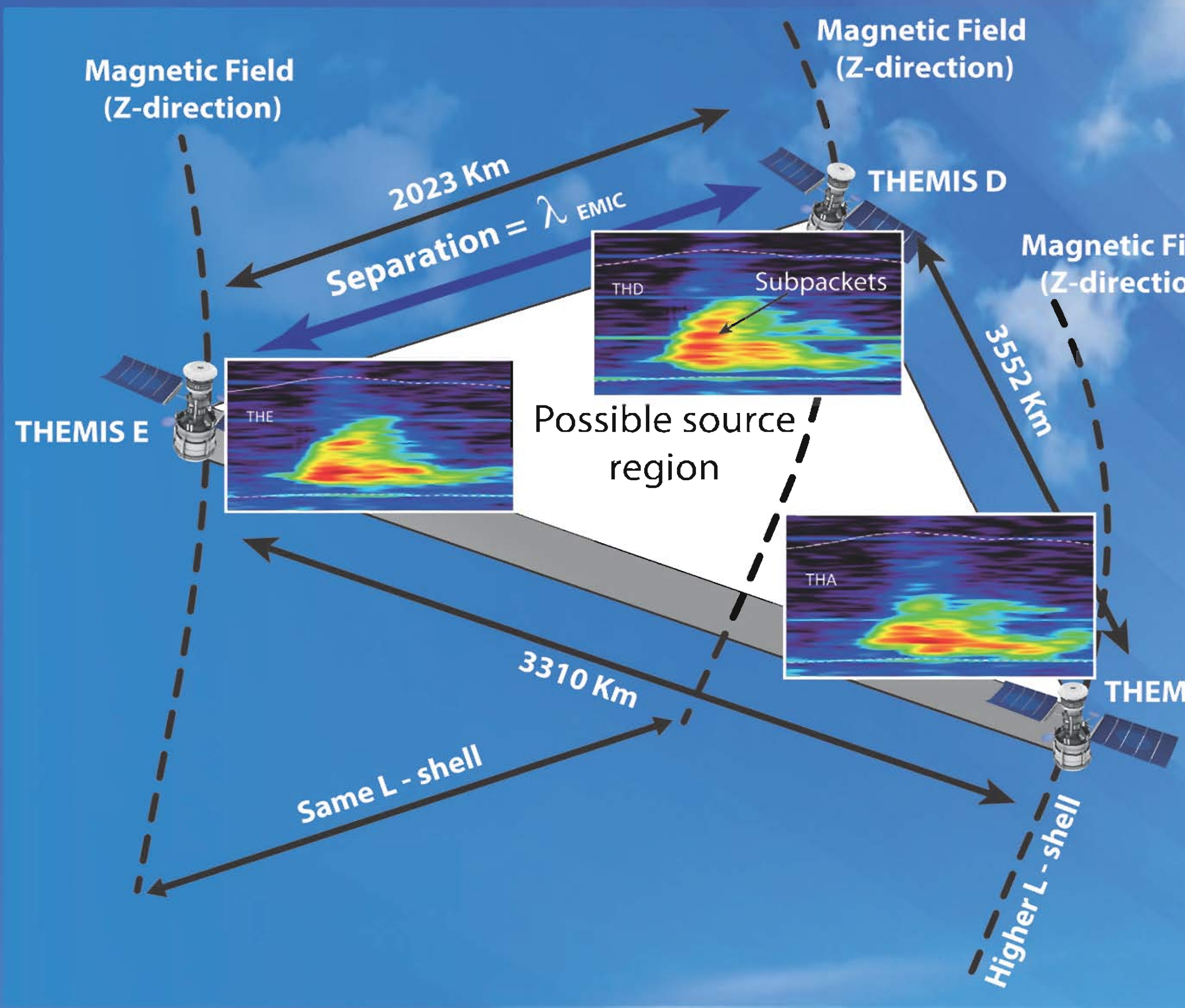
Annual Report
2021-2022



Indian Institute of Geomagnetism

New Panvel, Navi Mumbai

INDIAN INSTITUTE OF GEOMAGNETISM

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AUTONOMOUS RESEARCH INSTITUTE
UNDER
DEPARTMENT OF SCIENCE AND TECHNOLOGY
GOVERNMENT OF INDIA

PUBLICATION COMMITTEE

S. V. Singh, Gautam Gupta, Amar Kakad, Tulasi Ram, Gopi K. Seemala, B. I. Panchal, J. Kamra, M. D. Joshi

COVER PAGE:

Cartoon of the THEMIS constellation during the observed Electromagnetic Ion Cyclotron (EMIC) waves on September 9, 2010. Z-direction is along the magnetic field. Dynamic spectra of simultaneously observed EMIC rising tones are shown for each spacecraft. The triangular region in white is the possible source region. Separation of THD to THE spacecraft are one EMIC wavelength λ_{EMIC}(~2, 023 km) at ~14:23 UT, suggesting the evolution of the subpacket within one wavelength.

INDIAN INSTITUTE OF GEOMAGNETISM

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Director's Message

I am delighted and honoured to serve as Director of Indian Institute of Geomagnetism (IIG), a historical institute in the field of geomagnetism. The institute conducts research in the areas of geomagnetism and allied fields like Solid Earth Geomagnetism/Geophysics, Magnetosphere, Space and Atmospheric Sciences. It has active research groups working on theoretical, experimental, and observational aspects of physical phenomena. IIG has indigenously developed Proton Precession Magnetometer (PPM) and is currently involved in the in-house development of Overhauser Magnetometer, a state-of-the-art magnetometer calibration system and several other instruments required for the vast network of observatories spread across India. IIG has made significant progress in areas of atmosphere-ionosphere coupling processes, forecasting of geomagnetic activity, numerical simulation of electric field structures in magnetospheric and other space plasmas, prediction of Solar Cycles 26 and 27 using statistical techniques applied to past data, atmospheric gravity waves, interdisciplinary research on ionospheric seismology, geological and geophysical aspects of Deccan Volcanic Province, etc.
I take this opportunity to congratulate and thank IIG colleagues for the scientific outcome that had emerged during the year 2021-2022 and wish them the very best for future endeavours.

A. P. Dimri
Director

August 16, 2022

Foreword

An important milestone was reached by Indian Institute of Geomagnetism during 2021-2022 as this year marked the Golden Jubilee year of the Institute. IIG has indeed come a long way from its modest network of a handful of observatories during early 1971 to a dozen of them as on date, which are spread across the length and breadth of the country. Three regional centres have also come up during this period expanding the array of activities designed, built and developed for specific locations across the country, be they near the geomagnetic equator in the southern tip of the Indian peninsula or in plains of the Ganges or in the seismically prone North-East region.

During February this year, IIG hosted online the 15th Quadrennial Solar-Terrestrial Physics Symposium (STP-15) (21-25 February 2022). The thematic scientific presentations were organized in three parallel sessions and conducted in three virtual halls named after Nanabhai Moos, James Van Allen and J C Bose. A special session on 'Geomagnetism - The Connecting Link between Sun and Earth' was included in the scientific programme of STP-15 to mark the Golden Jubilee Year of IIG and make this edition of STP symposia special. Preceding STP-15 Symposium, IIG had organized a 2-day workshop on 'Solar-Terrestrial Physics for Students and Young Scientists (STEPSYS)', wherein eminent scientists from the STP community worldwide were invited to give tutorials/lectures to students and young scientists on topics related to Sun-Earth connections. Recorded videos of all deliberations of both STEPSYS and STP-15 were made available offline for the benefit of the participants.

This year saw a good progress in our efforts to develop an Overhauser magnetometer in-house. Following experiments with various solvents, the desired stability of the prototype sensor has been achieved with a measurable signal level. Further progress towards realising the Overhauser magnetometer is expected in the coming year or two. It is important that the observatory staff are reasonably equipped to deal with instrument related noise, artificial disturbance and environment related effects on the collected. With that objective, a data analysis workshop was conducted between 2 and 4 March 2022 to give this kind of training to the observatory besides offering hands-on training on the data processing software and applications developed in-house. The importance of continuously monitoring the decline of the geomagnetic field from Indian Antarctic station, Maitri, comes from the need to monitor the evolution of reverse magnetic flux patches occurring deep inside the Earth. One of the ongoing experiments of IIG at Maitri has been yielding data to decipher the secular variation of the geomagnetic field in this part of the Antarctic. Interestingly, the rate of decline during the last decade or so has decreased and is currently touching approximately 65 nT/year. Long-term observations of Schumann resonance (SR) parameters from Maitri have revealed a close relationship between the SR frequency and the X-ray and the EUV fluxes. On the other hand, the amplitude of the Schumann resonances depends on the global thunderstorm activity.

Several studies undertaken at IIG this year have focused on understanding the temporal and spatial morphologies of equatorial plasma bubbles (EPBs) using a variety of data sets. Term-by-term analysis of flux tube integrated linear growth rate of Rayleigh-Taylor instability for the midnight to post-midnight occurrences of EPBs suggests the contributions from the elevated F layer over the magnetic equator, weak eastward electric field and an equatorward wind. When it comes to application of artificial neural network to retrieving electron densities using global assimilated data, the recent effort that utilised the FORMOSAT-7/COSMIC-2 data yielded electron density profiles more in tune with observations. An intriguing EPB event was observed over Panhala during the night of 22 March 2017 wherein oppositely drifting plasma bubbles were observed and an explanation is sought in terms of the combined effects of the vertical electric field inside the bubble and the background zonal electric field.

On the understanding of the coupling processes in atmospheric regions, rare simultaneous observations of sprites and gravity waves were made using the Transient Luminous Events (TLEs) camera and all-sky airglow imager, respectively, both from Prayagraj. Around this time on 30 May 2014, a large part of central India witnessed an intense mesoscale convective system. Alongside the observation of columniform sprites using the TLE cameras, the imager detected gravity waves in OH emissions at mesospheric altitudes. Similar periodicities were noticed in the ionospheric Total Electron Content (TEC) variations as well, highlighting the importance of such a study in understanding the whole atmosphere-ionosphere coupling.

