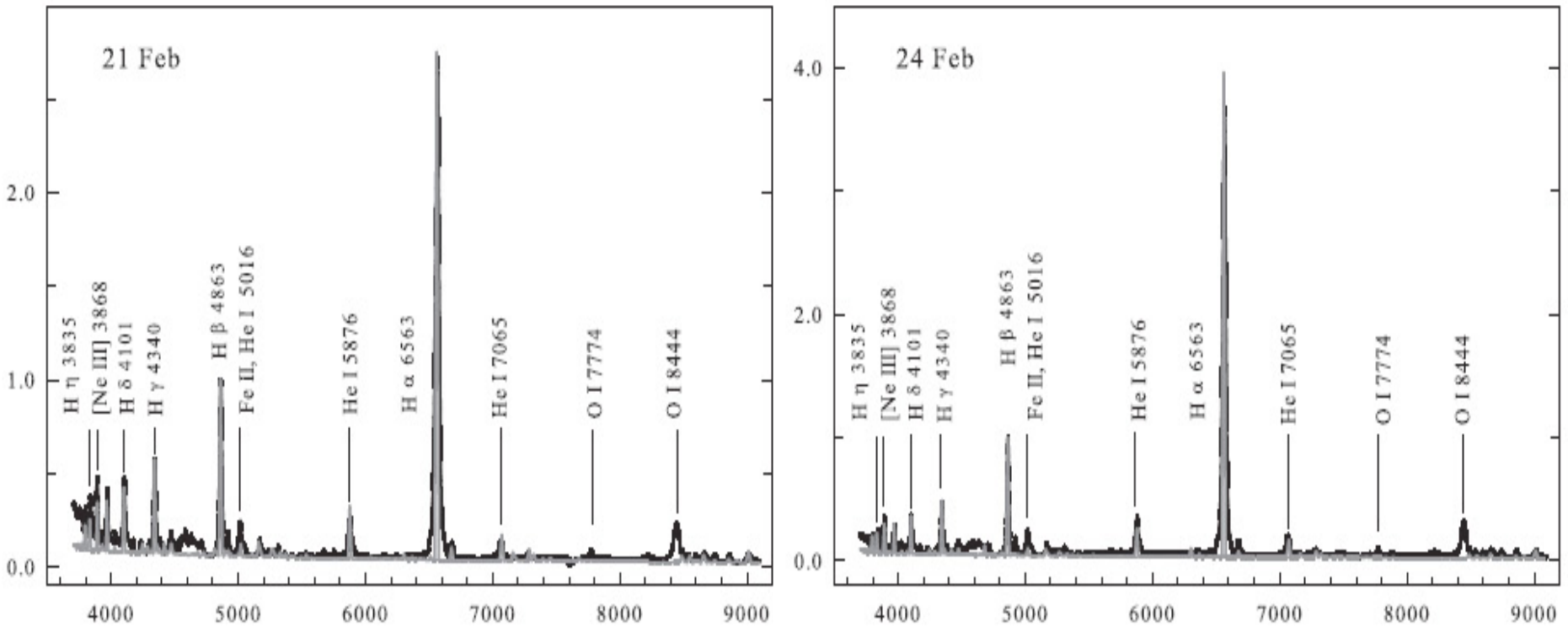


[L] optical/Near-IR light curves and periodgram analysis of optical light curve are shown,

Fig 4

- **Modeling Of Rs Oph Spectra From 2006 Outburst To Quiescence**

Analysis of the optical and infrared data of the well known recurrent nova RS Ophiucus observed during the 2006 outburst and quiescence period was done (Fig 5). The aim was to estimate and understand evolution of the physical parameters of the system. The photoionization code CLOUDY to generate synthetic spectra was used. The best fit model was chosen by using minimization techniqueThe best-fit model parameters are compatible with a hot white dwarf source with black body temperature of 5.5 - 5.8 × 10^5 K and roughly constant a luminosity of 6 - 8 × 10^{36} ergs s^{-1} and the ejecta is significantly enhanced, relative to solar, in helium, nitrogen, neon, iron and argon.



Best Cloudy model (gray line) fit to the observed optical (black lines) of RS Oph observed during the 2006 outburst. The spectra were normalized to H-beta. Also few of the strong features have been marked.
Fig 5

- **Optical And Near Infrared Study Of Dust Forming Nova V2676 Ophiucus**

Analysis has been done of optical spectrophotometric and near-infrared photometric observations of the nova V2676 Oph. The spectra were dominated by strong H I lines from the Balmer series, Fe II, N I, and [O I] lines in the initial days, typical of a Fe II type nova. The measured FWHM for the H

β and Hα lines was 800-1200 km s^{-1}. There was pronounced dust formation starting 90 days after the outburst. The J - K color was the largest among recent dust-forming novae.

- **Modeling And Theoretical Investigation**

A comprehensive grid of NLTE, spherical, hydrostatic model atmospheres using the basic parameters spanning over the probable parameter space appropriate for novae was constructed.

The future evolution of the universe was investigated using the Buchert framework for averaged back reaction in the context of a two-domain partition of the universe. It was shown that this approach allows for the possibility of the global acceleration vanishing at a finite future time, provided that none of the sub-domains accelerate individually

Investigation was made of the emergent universe scenario in the presence of interacting fluids. The non-linear equation of state (EoS) considered in the general theory of relativity for obtaining emergent universe is effectively a cosmological model with a composition of three fluids. In this work, two models were considered to realize viable cosmological scenarios, *viz*., (i) a two-fluid model with interaction of a pressureless fluid with the fluid having the non-linear EoS needed for the emergent universe, and (ii) a three-fluid model with interaction among the three fluids which originate from the EoS of the emergent universe. It is found that realistic cosmological models in accordance with observations are not ruled out for both the above cases

study was made of the effect of quantum statistics on the arrival time distribution of quantum particles computed through the probability current density. It is shown that symmetrization or asymmetrization of the wave function affects the arrival time distribution for even freely propagating particles.

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CHAPTER – 23
RESEARCH ACTIVITIES AT OTHER INSTITUTES AND UNIVERSITIES

This chapter deals with the research activities at various Universities

CHAPTER – 23.1
DEPARTMENT OF PHYSICS
BANARAS HINDU UNIVERSITY
VARANASI

Department of Physics, Institute of Science, Banaras Hindu University (BHU), Varanasi has heritage in Atmospheric and Space Science Research from last few decades. Active research activities have been carried out at the Department of Physics in Atmospheric Physics, Space Physics and Astrophysics. A brief summary of the recent activities during the period 2016-17 are listed below:

A. MAJOR FACILITIES / INSTRUMENTATION DEVELOPED

The Atmospheric Research Laboratory and Detector Development Laboratory are two major laboratories in Department of Physics, BHU which are equipped by various space research facilities. During 2016-17, two High Volume Air samplers: PM10 and PM2.5 are purchased and installed in the Department. The Atmospheric Research Lab is already equipped with two GPS receivers (One Trimble 7400 and one GSV4004B), three VLF receivers: one Automatic whistler detector (AWD); one AWESOME receiver and one SoftPAL VLF receiver for ionospheric and magnetospheric studies. For study of atmospheric aerosol and radiative forcing in Indo-Gangatic basin, a LIDAR for atmospheric measurements and probing (LAMP), a pair of MICROTOPS-II: Sunphotometer and Ozonometer and an Aerosol Spectrometer has been installed at BHU funded by ISRO. Currently there are four major research projects based on Space Physics funded by ISRO, University Grants Commission (UGC) and Department of Science and Technology (DST).

Detector Development group at Banaras Hindu University has been involved in developing a gaseous-based photon detector consisting of a photocathode and micro-pattern detector such as GEM (Gaseous Electron Multiplier) for High Energy Physics research and studies of various detector simulation tools for optimizing the detector performance parameters are carried out. Presently, extension of this technology for space science research is attempted.

B. SCIENCE RESULTS

1. ATMOSPHERE AND CLIMATE

In recent years much interest has developed in the study of atmospheric phenomena controlling biosphere/geosphere due to large variations experienced in climate changes worldwide. Some of the studies undertaken are provided here.

- **Lightning and projected change in climate over the Indian sub-continent:**

The association of lightning activity with the long-term as well as seasonal spatio-temporal distribution of convective available potential energy (CAPE), surface convective precipitation, vegetation cover and anthropogenic aerosol loading over the Indian sub-continent has been studied for the period 2000–2014. The north-east to north-west arc including the foothills of the Himalayas is the primary seat of lightning occurrences. The correlations of lightning activity with each of aerosol loading, vegetation cover, convective instability and convective precipitation helps us in understanding the definite entity that is responsible for changing the lightning activity in different parts of this tropical region. Lightning flash rate (LFR) has positive correlations (r ~0.5–0.7) with AOD, CAPE and surface convective precipitation but significant negative correlation (r ~−0.4)with Normalized Difference Vegetation Index (NDVI). Using global circulation models from the Climate Model Inter-comparison Project Phase 5 (CMIP5), time-series of observed and projected upper tropospheric water vapor, surface convective precipitation and aerosol optical depth (AOD) from the historical simulations (1996–2005) and RCP8.5 emission scenario (2036–2045) are analyzed over the Indian region that are vulnerable to climate change in terms of occurrence of convective events and associated hazardous lightning phenomena. This study indicates that upper tropospheric water vapor (300 hPa) has a significant linkage with the lightning occurrences associated with convective activities and strong updraft. During the mid- 21st century, AOD, surface convective precipitation and specific humidity are projected to increase by 1.42%, 2.01% and 1.40%, respectively which may result in regional changes in lightning activity over the Indian sub-continent.

- **Fireworks induced particle pollution: A spatio-temporal analysis:**

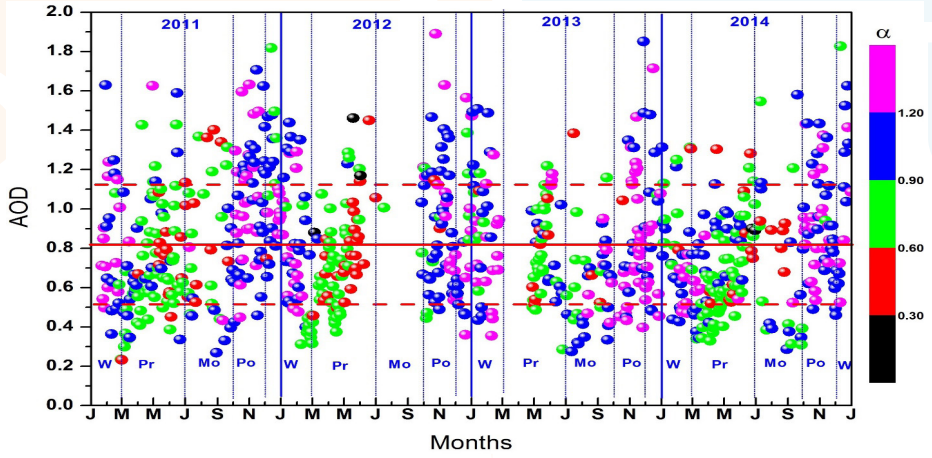
Diwali-specific firework induced particle pollution was measured in terms of aerosol mass loading, type, optical properties and vertical distribution. Entire nation exhibited an increase in particulate concentrations specifically in Indo-Gangetic Plain (IGP). Aerosol surface mass loading at middle IGP revealed an increase of 56–121% during festival days in comparison to their background concentrations. Space-borne measurements (Aqua and Terra-MODIS) typically identified IGP with moderate to high AOD (0.3–0.8) during pre-festive days which transmutes to very high AOD (0.4–1.8) during Diwali-day with accumulation of aerosol fine mode fractions (0.3–1.0). Most of the aerosol surface monitoring stations exhibited increase in PM2.5 especially on Diwali-day while PM10 exhibited increase on subsequent days. Elemental compositions strongly support K, Ba, Sr, Cd, S and P to be considered as firework tracers. The upper and middle IGP revealed dominance of absorbing aerosols (OMI-AI: 0.80–1.40) while CALIPSO altitude-orbit-cross-section profiles established the presence of polluted dust which eventually modified with association of smoke and polluted continental during extreme fireworks. These Diwali-specific observations have implications on associating fireworks induced particle pollution and human health while inclusion of these observations should improve regional air quality model .

- **Aerosol climatology over the Bay of Bengal and Arabian Sea inferred from Space-borne Radiometers and Lidar Observations:**

Atmospheric aerosols over the oceanic region are very important air pollutant and play a vital role in Earth's radiation budget and climate change. This study presents the aerosol climatology over the Bay of Bengal (BoB) and Arabian sea (AS) using long term (2006-2012) data from space-borne radiometers [Moderate-Resolution Imaging Spectroradiometer (MODIS), Ozone Monitoring Instrument (OMI)] and space-based active lidar onboard Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO). AS experiences higher AOD as compared to that over BoB during the study period. A good periodicity along with strong intra-seasonal/annual variability in aerosol loading is also observed over both the study regions. Approximately one month lag is found for maximum aerosol loading period over AS and BoB for almost every year i.e. June – July for AS and May – June for BoB. This lag could be explained by pathway and timing of summer monsoon over the Indian subcontinent. Elevated layers of absorbing dust up to 2-4 km altitudes are observed during the pre-monsoon and monsoon seasons over both the regions. The CALIPSO measurements show strong seasonal heterogeneity in aerosol properties over both the regions, which is well corroborated with MODIS and OMI observations. This significant seasonal heterogeneity in aerosol loading has been explained by the role of transportation of aerosols from various emission sources using NOAA Hybrid Single Particle Lagrangian Integrated Trajectories (HYSPLIT) back trajectory model at three different altitude levels viz. 500, 1500 and 2500 m height.