A method to forecast the geomagnetic activity in real time using Ensemble Kalman Filter was successfully developed using assimilated data on Dst indices with initial estimates based on ring current injection and decay. The proton fluxes entering the Earth's inner magnetosphere and their temporal variation were assessed in terms of their L-value, energy and magnetic local time using ACE and WIND satellite observations at L1, besides Van Allen Probes, GOES-15 and POES-15 satellite data sets. The Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGM) simulation outputs representing ionosphere-thermosphere dynamics during geomagnetic storms were studied and the role of the y-component (By) of the interplanetary magnetic field was ascertained.

On the theoretical and numerical simulation front, the pitch angle distributions of charged particles in the inner magnetosphere were studied using test-particle simulations under conditions when the adiabatic invariants were conserved and not when conserved. The test-particle simulations were also carried out for the South Atlantic Anomaly (SAA) region, where there has been considerable weakening of the Earth's magnetic field. It was shown that associated with this consistent weakening, the inner boundary of the radiation belt in this region has been moving earthward at a rate of 4.1 km/year. In this scenario there are increased risks to the satellites in orbit, especially when they fly over this region, besides having a bearing on life and climate at large.

As the solar activity cycle 25 has started picking up, IIG scientists have predicted the upcoming solar cycles 26 and 27 to be similar or slightly stronger than the previous two cycles. Kinetic Alfvén waves (KAWs) are a set of ultra-low frequency (UHF) waves observed in different regions of the magnetosphere. A 3-component theoretical model is developed with an ion beam as a source of free energy to study the generation of kinetic Alfvén waves. On the one hand, the ion beam feeds energy and supports wave growth, on the other hand the presence of electrons having a non-Maxwellian kappa distribution seems to impede the growth rate of these waves. Another study used the THEMIS space probes to carry out a multi-point analysis of the source regions of the electromagnetic ion cyclotron (EMIC) waves.

Prolonged ionospheric perturbations centered at a frequency of 4 mHz following the April 2012 Sumatra doublet earthquake were observed in the GPS derived ionospheric TEC. These perturbations were noticed towards north-northeast direction from the epicentre. The spatial variations in the resonant ionospheric signatures arising from the 2011 Tohoku-Oki earthquake were also examined and the importance of non-seismic parameters therein for their proper understanding was emphasised. All-sky imaging airglow observations of atmospheric gravity waves in the altitude region of 85-100 are now subject to reverse ray tracing to identify their sources below. Several of the back-traced rays terminated in the lower mesosphere and only a few reached the stratospheric and tropospheric heights. It remains to be seen whether those waves whose ray paths terminated in the mesosphere itself are secondary waves generated by the breaking of primary waves at intermediate heights.

The Deccan Volcanic Province (DVP) was the focus area for much of our SEG related activities. The varied geological and geophysical aspects of DVP that were studied included paleo-climate, effects of weathering and diagenesis during and after sediment deposition, magmatism, structure, tectonics, evolution, saline water ingress, aquifer mapping and water quality along the coastal areas, the hydrological behaviour of aquifer system in hard rock terrain, the crustal deformation along the coastal areas with microseismic activity and geophysical and geochemical characterisation of geothermal springs. To improve upon the secular variation of the geomagnetic field specific to the Indian subcontinent, archaeomagnetic studies are being pursued at IIG. Under this programme, archaeological artefacts are brought to the laboratory and rock magnetic investigations carried out in detail.

When it comes to publications by IIG scientists, there were 58 papers published in SCIE journals with a cumulative impact factor of 197.3, and impact factor per SCIE journal being 3.02. There were 65 papers presented in national and international conferences during this period. The Institute pursues an active science outreach programme. Besides conducting several in-house events, the outreach team had participated in events conducted elsewhere like the 7th India International Science Festival held in Goa during 10-13 December 2021 and the Shining Maharashtra 2022 held at Phaltan, Maharashtra, during 25-27 March 2022.

The scientific outcome of the Institute during this year has indeed been laudable as can be seen in several high quality scientific papers that had emerged. We express our gratitude to the members of the Research Advisory Committee and the Governing Council of IIG for their keen interest and encouragement towards the pursuit of our scientific activities.

S Gurubaran
Professor ‘G’

GEOMAGNETIC DATA-BASED RESEARCH

MAGNETIC OBSERVATORIES AND GEOMAGNETISM FROM THE INDIAN SUBCONTINENT AND POLAR REGIONS (MOGPR)

Chief Coordinator : Geeta Vichare

Members : All technical staff of ODA at HQ and other observatories; All instrumentation division staff at HQ and EGRL; All WDC staff, Gopi K. Seemala

Observatory maintenance and installation

Institute's magnetic observatories house various instruments such as DFM, DIM, PPM, and Overhauser magnetometer for magnetic field measurements. Indigenously developed PPMs for absolute magnetic field observations are used in all the IIG observatories. To equip the observatories with PM-7 (0.1nT), 2 units of PPMs were assembled, tested, and calibrated at LAB. These units were installed at Nagpur and Puducherry observatories after comparing them with Alibag standard PPM.

A survey was conducted at MO Jaipur for a suitable location in the observatory premises, to shift the absolute observations from the existing location due to the noise coming from new construction on outside premises.

IIG make data logger was installed at Sabhawala Observatory, Survey of India; and also data loggers were installed at MO Visakhapatnam and MO Nagpur.

Routine maintenance activities of observatory instrumentation were done from time to time for continuous operation of the observatory setup.

WDC Colaba and INTERMAGNET

IIG hosts the World Data Centre (WDC) for Geomagnetism, Mumbai as part of the World Data System (WDS) established by ICSU. Users from all over the globe get registered and access/download the data from the WDC website (http://wdciig.res.in) for their scientific usage. The process of switching over from MPLS (Multi-Protocol Label Switching) technology to ILL (Internet Lease Line) technology for point-to-point connectivity link between observatories and HQ with enhanced bandwidth for better communication facilities to transfer data and video conference, has been completed.

INTERMAGNET is a global network of observatories, monitoring the Earth's magnetic field, and adopting modern standards for measuring and recording equipment in order to facilitate high-resolution data exchange in near real-time. IIG is a participating Institute in this programme. Earth's magnetic field data received from ALIBAG and JAIPUR are processed and emailed to Kyoto GIN in near real-time. These data can be viewed as Quick-Look plots at the Kyoto website (http://wdc.kugi.kyoto-u.ac.jp/plot_realtime/intermagnet/index.html).

Development of Instrumentation

Following development work continued in order to achieve the target during the year.

1) Significant progress of IIG make Overhauser magnetometer has been achieved during 2021-22. The sensor stability has been achieved with vacuum sealing. Different solvents are being tested for the improvement of the signal-to-noise ratio. Currently, the prototype sensor exhibits stability with a signal level comparable to that of commercially imported equipment.
2) As an ongoing process of IIG PPM up-gradation, electronics are being tested for improved precision and sensitivity.
3) Preliminary study is going on for temperature regulation using an alternative method that will not induce noise and maintain stability.
4) Windows-based DFM data logger Software developed in Labview is modified to be compatible with windows 8 and installed at Tirunelveli and Nagpur. Development of Linux-based data logger software in Python Language is initiated.

ODA workshop

In order to produce a definitive time series from a set of variometer records and absolute measurements, quite rigorous data processing is required. To maintain the desired quality level, observatory data require accurate and reliable data management procedures through inspection, correction, baseline derivation, to preparation of data for publication. Data processing practice and procedure have to be rigorous, and consistent in order to ensure the homogeneity of data for a large period of time. In view of this, a workshop on geomagnetic data processing has been conducted from March 2-4, 2022 to give the data processing training to observatories staff. In this workshop training has been given on how to compare the data, how to identify and correct various types the noise, shift, artificial disturbance and time synchronization errorsthat appear in daily data. Hands-on training on data processing software which was developed in-house has been given to all observatories and processing staff.

Barometric pressure correction to gamma-ray observations and its energy dependence

It is well known that atmospheric pressure plays a vital role in the secondary cosmic rays (SCR) flux observed on the ground. Barometric pressure correction is a standard practice for neutron monitor (NM) data. For gamma-rays, however, being massless, their pressure dependence is not intuitive. Nevertheless, the pressure affects the particles such as electrons, positrons, and muons, which produce gamma rays in the cascade. Subsequently, the indirect pressure dependence of the gamma-ray flux can be anticipated. This aspect has been examined in detail by studying the gamma-ray counts detected by the NaI (Tl) detector. The study confirms that there is no correlation between the atmospheric pressure and the total counts covering the entire energy range (150 keV -10 MeV) recorded by the NaI detector. However, the scenario differs when the fluxes of different energies are investigated separately. It is observed that the counts of energy above 3 MeV are well anti-correlated with the atmospheric pressure. The barometric coefficient obtained here matches well with that reported by the previous studies which used anti-coincidence methods. It is demonstrated that applying the barometric correction formula to NaI (Tl) data successfully removes the pressure dependence in the flux above 3 MeV. Therefore, it is suggested that the particle flux data above 3 MeV measured by NaI (Tl) detector needs to be corrected for the local atmospheric pressure variations.

Polar Science Research

Indian Scientific Expedition to Antarctica

Two winter members i.e. one each for Maitri and Bharati and one summer member for Maitri were deputed for the expedition. All the experiments at both stations are running uninterrupted. Measurements of total magnetic field at Maitri in campaigns and by IGRF model had indicated large decline in magnetic field (~ 110 nT/year) at Maitri during the last few decades. However, the continuous monitoring of geomagnetic field at Maitri indicates that recently it is reducing at a rate of approximately 65 nT/year. A systematic rapid decline in the Earth's complex main magnetic field is important for monitoring the evolution of reverse magnetic flux patches due to physical processes occurring in the outer core of the Earth.