- **Aerosol characteristic and their heterogenious behaviour over Varanasi: a semi urban location in central Indo Gangetic Basin:**

Atmospheric aerosols, one of the key constituents of the Earth's atmosphere play a vital role in global and regional climate change through their direct, indirect and semi-direct effect. The main scope of the present study is to analyze first time the regular MICROTOPS sunphotometer measurements for long term from January 2011 – December 2014 over Varanasi (25.2 N and 82.9 E, ≈ 83mmsl) and to examine the variability of aerosol on different temporal scale. Figure 1 shows the daily-averaged AOD over Varanasi during 2011-2014.



Variation of daily-averaged AOD_{500} over Varanasi during January 2011-December 2014. The colour scale represents the daily-mean values of the $AE_{380-870}$. The solid red line represents the annual mean, while the dash red lines represent the ± 1σ from the mean.

Fig 1

The seasonal frequency distribution study is also conducted to understand the heterogeneity in aerosol concentrations. This is the first-time study over Varanasi to understand the seasonal variation in aerosol properties and heterogeneity in aerosol types using long data base. The HYSPLIT model is used to identify the sources of aerosol and their transported pathways.

2. IONOSPHERE, MAGNETOSPHERE AND SOLAR TERRESTRIAL RELATIONSHIP

- **A Study on Precursors Leading to Geomagnetic Storms using Artificial Neural Network:**

  Space weather prediction involves advance forecasting of the magnitude and the onset time of major geomagnetic storms at the Earth. An artificial neural network-based model (ANN) to study the precursor leading to intense and moderate geomagnetic storms following halo coronal mass ejection (CME) and related interplanetary (IP) events has been developed. IP inputs were considered within a 5-day time window after the commencement of storm. The artificial neural network (ANN) model training, testing and validation data sets were constructed based on 110 halo CMEs (both full and partial halo and their properties) observed during ascending phase of the 24th solar cycle between 2009 and 2014. The geomagnetic storm occurrence rate from halo CMEs is estimated at a probability of 79% by this model.

- **Ionospheric Irregularities at Low Latitude Using VHF Scintillations during Extreme Low Solar Activity Period:**

  In the present study, we have used 250 MHz radio signal radiated by geostationary satellite UFO-02 to study the occurrence characteristics of very high frequency (VHF) scintillations associated with ionospheric irregularities during recent extreme low solar activity period from 2008 to 2010 at low latitude Indian station Varanasi (Geomag. latitude =14^{o} $55^{/}$ N, long. = 154^{0} E, Dip angle = 37.3^{o}, Sub-ionospheric dip = 34^{0}). The impact of this recent extreme low solar activity period on ionosphere is investigated. It is observed that the scintillation occurrence is low, having maximum percentage occurrence during pre-midnight periods. With increasing interest in understanding the behavior of ionospheric irregularities, an effort has been made to examine also the influence of solar and magnetic activity over the occurrence of scintillations. During the extreme low solar activity years the scintillation occurrences do not vary linearly with the sunspot number. The inhibition and generation of irregularities during enhanced magnetic activity period are explained by considering changes in the electric field. The spectral analysis provide spectral index for irregularities which varied between -1.5 and -8 and characteristic length of irregularities varied between 400 m to 1200 m which confirms that 250 MHz scintillations observed over Varanasi were associated with intermediate scale irregularities.

- **Source Identification of moderate and intense geomagnetic Storms during ascending phase of Solar Cycle 24:**

  The origin of 39 moderate (-100 nT < DsT <-50 nT) and 12 intense (DsT < -100 nT) geomagnetic storms has been investigated using fixed time window and adoptive time window. Coronal mass ejections (CMEs) and corotating interaction region (CIR) are found to be the primary sources. Out of 12 intense geomagnetic storms, 6 (50%) events are associated with unique FSH CMEs, 2 (17%) events with multiple FSH CMEs, 3 events (25%) with partial halo CME with no surface signature and 1 event (8%) is caused due to a CIR. Out of 39 moderate geomagnetic storms 21 (54%) are associated with full halo CME and 5 (13%) with partial halo CME, 4 (10%) storms associated with high speed solar wind from CIR whereas 1 storm has been found to be due to the combined effect of CME and CIR. The remaining 8 (20%) storms have unknown solar origins and were mostly observed when solar activity was at the minimum. The probability of a CIR causing a moderate storm is almost double as compared to an intense storm during the ascending phase of weak solar cycle 24.

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CHAPTER 23.2

BANGALORE UNIVERSITY

BENGALURU

The Department of Physics of Bangalore University, Bengaluru is actively involved both in teaching and research in the areas of Atmospheric and Space Science. The Department is benefited by the ISROs Space Science Promotion Scheme (ISRO-SSPS) towards strengthening of academic and research activities in atmospheric and space science since 2010-11 and a course on Atmospheric and Space Science. Continuous efforts have been made to setup Atmospheric and Space Science Research (ASSR) Lab in the Department of Physics involved in working in the field of atmospheric radioactivity, aerosols, electricity, coupling between tropo-, strato-, and mesosphere, remote sensing, monsoon and its variability, boundary layer, roughness of the Earth's surface, flux exchange in the atmosphere, sun earth relationship, TEC, lightning activities and theoretical simulations. ASSR Lab has major facilities such as Automatic Weather station(AWS), Mini Boundary Layer Mast, Dr Pisharoty GPS Radiosonde balloon launch facility, World Wide Lightning Location Network (WWLLN) from University of Washington, USA for continuous monitoring of lightning flashes around Bengaluru, India.

SCIENCE RESULTS

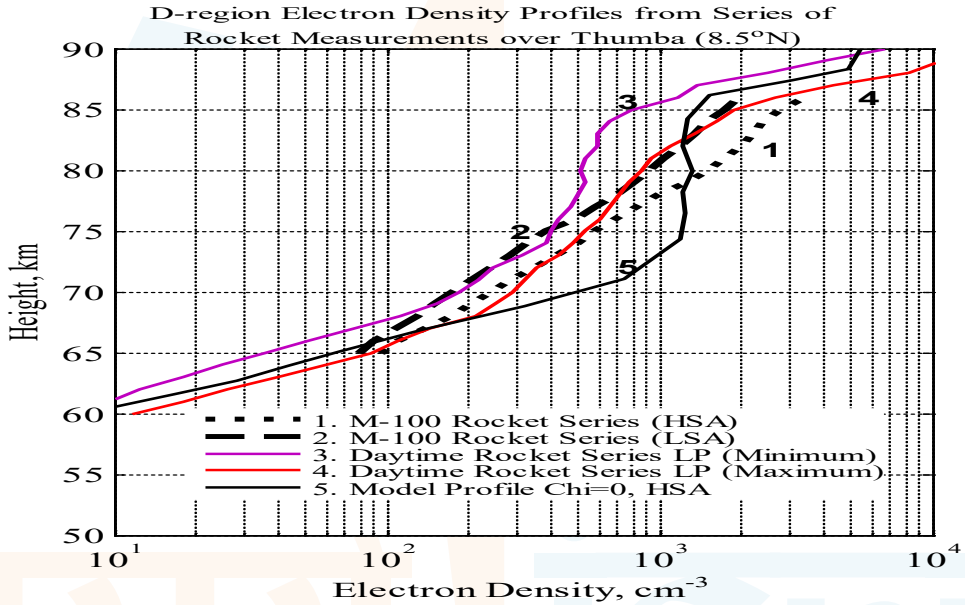
1. ATMOSPHERE AND CLIMATE

- **Variation of D-region ionisation and its effects on VLF radio wave propagation**

The D-region is part of the ionosphere and ranges from 60 to 90 km. Unlike E- and F- regions of the ionosphere where the plasma dynamics is controlled by the earth's magnetic and electric fields, the D-region plasma is more bound to the denser neutral atmosphere so that up to about 70-80 km the medium can be considered as isotropic. The D-region ionisation is the result of the interaction of solar EUV, X-ray and energetic charged particle radiations with the atmospheric molecular constituents like O_2, N_2 and NO.

A series of M-100 rockets carrying a version of Langmuir Probe (LP) were launched around 1600 hr at weekly interval from the Thumba Equatorial Rocket Launching station (TERLS) located at the geomagnetic equator (8.5° N, 76.9° E) during low sunspot years, 1984-86, and high sunspot years, 1979-80. Also over a period 1966-78 a number of Indian made rockets carrying LP were launched from Thumba during daytime covering low and high solar activity periods. Figure-1 shows the mean plots of D-region electron density profiles from these data published using 40 and 12 rockets respectively. For comparison the electron density profile generated using model calculation of the ion

production rates (χ=0) and the effective recombination coefficients is also shown. The VLF signals are very sensitive to the electron density variations in the height region below 80-85 km. It is seen from the figure that while the model average profile shows small variations in this range, the observed profiles show considerable variations. This needs to be kept in mind before interpreting day time signal variations due to the occurrence of solar or geophysical related events like solar flares, TLE/TRIMPI, Sprites/Elves, transit of stellar X-ray/γ-ray sources, earthquakes etc.

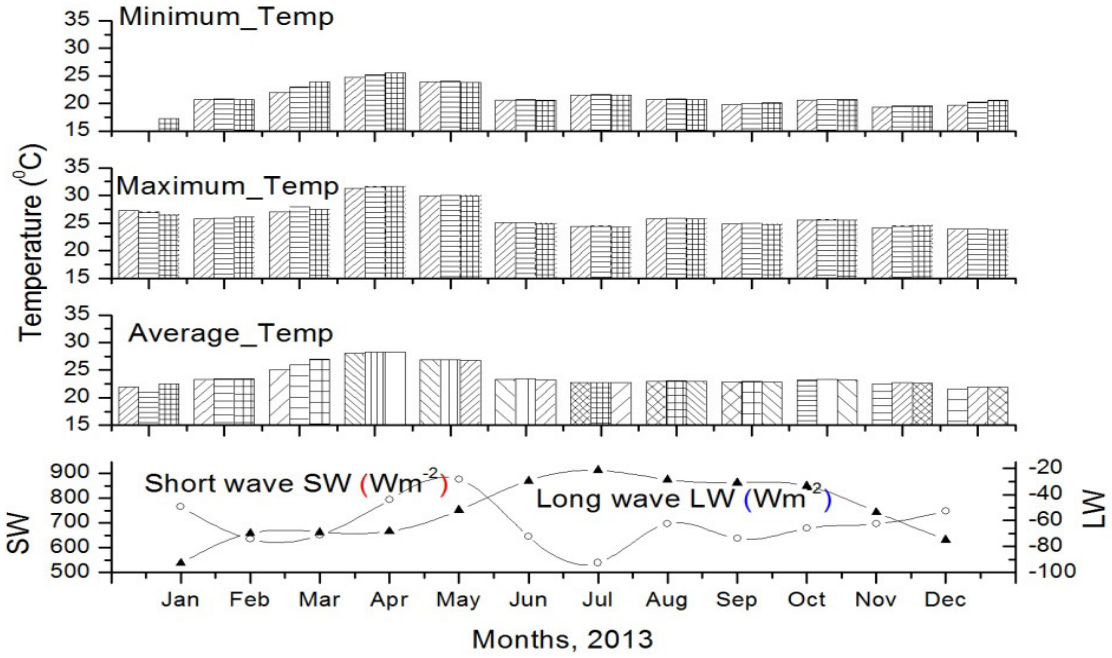


Variation of day time D-region mean electron density profiles from rocket flights

Fig 1

- **Short and long wave radiation over Bengaluru**

The surface radiative energy remains the primary component of the energy balance of the earth atmosphere system and is a central determinant of the earth's climate. One-year data is used to emphasize the separate contribution of each radiation balance component. The analysis shows important results such as the relevance of the short wave radiation in the net radiation budget especially in the wet season and the variations of the long wave radiation. The monthly statistical variation of temperature at 4, 8 and 15m and short/long-wave radiation for one year is shown in Fig. 2. The temperature is more or less constant throughout the year except during March, April and May. It shows that the year shown does not have any extreme weather conditions. Similar behaviour is found with incoming short wave radiation and is due to the geometry of earth and sun. However, the outgoing long wave radiation is considerably more during June to September and it evident of monsoon over the region.



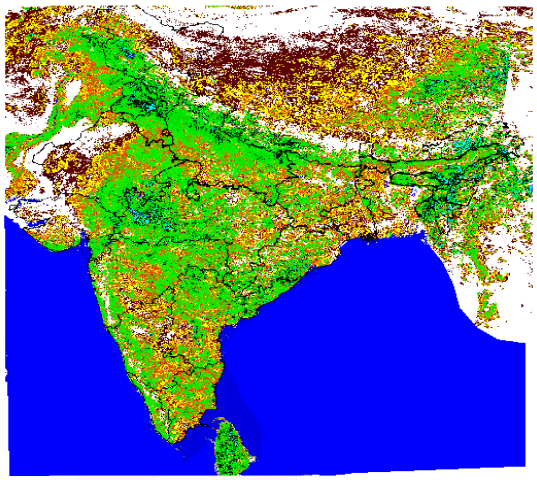
Variation of temperature for different height and short and long wave radiation

Fig 2

Continuous observations were made by making use of pyranometer and Pyrgeometer for incoming solar radiation and the radiation emitted by the Earth's surface for two years. The link between the earth's atmospheric temperature with short and/or long wave radiation and their correlations were studied in detail. The temperature at the surface shows correlation of 20%, 29% and 36% with shortwave, longwave and net radiation, respectively. It suggests that the temperature is mainly by the radiation energy budget of the Earth and it atmosphere.

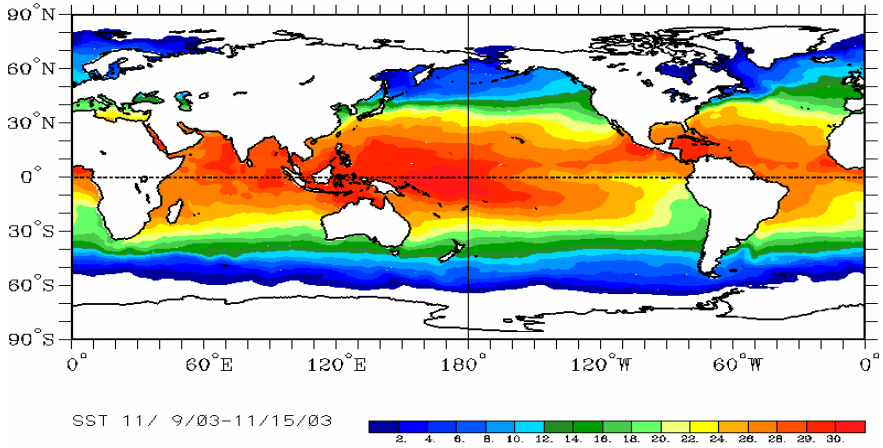
- **Role of Satellite Data in Climate Change Study**

The process of climate change is complex and needs to be understood well so that appropriate combative measures can be taken up. Climate change assessment needs long term series of observations of many parameters pertaining to ocean and atmosphere. The in situ observations alone cannot meet this requirement and there is need to supplement with satellite based observations which give repetitive and synoptic coverage. The INSAT and IRS satellites in early 1980s heralded the era of Space observations in India. The IRS satellites are providing primarily observations on land based parameters such as land use/cover, forest, water bodies, biodiversity, snow/glaciers etc. while INSAT provides quantitative products such as Cloud Motion Vectors (CMVs), Quantitative Precipitation Estimates (QPEs), Outgoing Long-wave Radiation (OLR), Vertical Temperature Profiles (VTPRs), Sea Surface Temperature.



Vegetation dynamics through NDVI
Fig 3

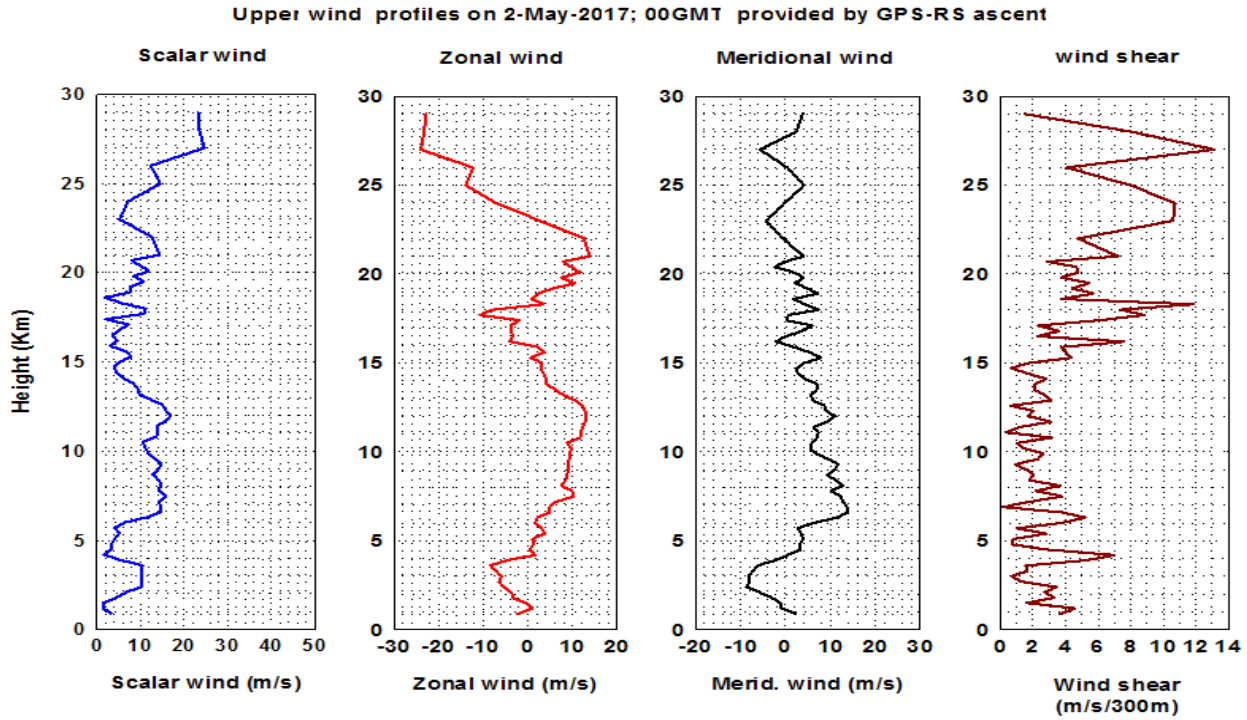
The Normalized Difference Vegetation Index (NDVI) is computed using NIR and Red satellite radiances and is sensitive to rainfall and reflects the anomaly in rainfall and vegetation response is shown in Fig 3. A long term database of 30 years is available for the countryOcean temperatures play a very crucial role in the Indian Monsoon and in the ocean productivity in terms of fishery potential and chlorophyll production. The satellite data from NOAA and INSAT geostationary satellite is used to prepare weekly Sea Surface Temperature maps is shown in Fig 4. The accuracy achieved is in the range of ± 0.5^{0}C. These maps form the basic data for analysis of El Nino/La Nina conditions in Pacific Ocean and Cyclogenesis conditions in the Indian oceans.



Global Sea Surface Temperature using NOAA data
Fig 4

- **Upper air observations over Bengaluru from GPS Radiosonde ascents**

The status of atmosphere is indicated in terms of atmospheric T, P, RH and winds. To know the vertical status of these atmospheric parameters, it is customary to have balloon borne radiosonde observations over a region. These parameters are of variable nature in time. Hence to understand the temporal variations in the upper atmospheric circulation features in terms of temperature, pressure and relative humidity, it is necessary to have periodical radiosonde observations. These data sets can be assimilated in numerical weather prediction inputs to know the future state of atmosphere. In connection with the launches from SDSC-SHAR, parallel GPS-RS ascents were carried out from Bangalore University campus (12.94N, 77.51E, 840m asl) to facilitate the 00and 12GMT atmospheric profiles for assimilation in NWP runs to obtain the weather predictions and typical variation for one day is shown in Fig 5. This input of GPS ascents over Bengaluru will provide the possible impact of Bengaluru weather over SHAR. The GPS-RS and related data obtained over Bengaluru University has been provided during 3-launch campaigns of GSLV-F09 (5 May 2017), GSLV-Mk3-D1 (5 June 2017) and PSLV-C38 (23 June 2017).



Upper wind profiles by GPS-RS ascent on 2 May 2017 of 00 GM
Fig 5

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CHAPTER 23.3

CENTRE FOR ATMOSPHERIC STUDIES, DIBRUGARH UNIVERSITY

DIBRUGARH

The Centre for Atmospheric studies, Dibrugarh University carries out research exclusively in the areas of Space and Atmospheric Sciences. The focus has been the characterization of the low latitude ionosphere through observation and modelling.

A. MAJOR FACILITIES/INSTRUMENTATION DEVELOPED

The centre in collaboration with SAMEER, Mumbai has developed an indigenous digital ionosonde which is currently under field trial in Dibrugah from November 2016.

Infrastructural facilities for conducting Atmospheric Science studies primarily aimed at characterization of surface and columnar aerosols and its impact on the regional climate were established in the last decade. The study on ozone and precursor gases is also a part of current research activities of the centre. In addition, a GPS TEC and scintillation monitor and an ionosonde are in operation since 2009 and 2010 respectively.The centre operates a meridional chain of three GNSS receiver stations (including Dibrugarh, Kohima and Aizwal) since January 2015.

B. SCIENCE RESULTS

1. ATMOSPHERE AND CLIMATE

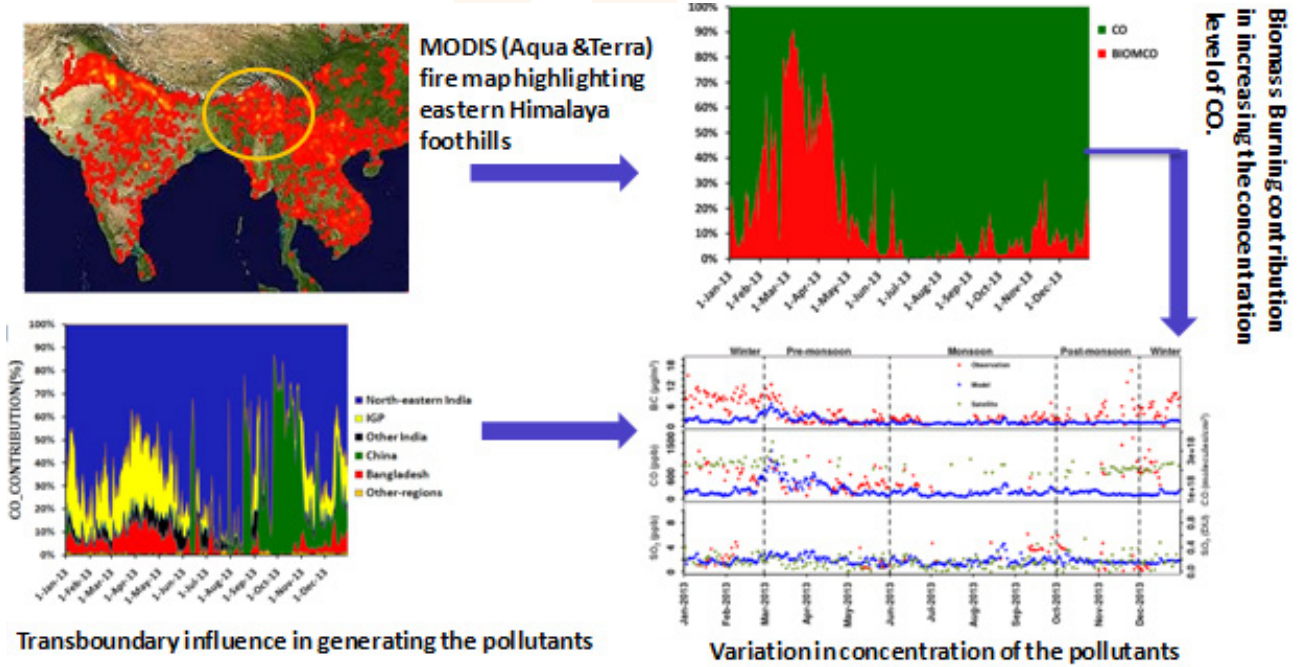
- **Aerosols characteristics, trends and their climatic implications over North-East India and adjoining South-Asia**

  Aerosol characteristics and climatic implications derived for selected locations of the North-Eastern Region (NER) of India and adjoining locations between 22-30°N and 88-98°E are examined. MODIS Level-3 Collection 6 AOD_{550} and Ångström exponent (AE) exhibit a significant and simultaneous increasing trend in the range of ~0.003 $year^{-1}$ to 0.012 $year^{-1}$ and ~-0.001 $year^{-1}$ to 0.020 $year^{1}$ during the period 2001-2014. Together with AE, increasing trend of TOMS and OMI retrieved aerosol index (AI) (~0.001 $year^{-1}$ to 0.007 $year^{-1}$ during 1979-2014) signifies an increase in anthropogenic aerosol loading, leading to an increase in number density of cloud condensation nuclei (CCN) and decrease/

increase of cloud effective radius (CER)/cloud optical depth (COD). This is further associated with overall decreasing trends of rainfall rate (RR) over this complex monsoon region. A slow increase in maximum temperature (T_{MAX}) (~0.008°C year^{-1} to 0.049°C year^{-1}) compared to that in minimum temperature (T_{MIN}) (~0.007°C year^{-1} to 0.068°C year^{-1}) is attributed to solar dimming due to increasing aerosol loading and COD (~0.056 year^{-1} to 0.15 year^{-1}). A decrease in high-level cloud (COD_{HIGH}) counteracts decreasing trends of ground reaching solar radiation over a few locations, including Dibrugarh. This study is important from aerosol radiation interaction (ARI) and aerosol cloud interaction (ACI) viewpoint, which facilitates in reaching a closure of model simulated present day climate change and future climate projections.

- **Assessment of air pollutants over the eastern Himalaya foothills: a study using surface observations, air quality model and satellite data**

Rapid urbanization and land-use changes, particularly in South Asia, have led to a gradual increase in air pollutant concentrations that affect both the climate and human health. Understanding their causes, effect and sources is important, and the Sulfur Transport and Deposition Model (STEM) was used for the first time to study the distribution of pollutants at temporal scales and their association with meteorology. The model simulations along with measured parameters using ground based analyzers, including MODIS fire count map have been presented in Figure 1.



MODIS fire count map over South Asia (top left panel), WRF-STEM-simulated total CO versus biomass burning CO (BIOMCO) percentage contribution over Dibrugarh during the year 2013 (top right panel), Annual anthropogenic CO loading over Dibrugarh from transportation from different regions, 2013 (bottom left panel) and Daily variation of observation, satellite-retrieved and model-simulated BC, CO and SO2 over Dibrugarh for the year 2013.