Global Electric Circuit

The Global Electric Circuit (GEC) studies were started to understand the solar-terrestrial relationship and associated changes in surface weather and the near-earth electrical environment. The observed diurnal variation is explained in terms of the dominant thunderstorm activity centered over the three convectively active regions, viz. Asia/Maritime Continent (Indonesia), South America and Africa. Atmospheric electric field variations during fair weather days in Maitri do not follow Carnegie Curve during summer time rather they are influenced by wind speed and direction.

Initially it was presumed that the Antarctic continent is the most suitable location for this study. Further investigations reveal that this is true as far as the Antarctic Plateau concerned. The coastal Antarctic regions has some in-situ electrical signals pertaining to the regional issues. Those issues are identified and the favourable conditions to detect the global representative data are obtained. The diurnal and seasonal variations observed and they are, most probably, the first of its kind in the coastal Antarctic region. As show in Figure 1, the strong diurnal variations in summer are attributed to the varying meteorological weather parameters and more particularly the Lenard effect that could arise from the melt water of the lake.

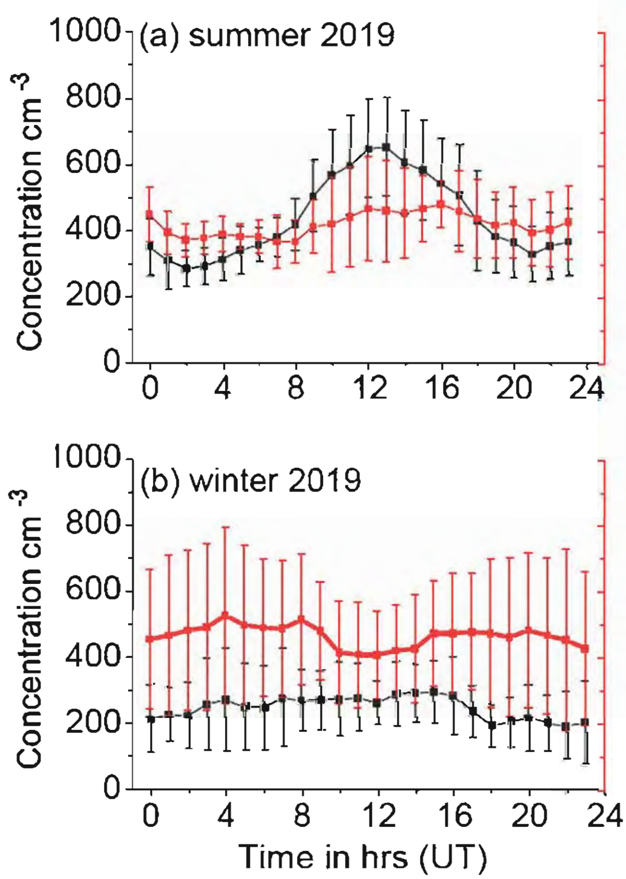

Figure 1 Hourly mean diurnal variation of the concentration of negative ions (Black curve) and positive ions (Red curve) for a selected fair-weather days.

Schumann Resonances (SR)

SR is a global electromagnetic resonance phenomenon generated by global lightning discharges within the Earth-ionosphere cavity. The 1st harmonic is at nearly 8 Hz and subsequent harmonics are separated by approximately 6 Hz. Intensity of Schumann resonance directly depends on overall thunderstorm activity over the globe as well as on the source-observation distance, whereas SR frequency depend on the dielectric permeability of the ionospheric D region. The regular diurnal variation of D region ionization resulting from solar zenith angle variation cause a systematic change in SR frequency, whereas a sudden ionospheric disturbance (SID) e.g. Solar flare, gamma ray burst and high-energy particle precipitation not only enhance the ionization in D region, but also modify the altitude of D region which cause a transient change in SR frequency. In this study, attempt has been made to study variation in the first order frequency of the Schumann resonance during such events. Also, the effects of solar cycle variation are also studied as shown in the Figure 2. Schumann resonance frequency increases significantly in both the field components (HNS and HEW) during solar X-ray flare. Increase in SR frequency during solar X-ray flare indicates that the reflection height (*h*2) of ionosphere is reduced. Long term variations of SR frequencies are in phase with variation of X-ray flux and solar radio emission as shown here.

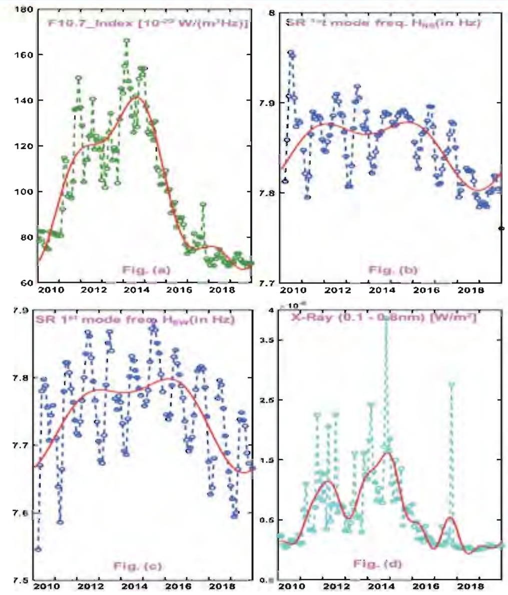

Figure 2 The figures (a), (b), (c) and (d) represent monthly mean of solar radio emission (F10.7_Index) , Peak frequencies of 1st SR mode in north-south (HNS), Peak frequencies of 1st SR mode in east-west (HEW) and Solar X-ray flux (0.1-0.8nm), from Jan 2010 to Dec 2019 respectively. Red curve in all figures represent filtered (periodicity more than 6 month have been removed) data of respective element.

UPPER ATMOSPHERIC RESEARCH

NEUTRAL AND ELECTRODYNAMICAL COUPLING OF THE ATMOSPHERE-IONOSPHERE SYSTEM (NECLAS)

Chief Coordinator : S. Sripathi

Coordinator : B. Veenadhari and S. Tulasiram

Members : S. Gurubaran, Geeta Vichare, Mala S. Bagiya, R. Ghodpage, Manohar Lal, P.T. Patil, Vinit C. Erram, K. Jawahar, C. Selvaraj, N. Venkatesh, K. Emperumal, Prabhakar Tiwari and S. Banola

Quasi-2-day Wave Coupling of the Atmosphere-Ionosphere System at low to mid-latitude

Planetary waves play a major role in the short-term variability of the Atmosphere-Ionosphere system. These global scale waves grow in the amplitude with increasing altitude and dominate the wind fields in the MLT and the ionosphere. Among the various normal mode oscillations 2-day wave is one of the most explored features of the neutral atmosphere as its transitory occurrence has significant impact on the MLT dynamics and the thermosphere-ionosphere system. An unusually strong quasi-2-day wave (Q2DW) activity in the mesosphere was observed by MLT radars at Kolhapur (74°E, 17°N), Pameungpeuk (108°E, 8°S), Cachoeira Paulista (45°W, 22°S). A detailed analysis had revealed that the 2-day wave activity was due to a W3 (westward propagating zonal wavenumber 3) mode. This activity with large amplitudes (~60 m/s) had affected background wind field and significant reduction in diurnal tide amplitude was observed during the activity. We used bispectrum analysis to study the interaction of dominant wave modes and the generation of secondary waves. We observed 16-hour oscillation in the presence of Q2DW and tide frequencies which might have been generated through nonlinear interaction of these parent waves.

Geomagnetic field variations prove to be a great tool for observing ionospheric variabilities. Most of the quiet time variabilities in the ionospheric Sq currents are caused by atmospheric waves. The Q2DW activity in the month of January 2015 has been observed through 23 ground based geomagnetic stations from the tropical region of both hemispheres. The 2-day oscillations were evident over almost all the stations. Among the X-, Y-, and Z- components of the magnetic field, the Y-component is exhibiting a clear 2-day oscillation as it is the least affected by any external activity. The observed oscillations agreed well with the MLT region Q2DW in terms of period and occurrence time. The geomagnetic stations were chosen over different longitudes to retrieve the zonal structure of the activity at the dynamo region heights. We used harmonic analysis to get the phase of the fundamental harmonic of 48-hour period. These phase values were then used to obtain the zonal wave number of the activity, which was strikingly very similar to the zonal wave number retrieved for MLT winds. Figure 3, shows the phase-longitude cross-section with slope nearly equal to 3. This indicates the presence of a westward propagating wave with zonal wave number 3 at these heights. The outcome from the present study is very promising and there is a plenty of scope to obtain greater insights of wave coupling of the atmosphere-ionosphere system using this kind of approach in future.

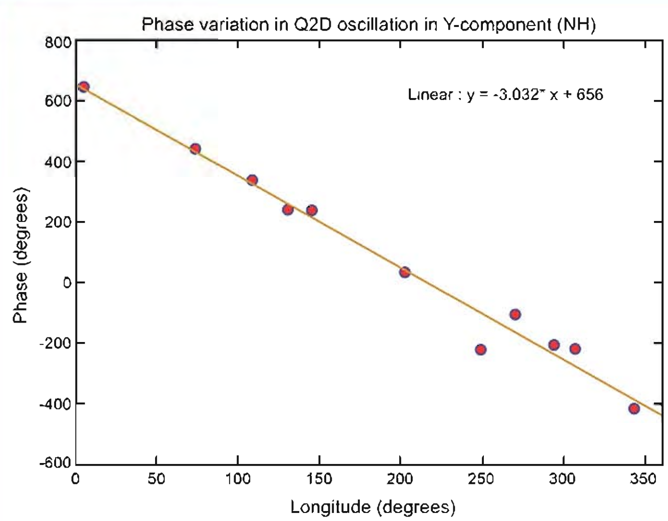

Figure 3 Variation in phase of the quasi-2-day wave (Q2DW) manifesting in the Y-component of the geomagnetic field across various longitudes in the Northern Hemisphere low latitude region.