Fig 1

Model-simulated carbon monoxide (CO) and black carbon (BC) captured the seasonality of the surface-measured CO and BC during the pre-monsoon season, but with differences in magnitude. Model-simulated CO and BC concentrations in monsoon, post-monsoon and winter seasons, however, were considerably lower than the surface measurement. Thus the model under prediction may be associated with inadequate emission inventories and uncertainties in the parameterization schemes used, and it failed to capture the real atmospheric conditions of this geographically and topographically complex region. In contrast, the weather research and forecasting (WRF) model was successful in simulating the seasonality and magnitude of the meteorological variables of the surface measurements. The daily variation in CO and SO_2 retrieved from the Measurements of Pollution in the Troposphere (MOPITT) and Ozone Monitoring Instrument (OMI) satellites was used to understand the behaviour of the pollutants and to interpret the result when there was a gap in the surface measurement. Observations and model showed elevated CO and BC during the dry months November–March, with the highest daily averaged value of 1632 ppb (observations) and 1295 ppb (model) for CO and 16.6 μg m^{-3} (observations) and 6.79 μg m^{-3} (model) for BC in November. The maximum observed SO_2 was around 6.5 ppb during the monsoon. The model-simulated SO_2 was able topredict the measured lower concentration values, while the satellite-retrieved SO_2 data were below the lower detection limit. Thus, there was no systematic variation in SO_2 throughout the analysis period, implying the unavailability of any significant seasonal emission sources. The observed peak values of SO_2 in certain periods indicated that emission was very local and near to the monitoring site. A region-tagged CO tracer was used to observe the trans-boundary inflow of the pollutant and CO loading over Dibrugarh. Evaluation of the biomass burning (BB) contribution of CO was based on model simulation and showed elevated levels during the pre-monsoon season. Species–species correlation was used to identify the source of emissions, where BC–CO was found to correlate better than BC–SO_2 and CO–SO_2.

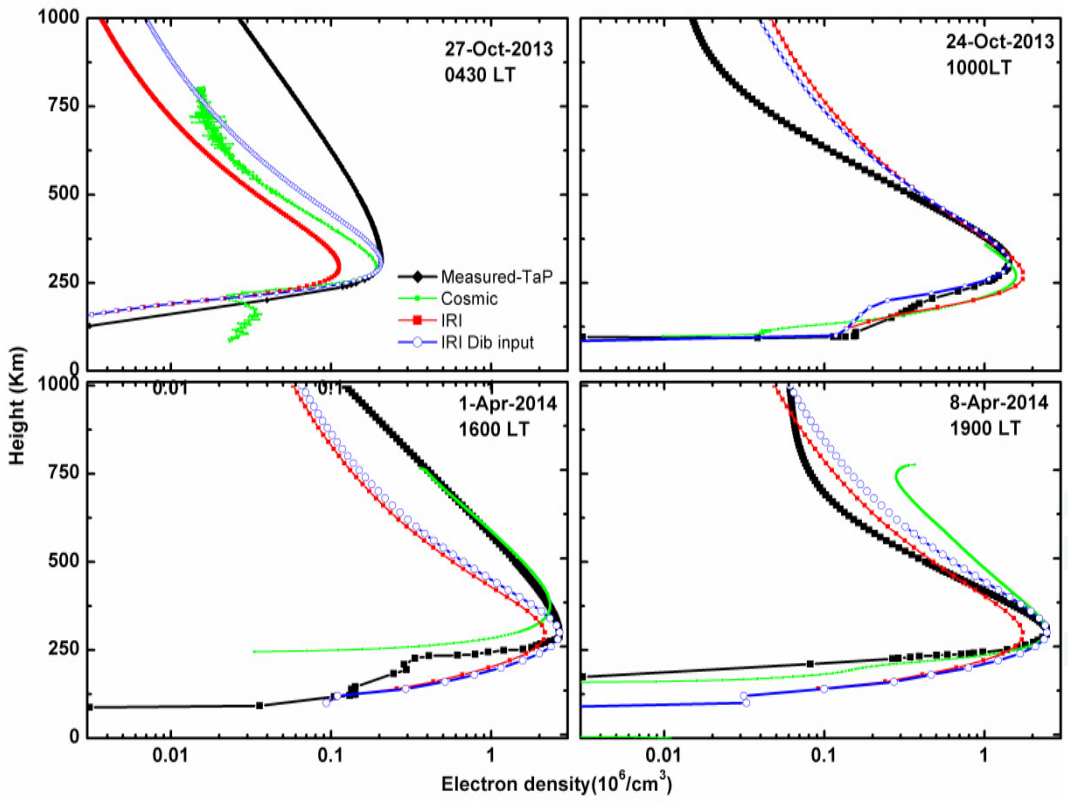
2. IONOSPHERE, MAGNETOSPHERE AND SOLAR TERRESTRIAL RELATIONSHIP

• Case Study of conjugate hemisphere ionospheric response to severe and moderate geo-magnetic disturbances

The effects of the St. Patrick's Day geomagnetic Storms of 2013 and 2015 in the equatorial and low latitude regions of both hemispheres in the 100ºE longitude sector was investigated The data from a chain of ionosondes and GPS/GNSS receivers at magnetic conjugate locations in the 100ºE sector were used. Rapid fluctuations in the F2 layer parameters were observed due to the perturbation in the equatorial zonal electric field due to the prompt penetration of the magnetospheric convective under shielding and over shielding electric field in the main phase of the storm. The direction of IMF Bz and disturbance electric field perturbations in the sunset/sunrise period was found to play a crucial role in deciding the extent of pre reversal enhancement (PRE) which in turn affected the irregularity formation (Equatorial Spread F) in the equatorial region. The northward (southward) IMF Bz in the sunset period inhibited (supported) the irregularity formation in 2015 (2013) in the 100ºE sector. In contrast, during sunrise period (18 March) of both storms, short duration equatorial irregularities were observed due to large height increase (hmF2). The westward disturbance electric field on 18 March inhibited the EIA causing negative (positive) storm effect in low (equatorial) region. The negative effect was amplified in low mid latitude by disturbed thermospheric composition which produced severe density/TEC depletion in 95ºE. The negative effect was less severe in the Indian longitude sector. The complex hemispheric asymmetry of storm response was noted and attributed to electrodynamics and thermospheric differences. The post storm effects lasted longer in 2015 as compared to 2013.

Total vertical electron density profile using integrated POLAN and TSM

The vertical electron density profiles over Dibrugarh (27.5ºN, 95ºE, 43º dip) a low mid latitude station normally located at the northern edge of the EIA for the period of July,2010 till October 2015 were reconstructed from the measured bottom side profiles and ionosonde-GPS TEC assisted Topside Sounder Model (TSM) topside profiles. The bottom side density profiles were obtained by using POLAN on the manually scaled ionograms. The topside was constructed by the modified ionosonde assisted TSM model (TaP-TSM assisted by POLAN) *which* is integrated with POLAN for the first time.



The comparison of estimated vertical density profile with IRI 2012 and COSMIC profiles in equinox conditions.
Fig 2

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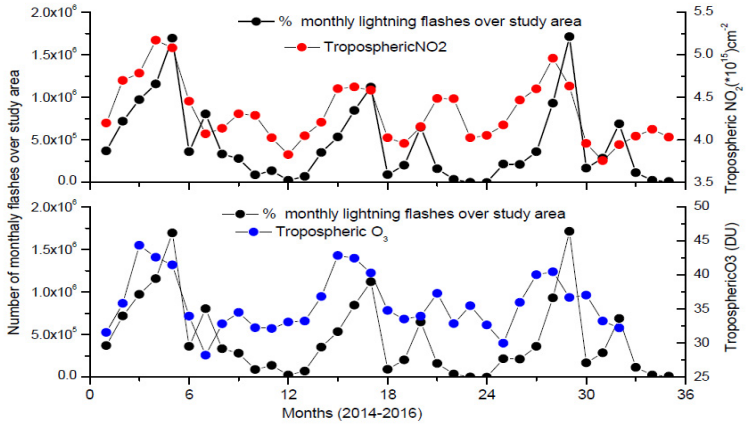
CHAPTER – 23.4
SAVITIRBAIPHULE PUNE UNIVERSITY
(FORMERLY UNIVERSITY OF PUNE)
DEPARTMENT OF ATMOSPHERIC & SPACE SCIENCES

Savitribai Phule Pune University is one of the premier universities in India, located in the North-western part of Pune city. The activities in Atmospheric & Space Sciences department of this universicty were concentrated on the following topics: Lightning modulation of Trace Gases, studies with Meteor Wind Radar,Ice Nuclei observations, Rain drop spectra in different cloud types, and Planetary Boundary layer (PBL) variation during Monsoon.

SCIENCE RESULTS

- **Lightning and Trace Gases:**

The seasonal or inter annual variability of Tropospheric NO_2 and O_3 and lightning activity over Maharashtra, India (15.5°N-22.5°N, 72.5°E-81.5°E) region, was analyzed to study the role of lightning activity in the seasonal variation of NO_2 and O_3 (fig 1). Satellite observations of Tropospheric NO_2 and O_3 from Aura-OMI/MLS for the period 2005-2016 and lightning data of 2014-2016 from lightning detection network over Maharashtra have been used for analysis. Analysis show that the seasonal variation of all three quantity matches with each other. The scattered diagram between monthly NO_2 concentration versus monthly lightning activity for years 2014-2015 also show good correlation between these two parameters (r=0.71 at 99.9% significant level).

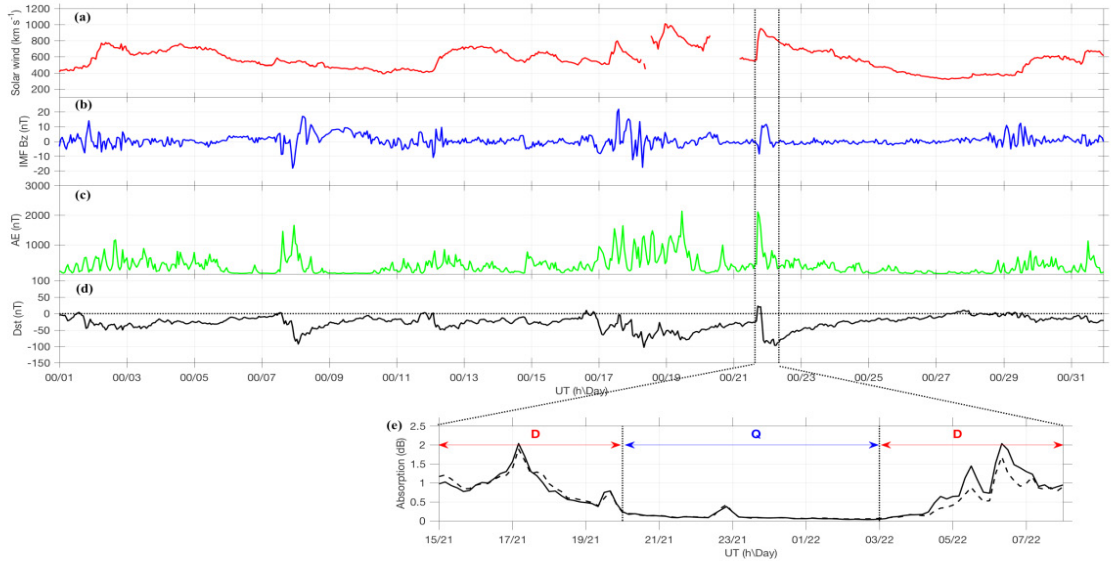


Lightning Vs Tropospheric NO_2 (upper panel), Tropospheric Ozone (Lower Panel).
Fig 1

However, monthly variations of NO_2, O_3 and lightning activity show deviation in the peak values. The analysis clearly demonstrates that the seasonal or inter-annual variations in NO_2 and O_3 are controlled by lightning activity over Maharashtra region However, biomass burning during April-May and increased air pollution during winter months (November-January) also play important role in the inter-annual variations of NO_2 and O_3 over this region.

- **Studies with Meteor Wind Radar:**

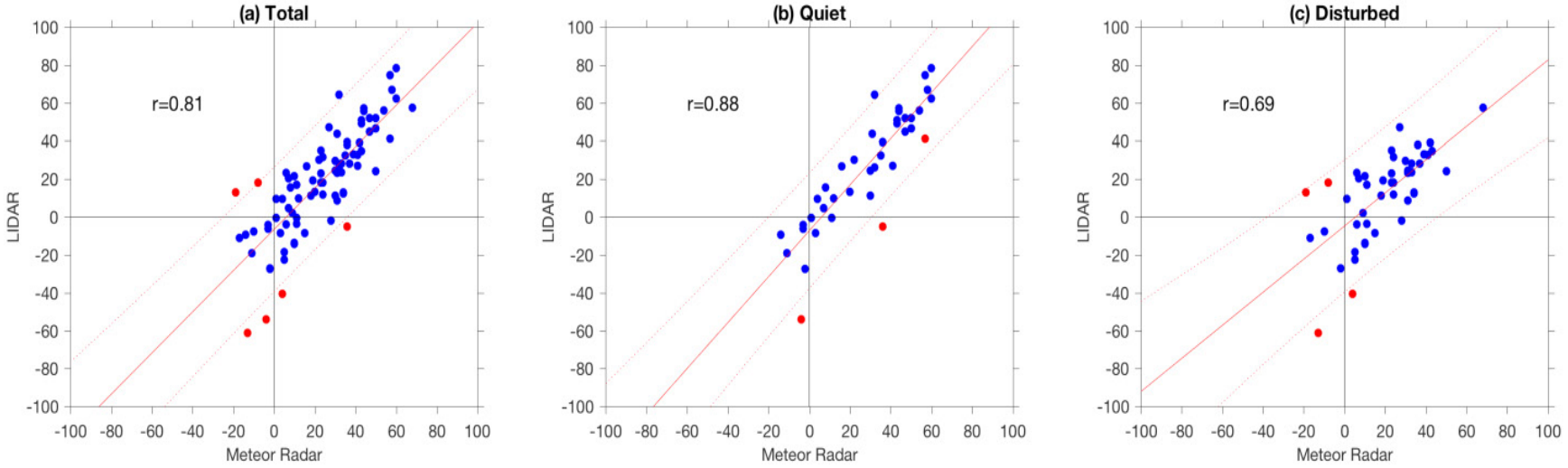
This study is to address the basic question "*Are the meteor radar winds reliable during high geomagnetic activity?*;. In the present case study, the Andenes (69.27°N, 16.04°E) meteor radar winds was compared with co-located ALOMAR Weber Nalidar wind measurements during geomagnetic storm to estimate the possible errors in the neutral wind estimation. Figure 2 illustrates the geomagnetic conditions during Jan 2005. The solar activity in this month was highly variable and clearly evident in the indices. A series of powerful X class flares was produced during this period, resulting in a series of solar proton events (SPEs) starting on 16 January 2005. Additionally, the aftermath of the SPEs was accompanied by an intense geomagnetic storm and substorm activity. The storm activity is clearly visible in cosmic radio noise absorption measurements, as illustrated in Figure 2(e). Based on the absorption data, the data set is divided into Quiet (20 UT on 21 January 2005 to 4 UT on 22 January 2005) and Disturbed (15-20 UT on 21 January 2005 and above 04 UT on 22 January 2005).