Solar Activity dependence of midnight EPBs

The occurrence of midnight Equatorial Plasma Bubbles (EPBs) during the June solstice period of the ascending phase of solar cycle 24, from 2010 to 2014, was investigated using data from the 47 MHz Equatorial Atmosphere Radar (EAR) at Kototabang, Indonesia. It is shown that the occurrence of midnight hour EPBs was at its maximum during the low solar activity year 2010 and monotonically decreased thereafter with increasing solar activity. Details of the dependence of midnight hour EPB occurrence on solar activity were investigated using SAMI2 model simulation with a realistic input of E × B drift velocity data obtained from the CINDI-IVM on board the C/NOFS satellite. The term-by-term analysis of the flux tube integrated linear growth rate of RT instability indicates that the formation of a high flux tube electron content height gradient (steep vertical gradient) region at higher altitudes, due to the elevated F layer, is the key factor enhancing the growth rate of RT instability during low solar activity June solstices. Other factors that also contribute to the generation of EPBs around midnight hours are the relatively weak westward zonal electric field in the presence of the equatorward neutral wind and north-to-south transequatorial wind around the midnight hours of low solar activity June solstices (Figure 4).

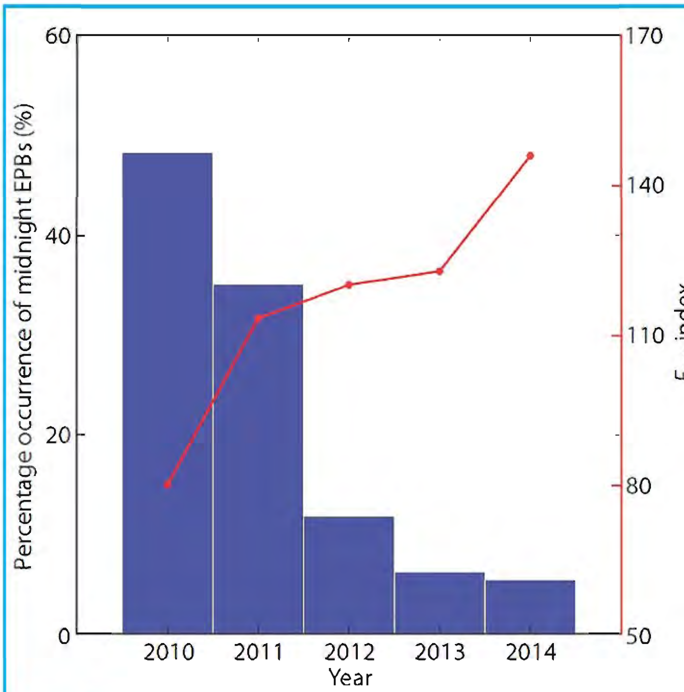

Figure 4 Occurrence of freshly developed EPBs around midnight hours of June solstice and the variation of solar activity (F10.7 cm solar flux)

Improved Abel retrieval for GNSS-RO using real-time data assimilation

The assumption of spherical uniformity while the retrieval of electron density profiles from the Global Navigation Satellite Systems-Radio Occultation (GNSS-RO) observations is often violated and introduces significant errors in the retrieved electron density profile data. In this context, an improved Abel-inversion technique is developed by incorporating the horizontal gradients in the ionosphere, which are routinely derived from the Artificial Neural Network (ANN) based background NmF2 (peak electron density of F2-layer) model (ANNC2) assimilated with near real-time Constellation Observing System for Meteorology, Ionosphere, and Climate-2 (FORMOSAT-7/COSMIC-2) NmF2 data. The ANNC2-aided Abel inversion is then implemented for more accurate retrieval of electron density profiles from COSMIC-2 in real-time. It is found that the ANNC2-aided inversion has improved the electron density values around the F2-region and below, which yields a clear separation between two anomaly crests. Further, the ANNC2-aided Abel inversion had significantly reduced the artificial plasma caves beneath the equatorial ionization anomaly crests. Furthermore, COSMIC-2 NmF2 observations obtained from both classical and the ANNC2-aided Abel inversion are compared with the ground-based Digisonde data and found that the ANNC2-aided inversion gives the better results. This study provides some new insights on the aided Abel inversion technique assisted by ANN models for the real-time correction of Abel retrieved electron density profiles (Figure 5).

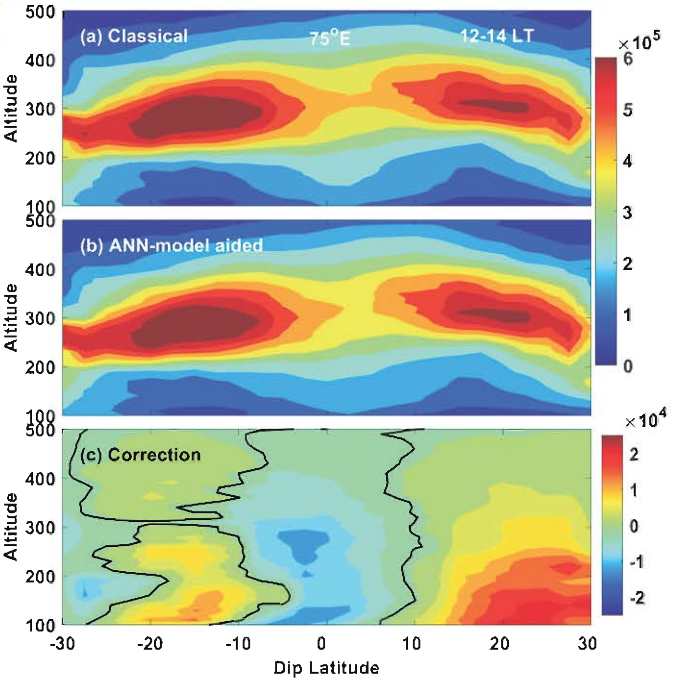

Figure 5 Dip-latitude and altitude distribution of electron density retrieved using (a) classical Abel, (b) ANNC2-aided Abel and (c) the correction/improvement in the ANNC2 aided method.

Intriguing Equatorial Plasma Bubble Event over Indian Sector

An interesting event of Equatorial Plasma Bubbles (EPBs) has been observed during the night of 22-23 March 2017 over Panhala temporary station where two EPBs were drifting in different directions. It is possible that this is the first evidence of differential drifts of EPBs recorded in an all-sky imager (ASIA) in a narrow longitudinal zone over the Indian region. To investigate the dynamics of these observed EPBs and their differential drifts, we analyzed multi-instrument observations as obtained with ASI, Canadian Advanced Digital Ionosonde (CADI) from Tirunelveli and ionospheric backscatter echoes data of Gadanki Ionospheric Radar Interferometer (GIRI) radar from Gadanki. The optical observations from Panhala reveal clear signatures of EPBs from 1630 UT onwards which were also recorded in Range time intensity map obtained by GIRI and corresponding ESF occurrence was also noted in CADI at Tirunelveli. On this night, two EPBs (EPB1 and EPB2) are observed with inter-depletion distance of ~600 km. The EPB1 drifts eastward and evolves with time as bifurcated structures while the trailing EPB2 drifts eastward initially and eventually drifts westward. The sequential nightglow images obtained in OI 630.0 nm emission on the night of March 22–23, 2017 are shown in Figure 6. These are the processed and unwrapped images having 140° FoV. The spatial scales pertaining to the observations are marked in the first image, while, the vertical and horizontal white strips marked in the second image are for the keogram analysis to investigate the latitudinal and longitudinal variability, respectively. During this night, we observed several EPBs. The two EPBs which are most prominent and are main focus of this study are marked as EPB1 (yellow arrow) and EPB2 (red arrow). The first EPB that appeared in the images around 1,600 UT is henceforth referred as EPB0 for the sake of easy understanding. EPB0 drifts eastward between 1,600 and 1,730 UT and after that, it got diminished and could not be clearly identified. Afterward, another three EPBs appeared between EPB0 and EPB1. One of these EPBs is situated very close to EPB1 and to the east of it. All these three intermediate EPBs between EPB0 and EPB1 are seen to move eastward. However, they are not the focus of this study. The EPB1 exhibits growth in the apex altitude between 1,641 and ~19:30 UT while drifting to the east. Around 1,930 UT, EPB1 reached the north most limit of our ASI FoV. Afterward, it might have propagated to higher apex altitudes which could not be ascertained from our images. At ~1,700 UT, EPB1 starts bifurcating with poleward expansion suggesting that EPB developed to very high altitudes. These structures (i.e., EPB1) got diminished after ~2, 153 UT. On the other hand, EPB2 started appearing into the FOV at ~18:30 UT as shown by red arrow in Figure 6. At around 19:17 UT, EPB1 and EPB2 had a separation of about ~600 km at zenith. It is noted that, similar to the EPB1, EPB2 also diminished after ~21:53 UT. To examine this differential nature of the drift velocity, the drift velocity estimated for the finger-like structures Bf1–Bf6 associated with EPB1 and are denoted as DV1..., DV6 etc are plotted in Figure 7. Upward tick arrows show that drifts were eastward while the downward tick arrows show westward drift.

Shown together with the ticks is the duration of the noted bifurcation. It is seen that drift velocity in general reduces as the longitude decreases. This suggests that EPB2 had external effects on its polarized electric field more than the EPB1. This is understandable from the view that EPB movements in general are a combined impact of vertical electric filed inside the bubble arising due to plasma polarization and background zonal (horizontal) electric fields. However, the polarization field inside EPB is upward; this means that the plasma inside EPB experiences two vertical fields: downward field due to background dynamo and upward field due to polarization.