Temporal variation of (a) Solar wind, (b) IMF Bz, (c) Auroral Electrojet (AE) index, (d) DST index observed during Jan 2005. (e) Cosmic radio noise absorption measured by imaging radio meter at Kilposjårvifrom 15 UT, 21 Jan 2005 to 08 UT, 22 Jan 2005. Note the solid line indicates Beam 15 and dotted line indicates Beam 8.

Fig 2

The meteor radar zonal wind deviations have been analyzed with respect to the lidar zonal winds (see Figure 3). Figure 3(a)-3(c) presents the scatter plots for meteor radar zonal winds against lidar zonal winds in the altitude region of 82 to 98 km including all measurement (total), and for measurement during quiet and disturbed conditions, respectively. The data in Figure 3 has been subjected to a variety of statistical algorithms. The correlation coefficients with probable errors between the different measurement series are 0.810.02±, 0.880.02± and 0.69±٠,٠٥ for Total, Quiet and Disturbed, respectively.

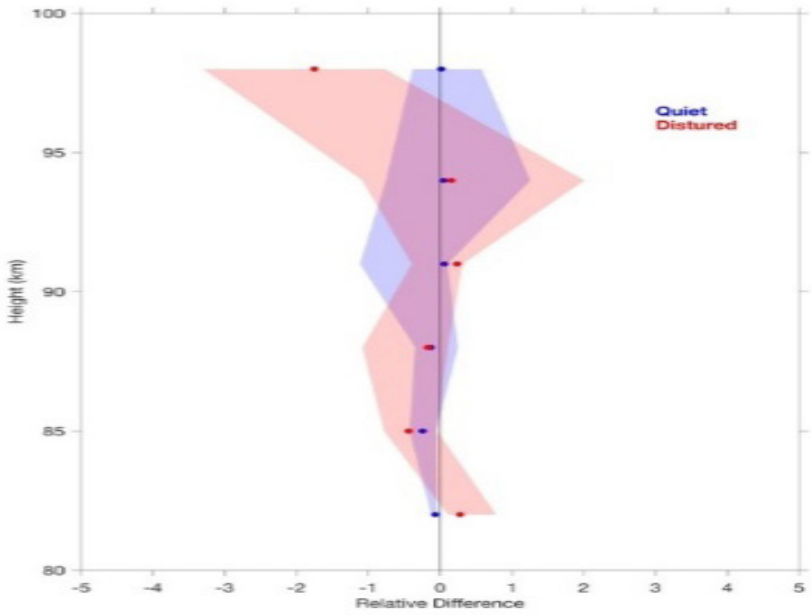


Scatter plots of the zonal wind observed by meteor radar and lidar in the altitude range of 82-98 km (a) total, (b) Quiet period and (c) disturbed period. The straight line indicates the linear fit between meteor radar and lidar. The dotted lines indicate the 95 % prediction bounds. The red dots indicate the outliers according to cook's distance.

Fig 3

The correlation coefficient is improved for quiet conditions compared to total observations, while it is decreased for disturbed conditions. Note that certain points (shown as red dots) biased the data. These outliers have been estimated according to the Cook's distance.

Figure 4 gives the relative differences between lidar and meteor radar winds with respect to the lidar zonal wind as function of altitude. The shaded region in the figure indicates 25 and 75 percentiles. A difference in the relative differences during Quiet and Disturbed conditions is judged significant when the frequency of one sample is not within the confidence interval of the other sample. The difference in the median zonal wind deviation between quiet and disturbed periods is in general small (within the 25 percentile) except for 98 km altitude



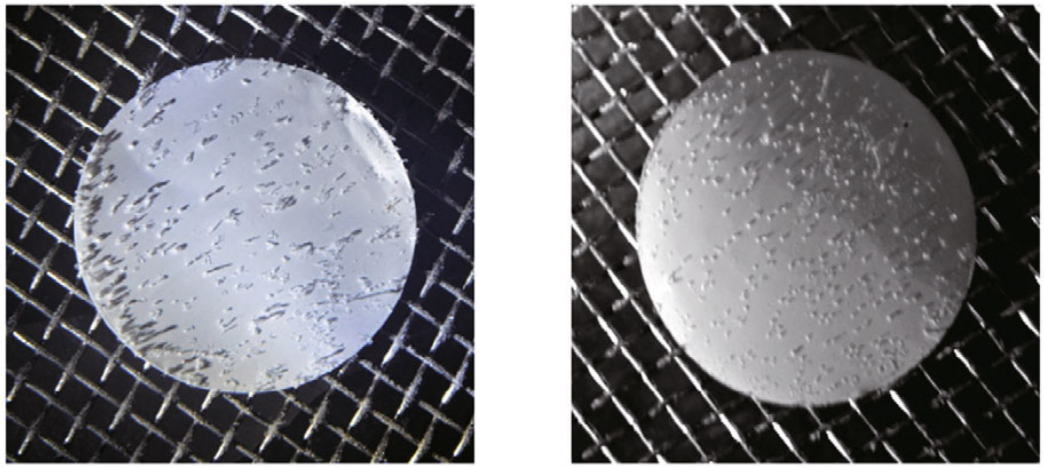
Vertical profiles of the median relative differences between zonal winds measured by lidar and meteor radar during quite period and distributed period. Shaded region indicates the 25 and 75 percentiles of the relative differences.
Fig 4

The large difference at 98 km indicates that there might be considerable errors due to the impact of an increased electric field and/or ionization on the wind estimates. It is acknowledged that one event is not sufficient to make any firm conclusion. The chief conclusion that can be drawn from this study is that care must be taken while considering the neutral winds at higher altitudes during geomagnetic disturbed conditions.

- **Ice Nucleation Studies:**

Ice nucleating particles (INPs) measurements were performed over two high altitude stations in India. Aerosols collected on filter papers at Girawali Observatory (IGO) of Inter University Center for Astronomy & Astrophysics and at Radio Astronomy Center, Ooty (RAC) were activated in deposition mode to determine the INPs, using a thermal gradient diffusion chamber (Fig. 5). The campaigns at IGO were conducted during 2011, 2013 and 2014 and at RAC during 2013, 2014. Maximum number concentration of INPs were found to be 1.0 L^{-1} and 1.6 L^{-1} for IGO and RAC respectively, when aerosol samples were exposed to ice super-saturation between 5 to 23% in the temperature range -17.6 to -22°C. Maximum correlation coefficient “R= 0.76” between INPs count and ice super-saturation has been observed. The airmass trajectories

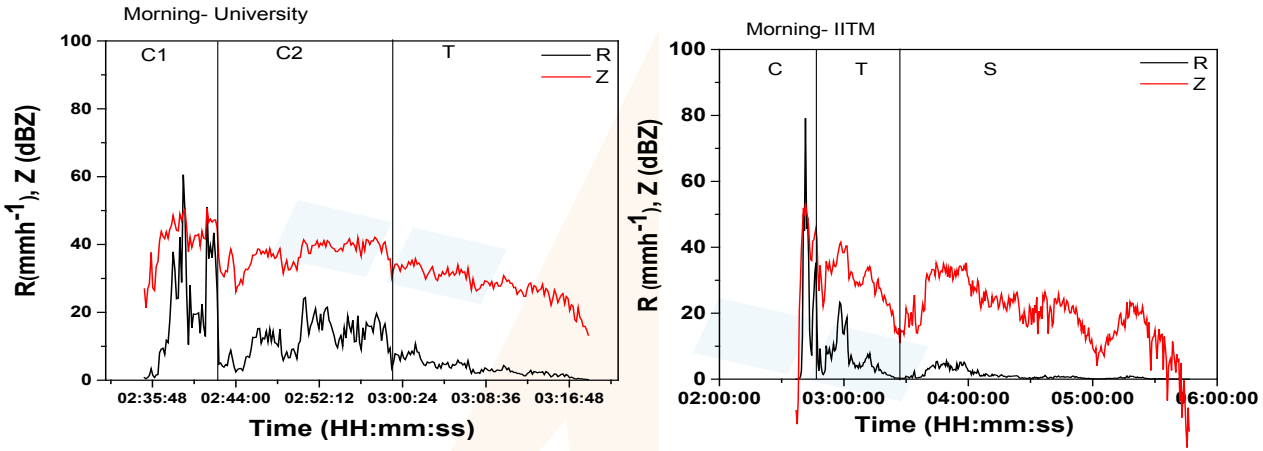
analyzed for the campaigns show that the Arabian Desert and arid regions are the main contributors for the INPs. Elemental analysis of particles shows the presence elements Na, Cl, Si, Al, Fe, Cu, Co, Cd, S, Mn, K and also some rare earth elements like Mo, Ru, La, Ce, V and Zr. The fraction of aerosols which act as INP is found to be $1:10^4$ to $1:10^6$, for IGO and $1:10^3$ to $1:10^4$ for RAC when aerosols in size range 0.5-20 µm are considered. The higher fraction of INPs to aerosols over RAC as compared to IGO may be attributed to the presence of rare earth elements observed in the aerosol samples of RAC which are absent in the SEM-EDX analysis of aerosols over IGO.



(a) Activated Ice Nuclei on Filter paper. (b) during storms.
Fig 5

- **Rain Drop Spectra:**

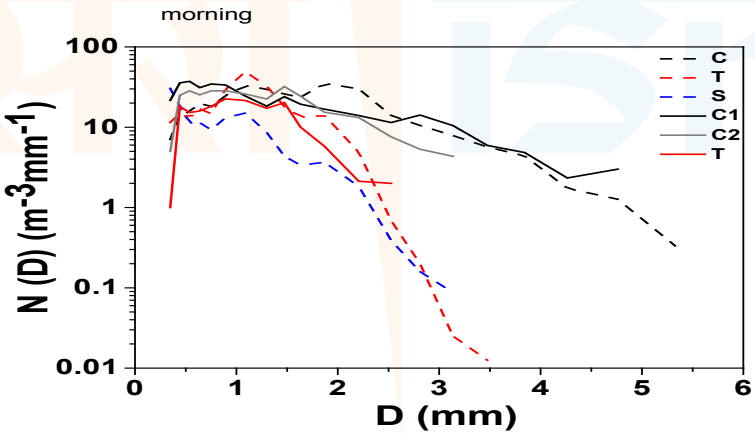
Inter-comparison of precipitation characteristics/variability from disdrometer datasets for rain events at two locations separated by a distance of 3 km were carried out. Figure 6 shows intercomparison of variability of the rain integral parameters rain rate (mm/hr) and reflectivity (dBZ) from Optical disdrometer (located at Savitribai Phule Pune University (SPPU)) and Impact disdrometer (located at Indian Institute of Tropical Meteorology (IITM) which is 3 km from SPPU) data for the case 18-09-2013 during morning period. It was intended to see the spatial distribution of drop size during the convective, transition and stratiform period. Here for University dataset convective1 (C1) and convective 2 (C2) periods are considered because the rain intensity falls below 10 mm/hr from peak in intensity (C1) and again the rain intensity goes above 10 mm/hr (C2) and after that steady rain rate is observed which we considered as transition (T) period. For the IITM dataset it was observed that one convective period is followed by transition and stratiform period. Though located within 3 km from each other large spatial variability is observed. Longer convective spell is observed over University as compared to IITM. IITM had its convective phase when University was in second convective spell. Transition period over both stations were comparable but stratiform period was longer over IITM while absent over University.



Intercomparison of variability of the rain integral parameters rain rate (mm/hr) and reflectivity (dBZ) from Optical disdrometer (located at University) and Impact disdrometer (located at IITM which is 3 km from SPPU) data for the case 18-09-2013 during morning period

Fig 6

In the Z-R relationship higher values of 'a' suggests that the drop diameter values are large. Also 'b' value is more for Convective1 period as compared to Transition (T) period. It is observed that for convective period 'a' value is small as compared to transition and stratiform period and 'b' value is more for Convective period as compared to Transition (T) and stratiform (S) period. Evaporation plays role in decreasing the number of small drops, thus increasing drop diameters. For the stratiform case over IITM there is a decrease in both R and Z, the former more than latter, in such a manner as to decrease the slope **b** of the Z-R relation and increase the coefficient **a**.



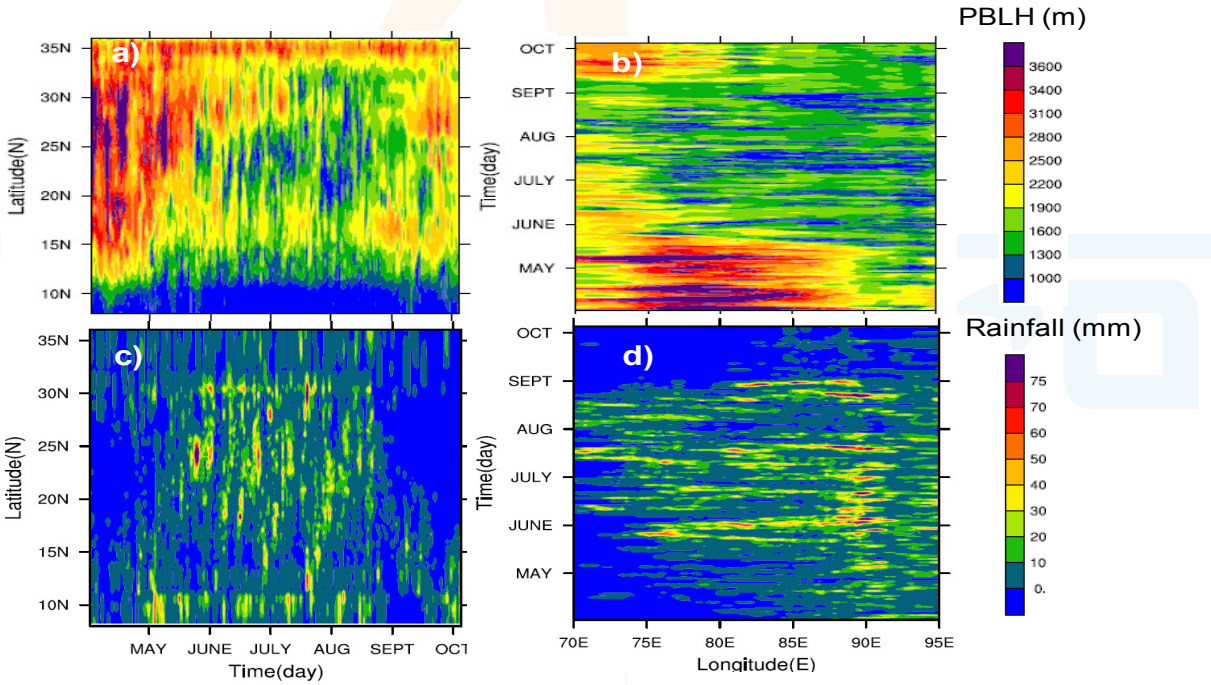
Average drop size distribution for Convective, Transition and stratiform periods for the case 18-09-2013 over SPPU, Pune (solid line) and IITM (dash line) datasets.

Fig 7

Figure 7 shows the average drop size distribution for convective, transition and stratiform periods for the case 18-09-2013 over University, Pune (solid line) and IITM (dash line) datasets. From the figure it is observed that for convective period drop number density is large as compared to transition and stratiform periods. Also, the drop diameter during convective period varies over wide range of values as compared to transition and stratiform periods, which can be attributed to higher rain intensity spell during convective period. In case of IITM dataset the variability in drop number density is more as compared to University data. There is a slight delay in observing the peak in number density as compared to University data.

- **PBL height over the Indian subcontinent in relation to monsoon:**

The response of boundary layer to the onset and progress of monsoon over the Indian subcontinent are studied using validated Modern Era Retrospective analysis for Research and Applications (MERRA) PBL height (PBLH). The daily maximum PBLH and total rainfall averaged along 2° wide latitudinal and longitudinal cross sections across central Indian region for the period May to October 2011 are depicted in the Hovmoller plots (Fig. 8).

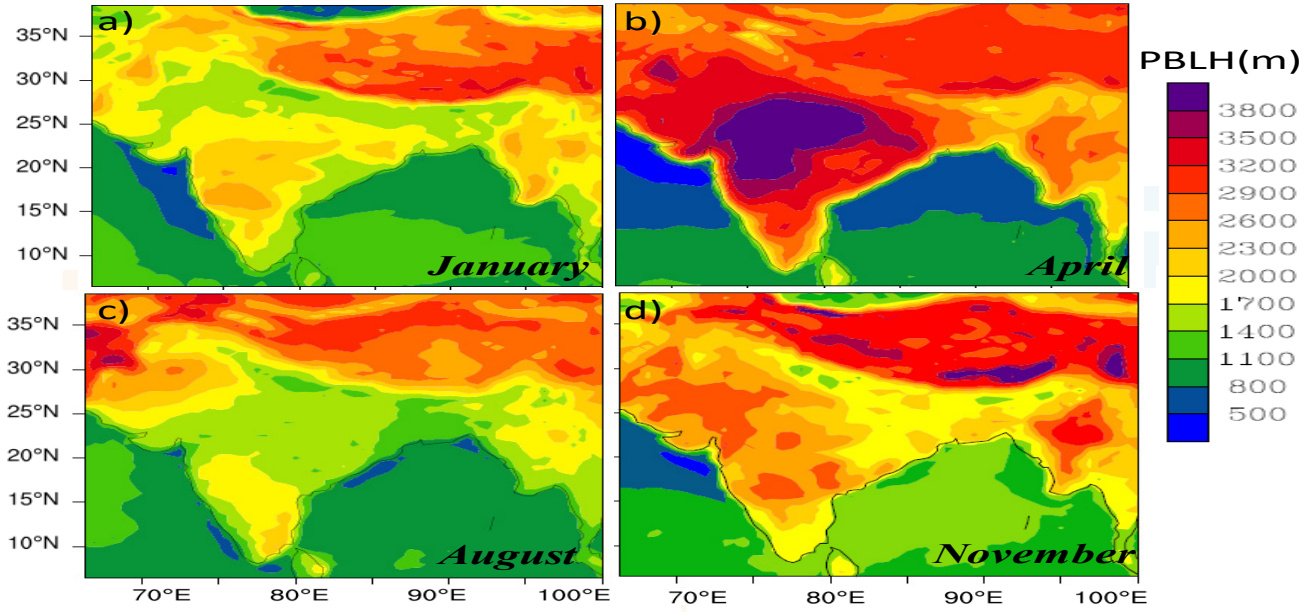


Hovmöller plots of MERRA PBLH and IMD rainfall. Latitudinal variation of PBL height and IMD rainfall averaged over the longitudinal cross section 77.25°E to 78.5°E (a and c) and Longitudinal variation of PBL height and IMD rainfall averaged over the latitudinal cross section 25°N to 27°N (c and d).

Fig 8

The influence of monsoon onset, its northward progression and intraseasonal variations (Fig. 8c) are very well reflected in the latitudinal PBLH variations (Fig. 8a). The PBLH is low (< 1000 m) up to nearly 10°N throughout the period as the lower part of belt falls over ocean. The PBLH starts decreasing from southern latitudes as monsoon onset takes place on 1st June, followed by gradual northward progression. The onset over north Indian latitudes (≈28°N) occurs only by 1st week of July. The monsoon onset and progress takes effect from the Arabian Sea side as well as from Bay of Bengal, which is evident in the longitudinal variations of PBLH (Fig. 8b). The northeastern regions (east of 90°E) receive rainfall from Nor'westers Starting March, followed by pre-monsoon in May (Fig. 8d), which must be the reason for low PBLH (< 2000 m) over that region in May. The rainfall onset over western parts of the selected latitude belt is from the Arabian Sea branch (early July) whereas over the eastern parts, it's from Bay of Bengal (early June), which is also evident in the PBLH variations. One feature noted in both latitudinal as well as longitudinal variations is that once onset takes place, the intraseasonal rainfall variations are not reflected at the same magnitude and periodicity in PBLH. This could be mainly due to the soil moisture memory controlling the surface fluxes for prolonged periods and their influence on BL growth.

In order to provide an overall understanding on the spatio-temporal variations, monthly composite of daily maximum PBLH for the months of January, April, August and November, representative of winter, premonsoon, monsoon and post-monsoon seasons respectively are presented in Fig. 9.



Monthly composite of daily maximum PBLH during four months representative of four seasons: a) January (winter), b) April (Pre-monsoon), c) August (Monsoon) and d) November (Post-monsoon), 2011.

Fig 9

The very large PBLHs observed over inland regions in pre-monsoon (Fig. 9b) are related to dry soil conditions and enhanced surface sensible heat flux. The lower PBL heights over coastal regions could be due to land-sea breeze circulations and moderate soil moisture conditions. The layered BL pattern over Arabian Sea and Bay of Bengal could be the influence of surface fluxes associated with the observed SST variations. The PBLH near to the coastline showed lower values during April both over the Northern BoB and Arabian sea extending towards south, which may be attributing to the persistent shallow convective clouds over these locations. Overcast, windy and wet surface conditions are contributing to lower PBLHs during monsoon over most of the sub-continent (Fig. 9c). The north-western desert and rain shadow region of Western Ghats, are the only regions where slightly large PBLHs are noted. Over ocean, the layered pattern noted during pre-monsoon months disappeared during monsoon. The lower heights noted in post-monsoon season (Fig. 9d) coincides with the regions influenced by NE monsoon rainfall. The winter PBLs over land are slightly deeper than SW monsoon period, except over the tip of Southern Peninsular east and west coasts, where the effects of NE monsoon prolongs. The oceanic regions depict the layered pattern as in pre-monsoon, with some differences in the orientation.

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CHAPTER – 23.5

S. K. MITRA CENTRE FOR RESEARCH IN SPACE ENVIRONMENT, INSTITUTE OF RADIO PHYSICS AND ELECTRONICS UNIVERSITY OF CALCUTTA, KOLKATA

The University of Calcutta has a rich tradition of radio and space research pioneered by Late Professor Sisir Kumar Mitra. The S. K. Mitra Centre for Research in Space Environment is an interdepartmental centre of the University of Calcutta with Institute of Radio Physics and Electronics as the nodal department. This centre provides a platform for multifaceted research activities in space, atmospheric and radio sciences in the University. A brief description of the work carried out during 2016-2017 at the Centre is provided here.

A. MAJOR FACILITIES/INSTRUMENTATION DEVELOPED

ST Radar Facility at the University of Calcutta

A major facility of Stratosphere Troposphere (ST) Radar, funded by SERB, DST, is coming up at the Haringhata Field Station of the University of Calcutta. to carry out scientific Studies on Stratosphere-troposphere exchange process, gravity waves, equatorial/planetary waves and ionospheric E and F region irregularities over Kolkata located at the verge of the tropics. The data products from the radar will be three component wind, Doppler spectral width and signal strength in the lower atmosphere and irregularity drift velocity and backscatter signal strength of ionospheric irregularities. Each antenna element in the array of 475 antennas will be fed by a separate transmitter with 2 kW power so that the radar will have flexible antenna beam steering capability. The frequency of operation of the radar will be around 53 MHz with an average power aperture product of 10^8 W.m^2. The proposed radar will probe the lower atmosphere from about 3-20 km and also ionospheric E and F region irregularities.

B. RESEARCH STUDIES

1. ATMOSPHERE AND CLIMATE

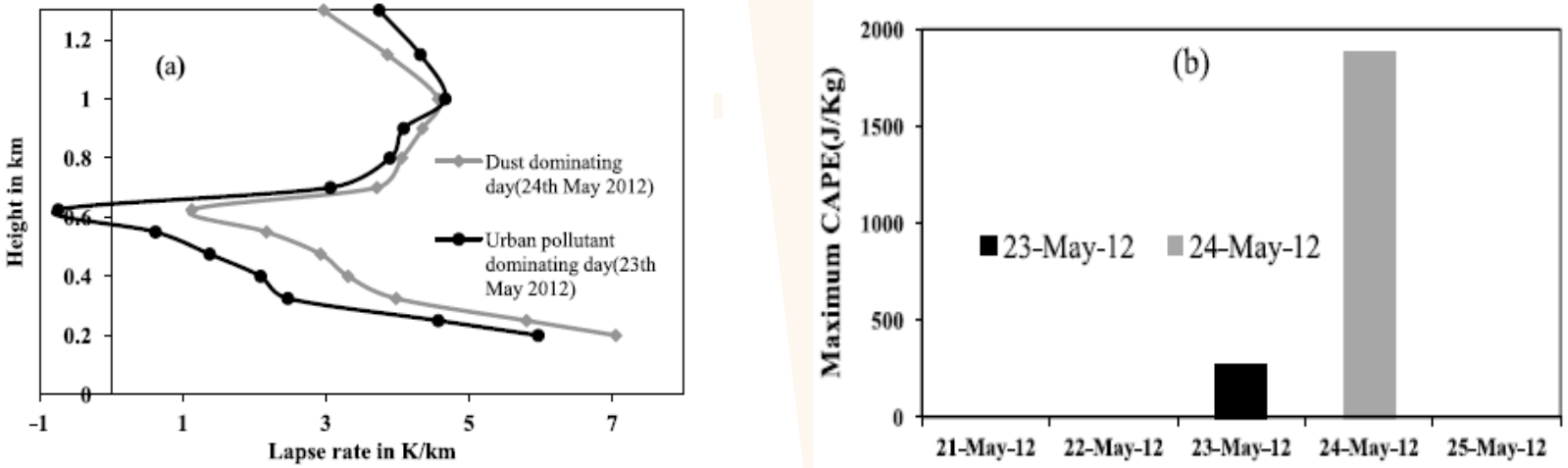
Prediction of convective events using multi-frequency radiometric observations

The efficacy of nowcasting convective activities using a microwave radiometer has been examined for Kolkata (22.65° N, 88.45° E), a tropical location. It has been found that the standard deviation of brightness temperature (BT) at 22 GHz and instability indices like Lifting Index (LI),

K Index (KI) and Humidity Index (HI) has shown definite changes before convective events. It is also seen that combination of standard deviation of BT at 22 GHz and LI can be most effective in predicting convection. A nowcasting model has been developed using various combinations of instability parameters to generate an alarm in every 30 min in case of convective events. It is seen that that a combination of LI and standard deviation of BT at 22 GHz can be most effective to nowcast convective activities with prediction efficiencies of about 80%. This technique tracks the convective growth in terms of changing atmospheric instability. The technique is suitable for nowcasting extreme weather conditions in a less involved way compared to RADAR and satellite measurements.