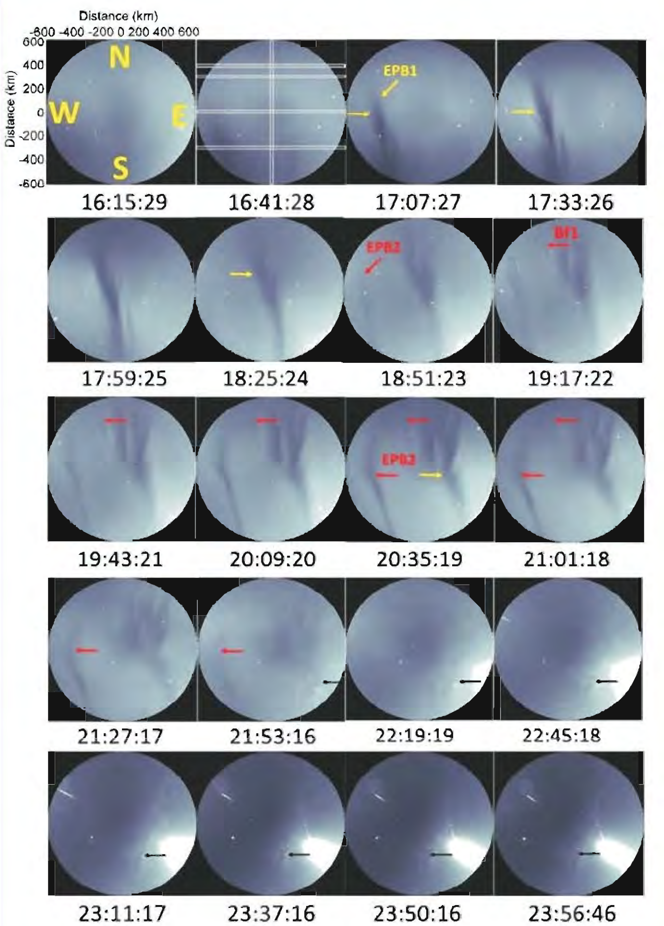

Figure 6 Shows the temporal sequences of unwrapped images of ASI with 140° field of view on March 22–23, 2017. The yellow and red arrows depict EPBs with differential zonal drifts. The time shown at the bottom of each image is in UT. The east-west and north-south distances in first image (top) are shown in kilometers. The bright region in last couple of images depicts the local moon entrance and the black arrows indicate the direction of milky-way galaxy.

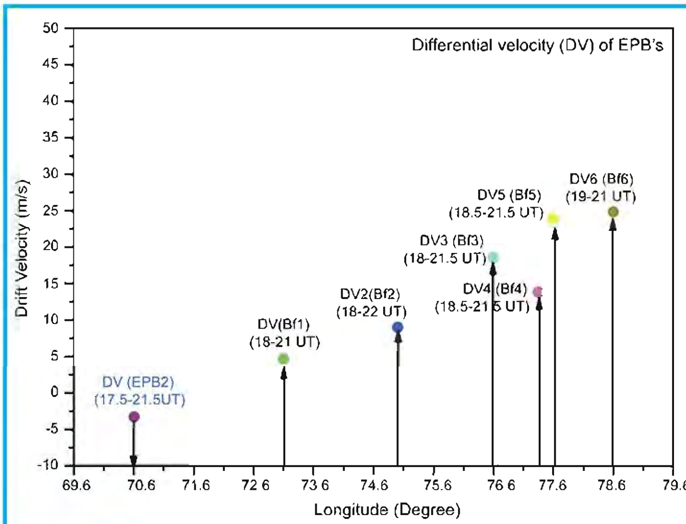

Figure 7 Shows the differential velocities of Equatorial Plasma Bubble2 (EPB2) and bifurcated structures of EPB1 namely Bf1, Bf2, Bf3, Bf4, Bf5 and Bf6 with respect to longitudes. The downward arrow shows the westward motion while upward arrow shows the eastward motion. The length of the arrow gives the average magnitude of the drift velocity.

Response of the storm-time electrodynamics under dawn and dusk sectors

It is known that the electrodynamics of the equatorial and low latitude ionosphere is significantly modified during geomagnetic storms due to convection electric fields and thermospheric winds at high latitudes. It is investigated that the ionospheric response during the main and recovery phases of the geomagnetic storm on December 20–21, 2015 as seen by the CADI ionosonde. This storm is third major storm after St Patrick's Day Geomagnetic storm in the year 2015. Figure 8a shows the variation of virtual height (h'F, in km) of F layer in red color during 12:00–12:00 IST on December 20–21, 2015 along with mean variation of h'F at every 15 min for the entire month of December 2015 shown in blue color with error bars. The light black color scatter plots show the variations of h'F during the month of December and bold black color lines representing the onset and duration of spread-F irregularities. The orange color shaded regions show the time of twin PRE in the post-sunset and height enhancement in the morning hours (morning hours PRE). Figure 8b depicts the height-time-frequency (HTF) variation at different frequencies, ranging from 4.0 to 9.0 MHz. This Figure 8b also shows nicely the rise of height in the post-sunset and post-midnight with smaller oscillations throughout night. From the both of these two figures, it can be seen that the height rise at twin times is ~400 and 375 km respectively (see point 1 and 2) with a dip at ~20:30 IST is observed between ~18:00 and 21:00 IST. This dip is reaching its value of ~270 km. Thereafter, h'F shows minor oscillatory behavior in its value during the remaining night time between 21:00 and 03:00 IST (shown by points 2, 3, and 4). However, during the pre-sunrise hours at ~05:30 IST, a conspicuous enhancement is observed in virtual height where the height reached its maximum altitude of ~600 km with ~50 m/sec vertical drift which is higher than the post-sunset drift. This produced ESF irregularities for a brief period in the ionosonde observations.

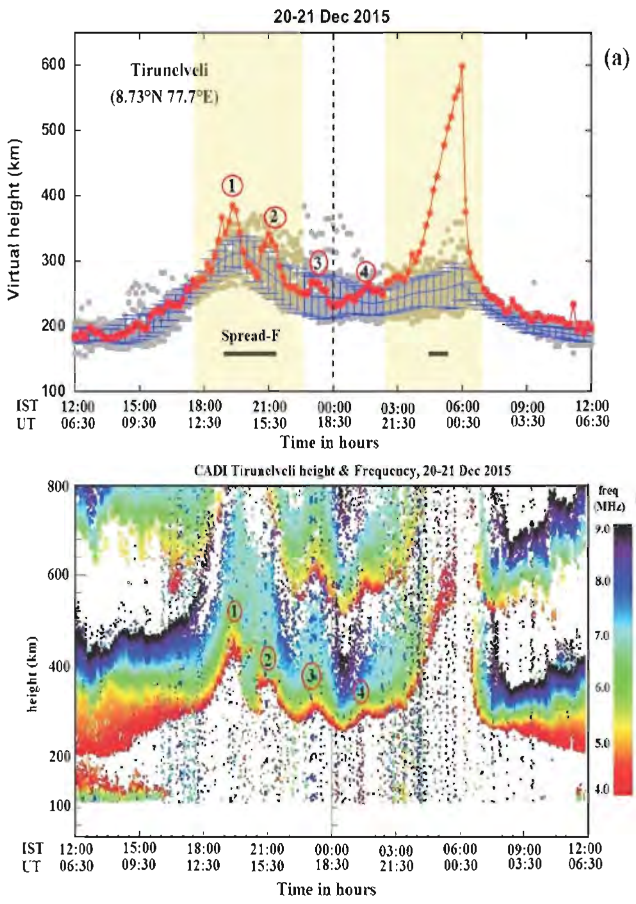

Figure 8 Temporal variation of nighttime ionospheric parameters namely (a) Virtual height (h'F) in km (red) along with mean of h'F on entire month of December 2015 at Tirunelveli. The shaded vertical boxes during the 17:00–23:00 IST and 01:00–07:00 IST indicate the evening and pre-sunrise hour height enhancement. (b) The variation of Range-Time-Frequency (RTF) at frequencies between 4 and 9 MHz on December 20–21, 2015.

To understand the storm and substorm driven electric field disturbances, we have performed a analysis using the wavelet, cross wavelet and wavelet coherence techniques. Figures 9a–9f shows the temporal variation of drift and IEFy and AE indices (a, b, and c) along with a smoothed curve based on the SG algorithm (red), residual curve (black) and their wavelet spectrum (9d, e, and f) on their residuals between 17:30 and 07:30 IST on December 20–21, 2015. From the Figure, it can be seen clearly that residual of vertical drift believed to be correlated with residuals of both AE and IEFy at times (showed in the pink color shaded region). The wavelet spectrum analysis shows smaller and larger dominant periods with period of ~20 and 50–70 min in drift, IEFy and AE indices. The observations of twin episodes of pre-reversal enhancement (PRE) in the dusk sector is attributed to undershielding and overshielding conditions respectively. In the midnight to post-midnight, the h'F (km) and drifts have undergone several oscillations with their highest peaks occurring in the dawn sector. Using just wavelet analysis, it appears difficult to identify source terms that are playing dominant role. Accordingly, we examined the cross wavelets and wavelet coherence. Figures 10a–10d shows the cross wavelet (left) and wavelet coherence (right) analysis of vertical plasma drift between (a) IEFy and (b) AE index respectively. From the Figures 10a and 10b it can be seen that dominant periods are ~20–70 min between ~20:00 and 23:00 IST and ~20–70 min between 03:00 and 06:00 IST. However, wavelet coherence analysis shown in Figures 10c and 10d suggest that ~15–30 min periods are in phase between drift and IEFy at ~18:30–20:00 IST. So, this study brings out that it is possible to isolate the source terms using cross wavelet and wavelet coherence. In addition, presence of large upward vertical plasma drift and occurrence of fresh plasma irregularities in the dawn sector is suggested to be linked to the eastward DD electric field.

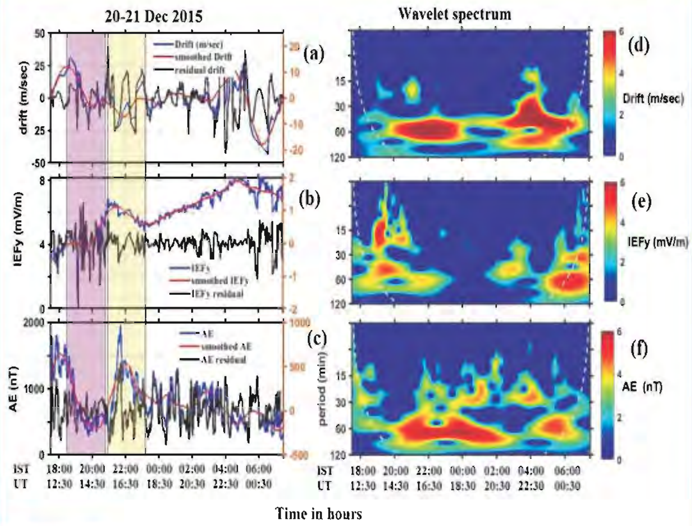

Figure 9 (Left) the blue color lines show the variations in vertical drift, solar wind velocity, and interplanetary electric fields (IEFy) between 17:30 and 07.30 IST on December 20–21, 2015, red color lines represent smoothed value of respective parameter and black color lines represent residual value. The shaded vertical boxes indicate the in phase and out of phase variations of residual value of drift, IEFy and auroral electrojet (AE), and (d–f) (right) Morlet wavelet spectrum analysis of respective parameters during the same period.

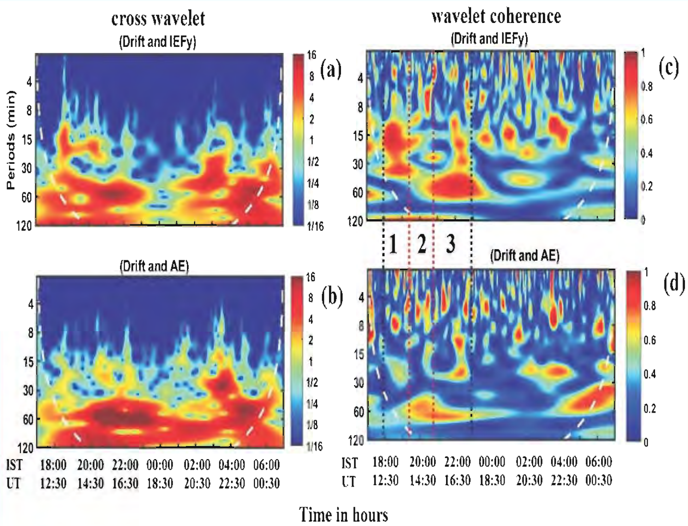

Figure 10 Cross-wavelet (Morlet) analysis between drift (residual) and residual of (a) interplanetary electric fields (IEFy), (b) auroral electrojet (AE) index, and wavelet coherence between drift (residual) and residual of (c) IEFy, and (d) AE index between 17:30 and 07:30 IST on December 20–21, 2015. Region-1 (between black and red vertical lines) shows times when ~30 min period in drift are similar/in phase with IEFy but out of phase with AE, region-2 indicates times when (between two vertical lines) ~60 min period in drift are similar/in phase with AE but out of phase with IEFy, and region-3 represents times when ~20 and 60 min periods are similar/in phase between drift, IEF and AE.

Longitudinal variation of ESF at two nearby equatorial stations

The equatorial spread-F (ESF) statistics at two stations near the magnetic equator and longitudinally separated: Tirunelveli (TIR) station (8.73°N, 77.7°E; geomagnetic latitude: 0.32°N), India and Chumphon (CPN) station (10.7°N, 99.4°E; geomagnetic latitude: 3.0°N), Thailand have been investigated during the low solar activity (LSA) in 2008 and the high solar activity (HSA) in 2014. In particular, the range-type spread F (RSF) statistics are extensively analysed. The ESF occurrence percentages, durations, and its day-to-day variabilities are studied. At both stations, the percentages of the ESF occurrences are generally higher as the F10.7 solar flux values increase, therefore, resulting in more occurrences in HSA than LSA. The percentages of the ESF occurrences could reach up to 50% and 90% during LSA and HSA, respectively. The post-midnight ESF occurrences are more frequent at TIR station than CPN station. The onset time analyses of ESF events show that during HSA (2014), the ESF onsets at TIR station are earlier than CPN station by 15 min to 1 h and as frequent as 72% in each month. During LSA, the long ESF durations are observed at TIR station more frequently than at CPN station. In addition, the comparison between the observations and the predictions of the IRI-2016 model shows that the overestimations of the IRI-2016 model are up to 33% during LSA, but underestimations of the model are up to 25% during HSA.

Obscured growth of an equatorial spread-F associated airglow depletions observed near the EIA crest under the influence of reverse fountain effect

Under the influence of the backward motion of the EIA towards equator, plasma depletions showed an obscured poleward growth. During the EIA retreat's maximum phase, its poleward extension was restricted to about one-third of field-of-view. As the EIA decayed, its apex extended poleward. Later the depletion started disappearing in the background near midnight hours, thereby resulting in formation of few isolated depletions. Present observation of an obscured poleward growth of airglow depletions under the influence of EIA retreat is rare and demand further investigation.

An imaging evidence of the east wall structuring of eastward drifting depletions observed near the EIA crest in India

Generally the west (east) wall of eastward (westward) drifting airglow depletion is unstable to eastward (westward) drifts and hosts secondary instabilities. Present study features the rare occurrences of their growth on the east wall of an eastward drifting depletion. Concerned depletion was linear in the beginning and had a significant westward tilt; however, several structuring developed on both its walls as it drifted eastward. First prominent one occurred on its west wall that later swiftly surged poleward and bifurcated like usual depletion i.e. was like a secondary depletion. Second west wall structuring followed this one but had considerably subdued growth. Simultaneously, main depletion bent slightly eastward above its branching node and two structuring appeared on the east wall in succession. Secondary depletion then too developed structuring on its east wall that later extended eastward and got linked with main depletion. Second west wall structuring later disappeared; while, those on the east wall swiftly evolved, surged poleward and gained prominence. During the occurrence of these events, gravity waves and the retreat of equatorial ionization anomaly were active overhead. Current observations show that the east wall of a westward tilted depletion can become unstable and host secondary instabilities.

SPACE WEATHER: OBSERVATIONS AND MODELING (SWOM)

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Forecasting Geomagnetic activity (Dst Index) using the ensemble Kalman Filter

A novel Ensemble Kalman Filter method to forecast the geomagnetic activity (Dst-index) has been developed. The EnKF makes an educated forecast of Dst using the information about the previous Dst value and state dynamics like ring current decay and injection rates based on the solar wind parameters. This forecasted Dst is further updated with the direct measurements like Dst or indirect measurements like Δ H from a ground-based magnetometer at a single low-latitude station, Alibag. This method is thoroughly validated with the true Dst values provided by the WDC, Kyoto University under a severely disturbed geomagnetic activity period in the year 2001 (day number 1 to 300) which consists of 2 superstorms, 8 intense storms and nearly 13 moderate storms. This EnKF method assimilated with true Dst found to provide very accurate forecasts on the next state of Dst compared to the other empirical models during the geomagnetic storms of different intensities (Figure 11). Further, the EnKF method also provides accurate forecasts of Dst even with assimilation of ΔH measurements from a single low-latitude magnetometer observations. This EnKF is a very promising method to make a reliable forecast of Dst in real-time applications.

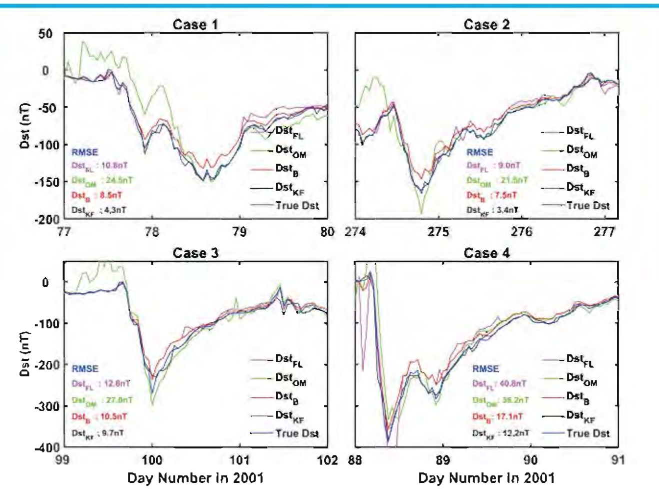

Figure 11 Comparison of Dst forecasts by Ensemble Kalman Filter (EnKF) method with other empirical methods during the geomagnetic storms of different intensities.

Diurnal UT Variation of low Latitude Geomagnetic Storms Using six Indices

The occurrence of Geomagnetic storms was found to show a pronounced quasi-semidiurnal pattern of their peak negative Dst times in universal time (UT). However, the solar wind parameters (like V, N, IMF Bz) do not show any UT preference. The quasi-semidiurnal UT pattern of storm occurrence has been argued as apparent due to uneven longitude distribution of the four Dst observatories. Unlike earlier studies, this study investigates the diurnal UT variation of the storms automatically identified in six available indices including Kyoto Dst, USGS (United States Geological Survey) Dst, SymH (symmetric-H), RC (ring current), Dcx (corrected extended Dst) and AER (Atmospheric and Environmental Research) in 50, 50, 36, 21, 5 and 7 years, respectively. The indices are derived using 4, 4, 12, 14 and 14 ground observatories (with maximum longitude separations of ~120°, 120°, 70°, 110° and 50°) and 4 DMSP (Defense Meteorology Satellite Program) satellites, respectively. The UT distribution of the storm intensity (minimum value of an index during the storm main phase) in all indices shows a striking quasi-semidiurnal variation with maxima around 06-08 UT and 21-23 UT and minima around 03-05 UT and 13-15 UT. Similar variation also exists in the computed value of the main energy input in the ring current. The quasi-semidiurnal variation correlates well with the variations of the dipole tilt angles μ and θ involved in the equinoctial hypothesis and Russell–Mcpherron (RM) effect, respectively. The variation seems real and can be explained by the physical mechanisms of equinoctial hypothesis or RM effect or their combination.