Dominance of pollutant aerosols over an urban region and its impact on boundary layer temperature profile

A study has been made on the aerosol optical properties over Kolkata, a densely populated urban location near the land-ocean boundary in eastern India, using ground-based measurements. Collocated measurements of aerosol optical depth (AOD) and black carbon at different wavelengths have been used to calculate aerosol single scattering albedo (SSA). The wavelength dependence of SSA and AOD has been utilized to discriminate the aerosol types over this highly populated metropolitan area. The spectral pattern shows that SSA decreases with wavelength mostly in a year showing the dominance of fine-mode pollutant particles over the city. The temperature lapse rate profile within the surface boundary layer is influenced by the heating effect of fine-mode pollutants (Fig. 1) and consequently affect the growth of the convective processes in the lower troposphere.

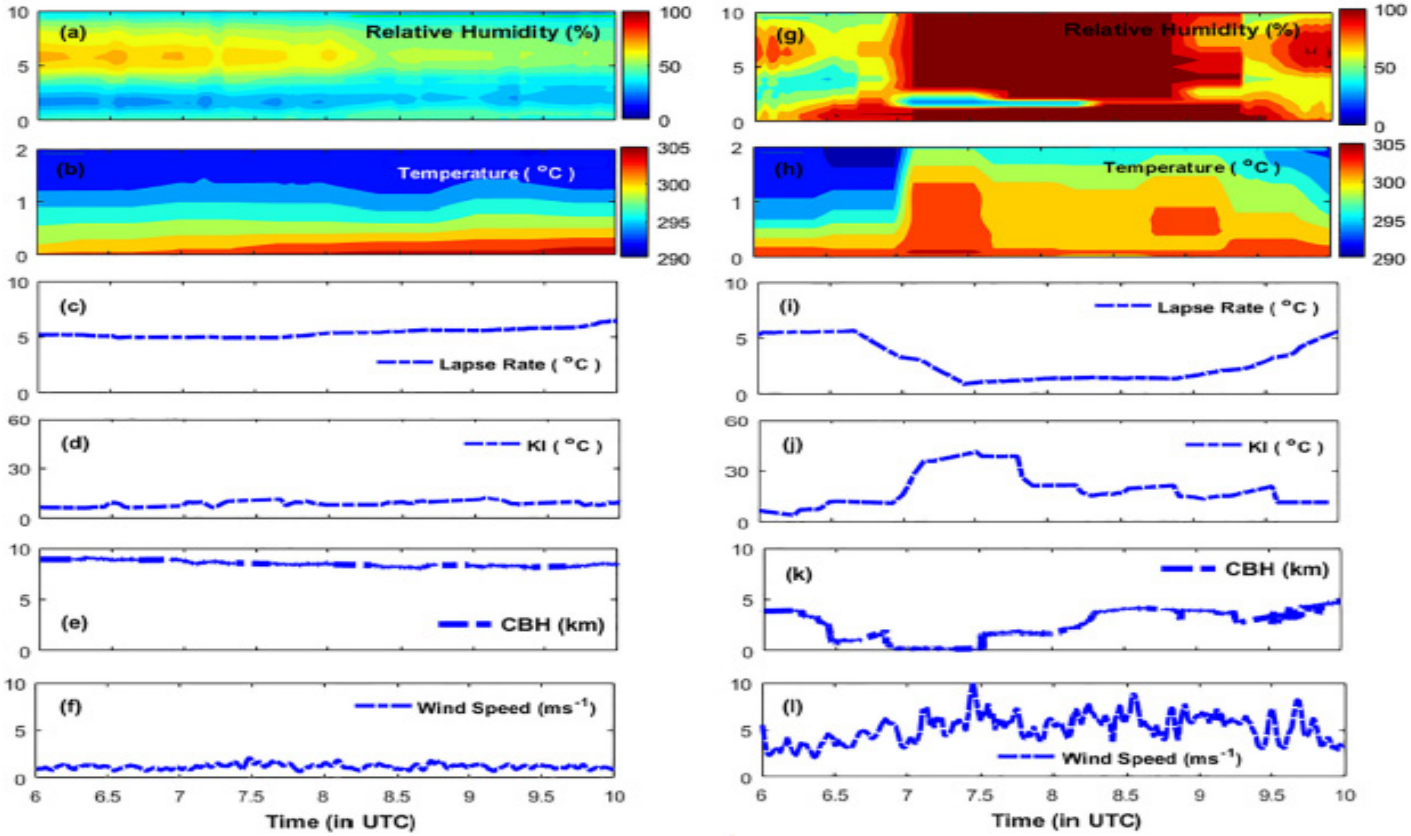


Comparison between (a) lapse rate for a pollutant-dominating day (23 May 2012) and dust-dominating day (24 May 2012) and (b) corresponding CAPE values.

Fig 1

Anomalies in relative humidity profile in the boundary layer during convective rain

A reduction of relative humidity at 1–2 km (boundary layer) height is observed during convective rain which is due to the decreased lapse rate at that height. This depletion of relative humidity is not seen during calm conditions. The reason for such anomalies in the planetary boundary layer humidity profile is due to the release of latent heat at the mentioned altitude. The abundance of pollutant aerosols in urban regions has also been found to contribute to this relative humidity anomaly. It has been also found that the distinct patch in relative humidity profiles is absent in stratiform rain events providing a demarcation regarding convective cases (Fig. 2). The present feature can hence serve to determine the rain type using the relative humidity at boundary layer as an only input compared to bright band structures from radar reflectivity profiles which are both costly and complicated in operation.

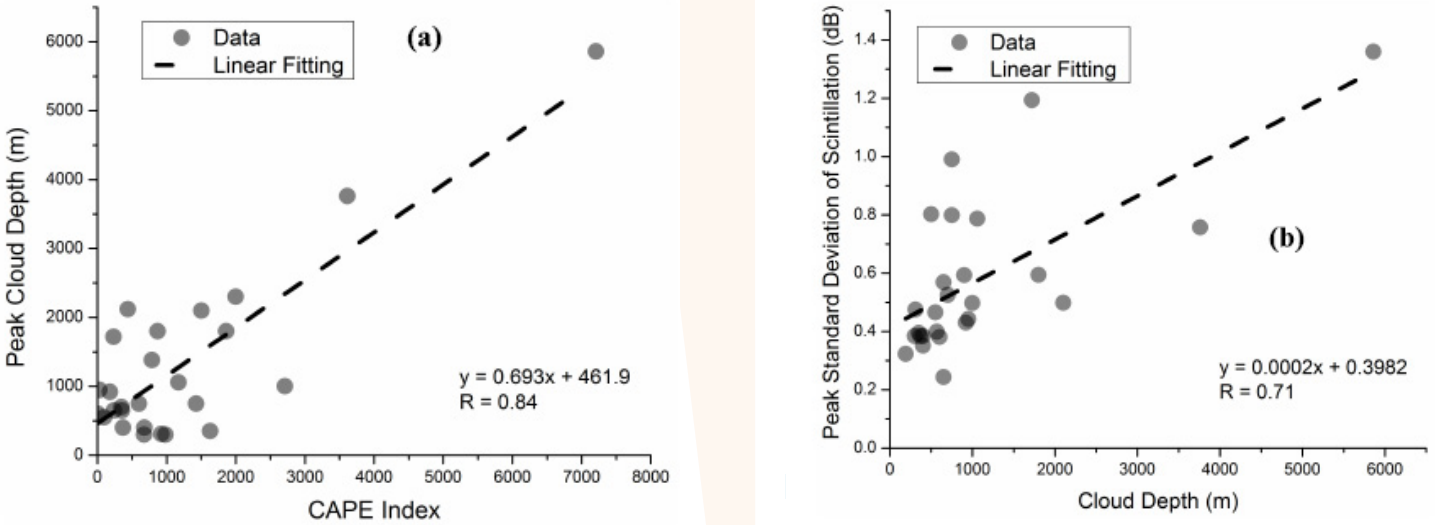


Left panel: (a)–(f) Variation of atmospheric parameters during a clear day on 01 April 2012 for relative humidity, boundary layer temperature profiles, boundary layer temperature lapse rates, K Index from radiometer, cloud base height from Infrared Radiometer observations, and wind speed data from Automatic Weather station respectively. Right panel: (g)–(l) same as (a)–(f) but for a convective event on 04 April 2012.

Fig 2

Pre-rain Scintillations of Ku-Band Satellite Signal in Relation to Cloud and Convective Parameters

This study shows the association of the tropospheric pre-rain scintillations with both the cloud thickness and the prevailing convection. Scintillations at 11.172 GHz are found to be connected to the prevailing meteorological conditions associated with cloud formations. The variance of fast fluctuations shows an increase with cloud thickness and convective available potential energy (CAPE) (Fig. 3). In view of the predominance of convective phenomenon in the tropical region, these features of pre-rain scintillations are of much significance in assessing the propagation effects of satellite communication links prior to rain events.

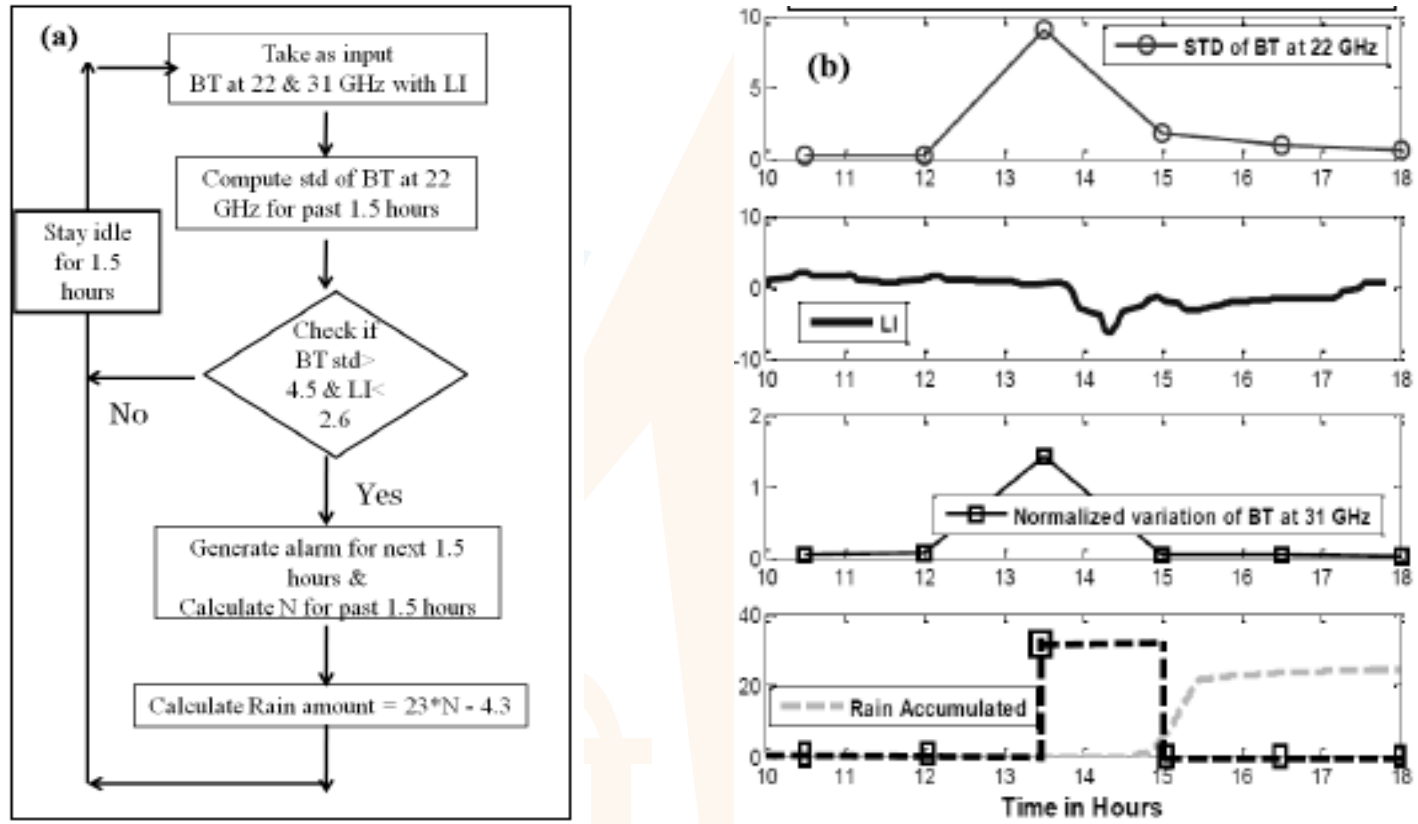


(a) Variation of peak cloud depth with respect to maximum CAPE index.
(b) Variation of scintillation peak standard deviation with prevailing maximum cloud thickness.
Fig 3

2. REMOTE SENSING OF EARTH'S RESOURCES AND ENVIRONMENT

Prediction of Rain Using Radiometric Observations

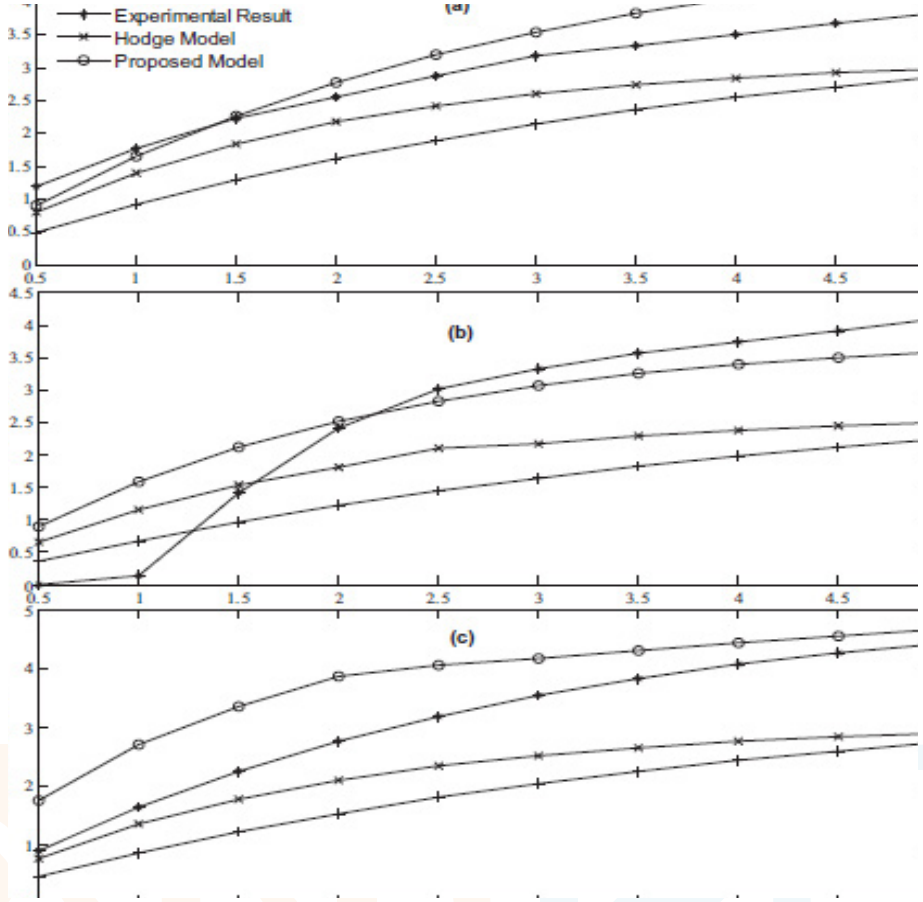
This study uses radiometric observations of brightness temperature at 22 and 31 GHz and the lifting index to predict heavy rain events over Kolkata (22.65°N, 88.45°E), a tropical location. It has been observed that a combination of these three parameters can be effective in predicting rain events both qualitatively and quantitatively with prediction efficiencies of about 80% and false alarm rates of 18%. The schematic of the prediction algorithm is shown in Fig. 4(a). The prediction model is tested on several intense rain events during the period 2014–2015. The model is found to perform well in predicting intense rain about 70–75 min in advance. A demonstration of the prediction technique is shown in Fig. 4(b) for a typical heavy rain event on August 26, 2013 starting at 15:00 IST.



Performance of the complete prediction technique. (a) Flowchart of the prediction algorithm. (b) A test case showing the performance of the technique for a rain event on August 26, 2013.
Fig 4

Diversity gain for rain attenuation over Earth-space path

A new technique has been proposed to estimate diversity gain using the Earth-space propagation data obtained at a single receiving site. The technique is crucial in estimating diversity parameters in the absence of multi-station data. The rain decay parameter, as defined in the Simple Attenuation Model (SAM), has been used to get the rain rates and subsequently rain attenuation at distant locations from the single receiver site within the rain cell. A comparison of the diversity gain got from the present propagation data and the ITU-R model shows the necessity of changing the model parameters of the ITU-R model. The changed model incorporates the seasonal variation and exhibits better prediction capability than the ITU-R model as related to the tropical location (Fig 5).

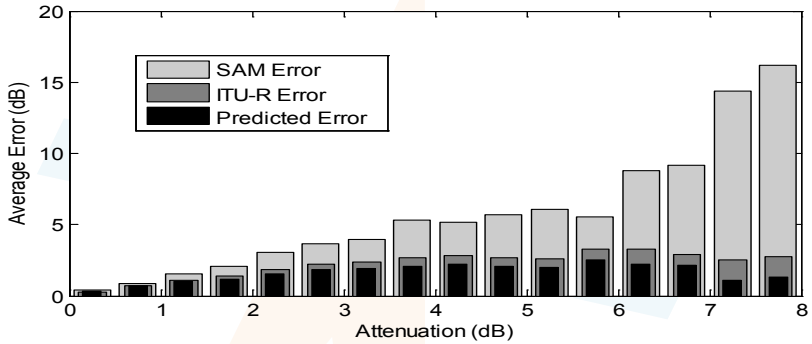


Comparison of the proposed model with ITU-R and Hodge model and experimental observations for (a) monsoon, (b) pre-monsoon and (c) post monsoon of 2009–2010.
Fig 5

Modelling of rain decay parameter for attenuation estimation

The Simple Attenuation Model (SAM) estimated rain attenuation values are often found to exhibit substantial deviation from the actual measurements over the location, Kolkata due to the wide rain variability of the tropical region. Thus a technique of rain attenuation estimation is proposed using the decay parameter of rain rate which is obtained from the simultaneous measurements of rain attenuation and rain rate. The median and median absolute deviation of decay parameter are modelled in terms of rain rate which are further utilized to randomly generate decay parameter values to predict rain attenuation. The accuracy of the proposed model compared to the existing SAM and ITU-R models has been examined and it is found

that at high rain rates, the proposed model give a better estimation of rain attenuation compared to other models (Fig. 6). The present technique and the proposed model can be effective in predicting rain attenuation from ground based rain rate measurements.

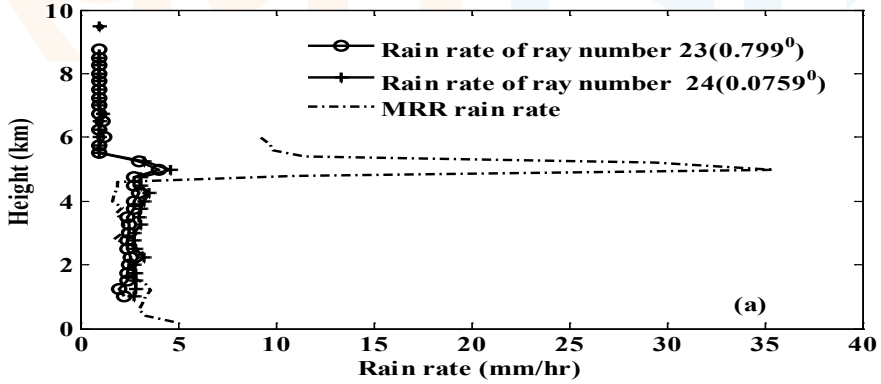


Comparison of rain attenuation estimation errors for all the rain events of 2010 in terms of average error.

Fig 6

Radar Observations of Vertical Profile of Rain Features

The possibility of combining space based and ground based radar observations in understanding the precipitation structure over the rain height. The feasibility of developing a dual frequency radar dataset using the simultaneous TRMM and MRR observations has been explained. However, it is also observed that whenever it is possible to combine the two radar measurements, extended information about the precipitation structure is obtained which is otherwise not possible to get (Fig. 7). The structure of vertical variation is also captured well by these two instruments. The difference in magnitude of radar reflectivity is mainly due to the effect of DSD at the two different frequencies and rain attenuation effect. The study highlights possibility of using such observations in developing suitable data set of vertical precipitation structure and radar reflectivity at dual frequencies from different regions.



Comparison of the profiles of rain rate and radar reflectivity obtained from TRMM and MRR on July 18, 2012.

Fig 7

Fade-Slope Model for Rain Attenuation Prediction

The Van de Kamp (VDK) model is used to describe the probability distribution of the fade slope for temperate regions. The validity of the VDK model to describe the probability distribution of the measured fade slope for a tropical location, Kolkata, India, has been tested. The time-series prediction of rain attenuation during the rain event is done using the modified VDK model which provides a better prediction not only on individual events but also on a long-term basis compared to that obtained using direct slope measurements.

3. IONOSPHERE, MAGNETOSPHERE AND SOLAR TERRESTRIAL RELATIONSHIP

Response of data-driven artificial neural network-based TEC models to neutral wind for different locations, seasons, and solar activity levels from the Indian longitude sector

The dynamic nature of the ionosphere in the low-latitude equatorial region and the Indian longitude sector has specific characteristics such as sharp temporal and latitudinal variation of total electron content (TEC). TEC in the Indian longitude sector also undergoes seasonal variations. The large magnitude and sharp variation of TEC cause large and variable range errors for satellite-based navigation system such as Global Positioning System (GPS) throughout the day. For accurate navigation using satellite-based augmentation systems, proper prediction of TEC under certain geophysical conditions is necessary in the equatorial region. A set of observations carried out in the Indian longitude sector have been reported in this study to find the amount of improvement in performance accuracy of an artificial neural network (ANN)-based vertical TEC (VTEC) model after incorporation of neutral wind as model input. The variations of this improvement in prediction accuracy with respect to latitude, longitude, season, and solar activity have also been reported in this paper. This absence of prominent variation of effects of neutral wind on performance accuracies of VTEC models between different stations could be explained in terms of close geomagnetic inclination angles and declination angles of these stations. Thus, this study may provide a better picture to the ionospheric community about the variabilities of performances of ANN-based feed-forward back-propagation TEC forecasting models with neutral wind over different latitudes, longitudes, seasons, and different phases of solar cycle in this highly dynamic Indian longitude sector.

Assessment of GPS Multifrequency Signal Characteristics During Periods of Ionospheric Scintillations from an Anomaly Crest Location

Multifrequency GPS transmissions have provided the opportunity for testing the applicability of the principle of frequency diversity for scintillation mitigation. Multifrequency scattering within the same L band is often the attributed cause behind simultaneous decorrelated signal fluctuations. The present study aims to provide a proportion of time during scintillation patches that decorrelations are found across GPS L1, L2, and L5 frequencies associated with high S4, corresponding high values of scattering coefficients, and large receiver position deviations thereby seriously compromising the performance of satellite-based navigation system. Results from the anomaly crest station at Calcutta indicate maximum 40% of scintillation time during February–April 2014 and 33% during August–October 2014 that the signals are decorrelated. It is important to note that it is only during these time intervals that the principle of frequency diversity could be applied for scintillation mitigation.

Relation of decorrelated transionospheric GPS signal fluctuations from two Stations in the northern anomaly crest region with equatorial ionospheric dynamics

The ionosphere around the northern crest of the equatorial ionization anomaly (EIA) and beyond exhibits rapid temporal as well as spatial development of ionization density irregularities during post-sunset hours. A GPS campaign was conducted during September 2012 and April 2013 from the Institute of Radio Physics and Electronics, Calcutta (22.58°N, 88.38°E geographic; magnetic dip: 32°N), and North Bengal University (NBU), Siliguri (26.72°N, 88.39°E geographic, magnetic dip: 39.49°N) in India to assess and quantify differences, if any, in the nature of carrier to noise ratio (C/N_0) fluctuations observed on the same satellite link around the same time interval from these stations. Significant decorrelation of the received signals was found when tracking the same satellite vehicle (SV) link from these stations during periods of scintillations. Low values of correlation coefficient of C/N_0 at L1 frequency recorded on the same SV link at these two stations were found to correspond with high irregularity characteristic velocities. North-south spatial displacement rates of the impact of ionospheric irregularities were calculated based on coordinated GPS observations which followed an increasing trend with irregularity characteristic velocities measured at VHF. Values of characteristic velocities over 36 m/s were also found to result in large receiver position deviations ~3.5–4.0 m during periods of scintillations. Spatial displacement rate, which corresponds to the north-south propagation velocity of the impact of the ionospheric irregularity on ground-based GPS receivers located at Calcutta and Siliguri, has been calculated which could be used for predicting satellite signal outages at stations along the same meridian.

Study of the effect of 17–18 March 2015 geomagnetic Storm on the Indian longitudes using GPS and C/NOFS

The largest geomagnetic storm in solar cycle 24 occurred during 17–18 March 2015 where the main phase of the storm commenced from 07:00 UT of 17 March 2015 and reached the DST negative minimum at 22:00 UT. The present paper reports observations of total electron content (TEC), amplitude, and phase scintillations from different GPS Stations of India during the storm of 17 March and highlights its effects on GPS. It also presents the global equatorial spread F (ESF) occurrence during the storm using total ion density drift measurements from Communication and Navigation Outage Forecast System (C/NOFS) satellite. TEC enhancements were noted from stations along 77°E meridian around 10:00 UT on 17 March compared to 16 and 18 March showing positive storm effects arising out of equatorward neutral wind in the local morning to noon sector of the main phase. Intense scintillation observations from Calcutta were most extensive during 15:00–16:00 UT, 17 March, and the receiver recorded a longitude deviation of 5.2m during this time. Cycle slips of the order of 8 s could be observed during periods of intense phase scintillations on the same night. The total ion density measured globally by C/NOFS reveals two distinct longitude regions of ESF occurrence during the storm: (i) East Pacific sector and (ii) Indian longitude during the storm. The time and longitude of ESF occurrence could be predicted using the time of southward turning of interplanetary magnetic field Bz. The unacceptable position deviations observed corresponding to amplitude scintillation observations on 17 March at Calcutta and cycle slips observed during phase scintillations on the same night, demonstrate the degradation of GPS receiver performance when subjected to a storm of such severity. The degradation of GPS receiver performance implies that its measurements become unreliable under intense geomagnetic storm conditions.

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