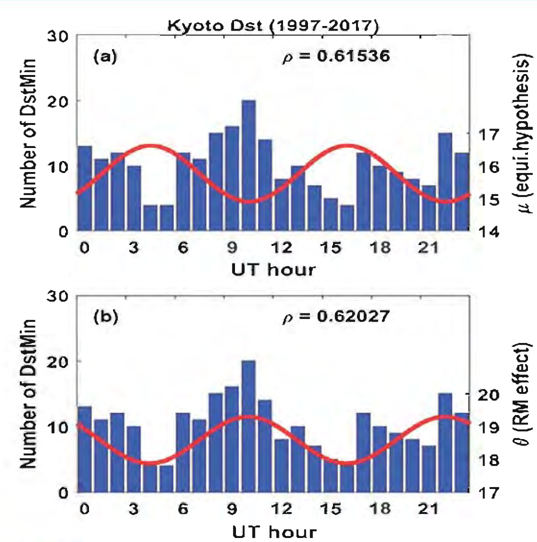

Figure 12 Quasi semi-diurnal UT variation in the peak negative Dst occurrence and its relationship with dipole tilt angles involved in the Russell-McPherron effect and Equinoctial hypothesis.

Quantitative assessment of protons during the solar proton events of September 2017

It present multi-spacecraft observations of the proton fluxes spanning from 1.5 to 433 MeV for the largest solar proton event of solar cycle 24, i.e., September 7 and 10, 2017. In September 2017, M5.5 flare on September 4, X9.3 flare on September 6 and X8.2 flare on September 10 gave rise to solar proton event when observed by near-Earth spacecrafts. On September 7 and September 10, 2017, a strong enhancement in the proton intensities was observed by Advanced Composition Explorer (ACE) and WIND at L1 and Van Allen Probes, GOES-15 and POES-19 in the Earth's inner magnetosphere. Below geosynchronous orbit, Van Allen Probes and POES-19 show that no significant proton flux was observed with energies < 25 MeV on September 4, while the fluxes peaked 3 to 7-times during September 7 and by 25 times during the third proton flux event on September 10, 2017. The measurements from multiple spacecrafts located in the different regions of the Earth's magnetosphere show that the increased level of solar proton flux population persisted for ~ 2 days. Thus, It is quantified that the temporal flux variability in terms of L-value, energy and MLT.

Influence of IMF-By on the equatorial ionospheric plasma drifts: TIEGCM simulations

The influence of east-west component of interplanetary magnetic field (IMF-By) on ionospheric plasma convection over polar region is well established by both observation and modeling studies. However, its influence beyond polar latitudes has rarely been addressed. To understand the effects of IMF-By at low-latitudes during geomagnetic storm times, we have designed simulation experiments using Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) Figure 13, and found that strong IMF-By and its polarity has effects on the storm-time ionosphere-thermosphere dynamics even near equator. It can change zonal electric field, magnitude of morning/ evening time pre-reversal-enhancements (PRE) and meridional winds. At the storm onset when prompt penetration electric fields prevail, a strong IMF-By, in general, reduces the vertical plasma drifts over the equator and the largest effects are observed near sunrise and sunset terminators. Later when disturbance dynamo is active, morning PRE appears, and a strongly positive IMF-By strengthens morning PRE and weakens evening PRE, with respect to zero IMF-By conditions. A strongly negative IMF-By just shows the reverse, thus indicates dawn-dusk asymmetry due to IMF-By. It is also seen that the meridional winds are oppositely directed during positive and negative IMF-By conditions. The effects of IMF-By transition are observed on the evening PRE within 2 hours from the transition (Figure 14).

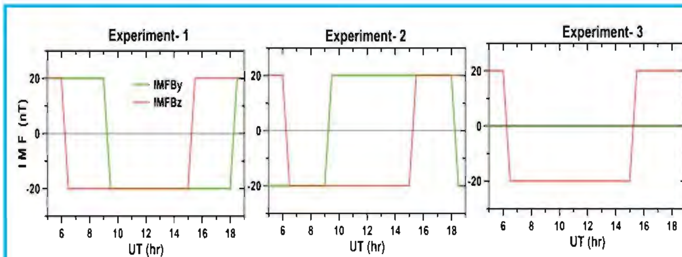

Figure 13 Interplanetary magnetic field conditions during three TIEGCM simulation experiments.

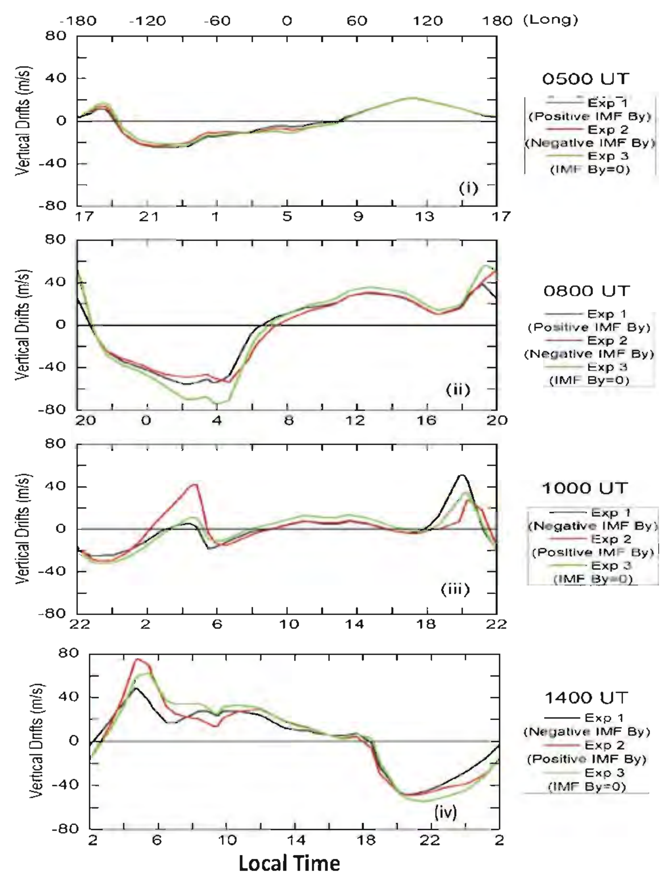

Figure 14 F-region vertical plasma drifts over geomagnetic equator at different stages of IMF orientations.

EARTH MAGNETOSPHERE, SOLAR WIND INTERACTION WITH PLANETARY MAGNETOSPHERE & IONOSPHERES – THEORY, OBSERVATIONS & SIMULATIONS (EPTOS)

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Pitch angle distribution of magnetospheric trapped particles: A test-particle simulation

The difference in the pitch angle distributions (PADs) of the charged particles in the Earth's inner magnetosphere using test-particle simulations is investigated. These charged particles undergo gyration, bounce, and azimuthal drift in the Earth's inner magnetosphere. They are trapped until their pitch angle falls into the loss-cone to get lost into the upper atmosphere. It is found that when adiabatic invariants are conserved, the particles possess butterfly-type pitch angle distributions (see Figure 15). Whereas, when adiabatic invariants are not conserved, the particle's pitch angle distribution bunches toward the 900-peaked distribution.

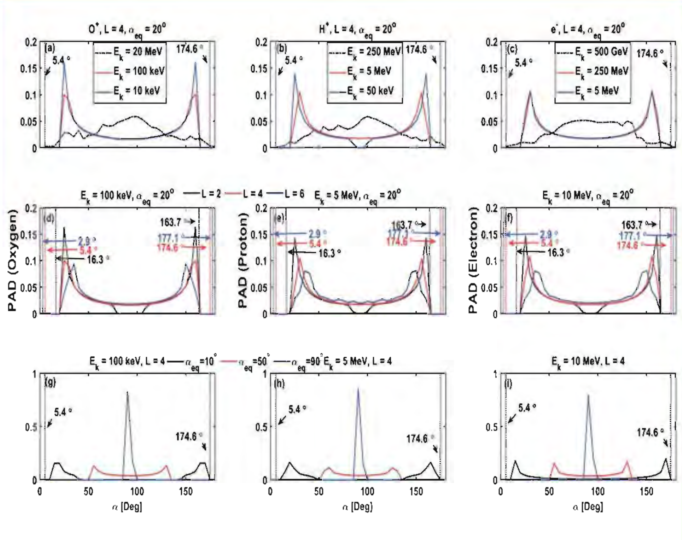

Figure 15 Pitch angle distribution of charged particle for different energies, L-shell, and equatorial pitch angle obtained in the latitudinal range of −40°<λ<40°. The pitch angle distribution are shown in panels (a,d,g) for oxygen, panels (b,e,h) for proton, and panels (c,f,i) for electrons. In (a), (b) and, (c) the pitch angle distribution shown by dash-dotted lines represents the case where adiabatic invariants are not conserved and charged particle tend to possess the 90°-peaked pitch angle distribution. In all other cases the adiabatic in variants are conserved. The vertical lines in the panels are corresponding to the loss cone angle, αl for respective L-shell.

Deepening of radiation belt particles in South Atlantic Anomaly Region

The geomagnetic field has an unusual weak spot over South America and the South Atlantic Ocean, called South Atlantic Anomaly (SAA). The magnetospheric particles trapped in this field penetrate deep into the atmosphere over the SAA resulting in lower inner boundary of the radiation belt. Over the past 400 years, the magnetic field in the SAA region has decreased consistently. The study shows that the weakened geomagnetic field has a bearing on the position of the inner boundary of the radiation belt. The test particle simulations revealed that the inner boundary of the radiation belt over the SAA region is moving earthward at the rate of 4.1 km/year and that earthward penetration of energetic particles hasincreased by ~480 km during period 1900-2020 (see Figure 16). If the geomagnetic field in the SAA region continues to decrease, the resulting deepening of the radiation belt will pose increased risks to our satellites, life, and climate.

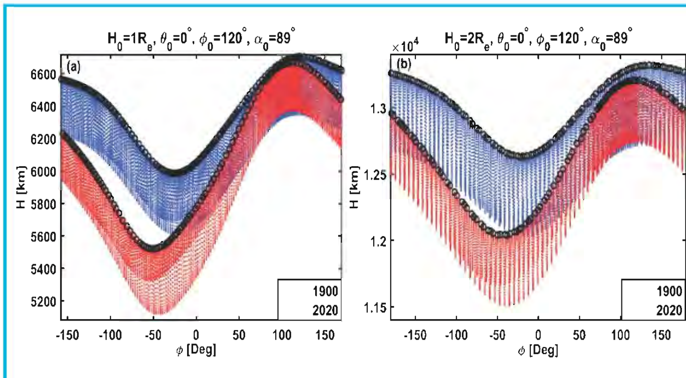

Figure 16 Variation of the 10 MeV proton's altitude H=r-R_e above the Earth's surface as a function of the geographic longitude for the years 2020 (red) and 1900 (blue) for different initial locations: (a) H_0=1R_e and (b) H_0=2R_e . The black circles provide the upper boundary (H^u) of altitude variation and it represents the altitude of the proton associated with B_{min}experienced by particle during their bounce motion.

Forecasting peak smooth sunspot number of solar cycle 25

The knowledge about future solar activity is necessary to plan our space-based missions. As yet, several prediction models have been developed to forecast the peak smoothed sunspot number. We have developed a new model to predict peak of solar cycle 25 and sum of peak of solar cycle 26 and 27. The solar cycles are paired using even-odd cycles, therefore in this model n is allowed to take even number. Model suggest that the solar cycle 26 and 27 would be similar or slightly stronger than solar cycle 24 and 25 (see Figure 17).

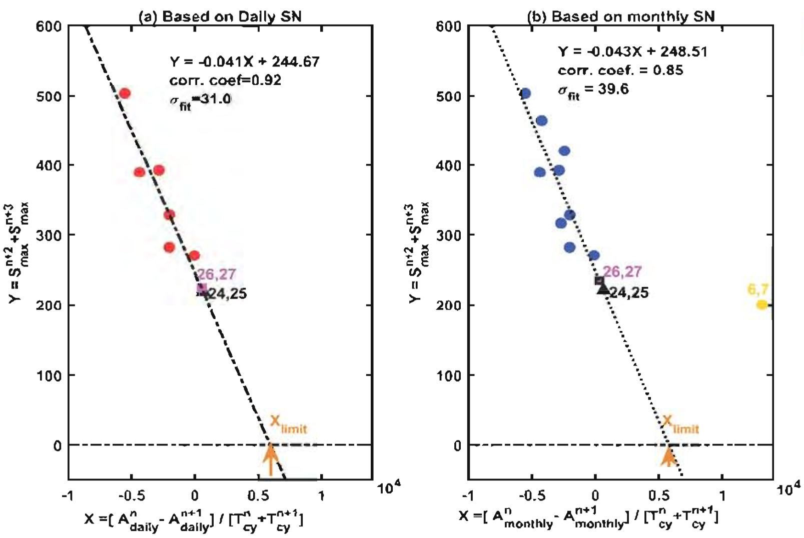

Figure 17

Model parameters, $Y = [S^{n+2}_{max} + S^{n+3}_{max}]$ as a function of $X = [A^{n} - A^{n+1}]/[T^{n}_{cy} + T^{n+1}_{cy}]$ for (a) solar cycles 10-22 using daily sunspot-number data, and (b) solar cycles 2 – 22 using monthly sunspot-number data. Here, n is allowed to take only even-numbered solar cycles. The predicted summation of peak SSN for solar cycles 24-25 and solar cycles 26-27 are marked by black and magenta color, respectively. The least square first order fit equation is given in respective subplots. The upper limiting value of X_{limit} in the respective case is marked by an arrow and it represents the X parameter beyond which the corresponding model equation is not applicable.

New method for implementation of nonthermal distributions in the simulation

To understand the role of ambient plasma distribution function, a new method is developed to incorporate non-thermal, kappa distribution function for the ambient plasma in the simulation. This method for generation of kappa distribution function has less error and takes few seconds to distribute 105 -1022 particles in velocity space (see Figure 18). The MatLab code of the function is provided for the ease of implementation of such a nonthermal particle distributions in the simulation for general purposes.

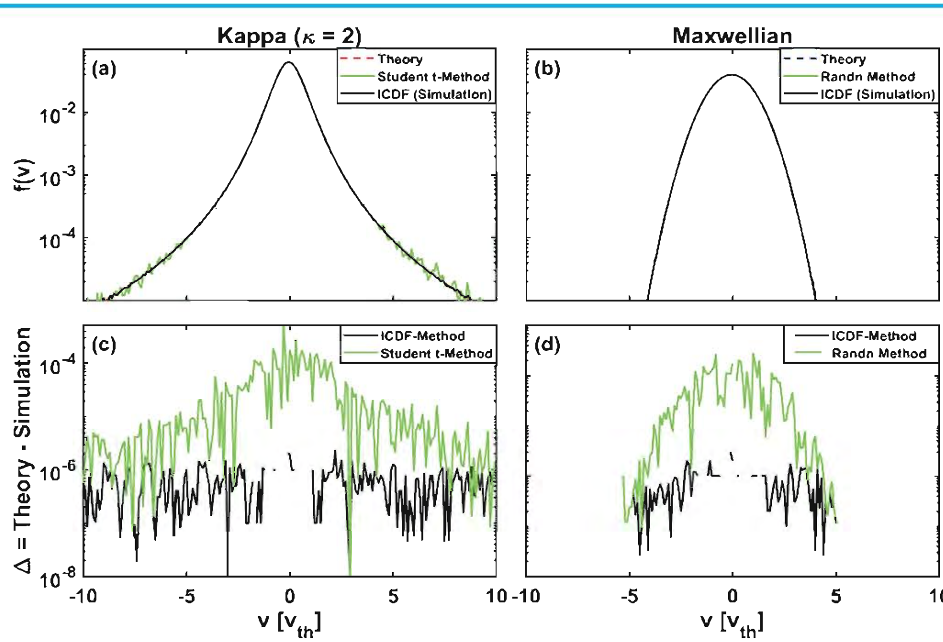

Figure 18 (a) The kappa distribution function generated using inverse CDF method (black color), the student t-distribution function (green color) and its theoretical form (red dotted line). (b) The Maxwellian distribution function generated using the inverse CDF method (black colour) and from random number method (green colour) is compared with its theoretical form (blue dotted line). The difference between the theoretical and simulated kappa and Maxwellian distribution functions are plotted in panels (c) and (d), respectively.

An audit of geomagnetic field in polar and south Atlantic anomaly regions over two centuries

There are two prominent regions of consistently decreasing geomagnetic field namely: the South Atlantic Anomaly (SAA) and the southern pole region. However, it is found that over the past few decades (since 1950), the average magnetic field in the southern polar region has decreased to such an extent that presently it is weaker than the northern polar magnetic field. This tendency of cross-over in the magnitudes of average polar magnetic field strength is also evident in the ground magnetic field observations. On the ground at Hermanus (station in the SAA region), the rate of decrease of the magnetic field is found to be much higher (98 nT/year) during 1950–2020. Such a significant decrease in the magnetic field at Hermanus could be associated with the splitting of the SAA as it is situated close to the second minima in the SAA region. Also, it is found that the magnetic field gradients around the center of the SAA become shallower as one move towards the higher altitudes (see Figure 19). Though the weakening of the geomagnetic field is not an impulsive phenomenon but can invoke serious concerns to our life, satellites, and climate in near future.

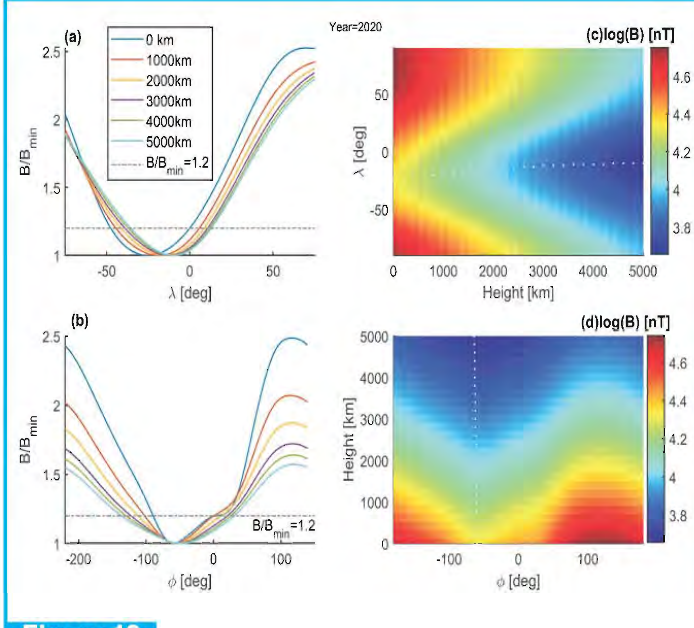

Figure 19

For the year 2020, the variation of the magnetic field in (a) latitudinal direction and (b) longitudinal direction around the location of B_{min} is plotted for different altitudes. Here, the y-scale starts from one as we have a normalized magnetic field with the minimum magnetic field at that altitude. B/B_{min}=1 indicate the location of B_{min}. The magnetic field variation in (c) latitudinal-altitudinal plane and (d) longitudinal-altitudinal plane at the location of B_{min}. Here, the color bar represents the magnetic field strength in the log scale.

Optical remote sensing of the mesosphere-lower thermosphere-ionosphere (MLTI) region using nightglow to study the dynamical & electrodynamical processes in the MLTI region

Gravity waves (GWs) are the important dynamical drivers of the coupling of atmosphere-ionosphere system. Being involved in the energy and momentum transfer processes, GWs play a critical role in understanding atmospheric coupling. Numerous studies have reported GWs associated with thunderstorms/lightning discharges. It has been suggested that the convection in a thunderstorm could effectively launch upward propagating GWs. It has also been reported that the Transient Luminous Events (TLEs) like Sprites can be associated with the large mesoscale thunderstorm generated GWs which modulate atmospheric density at mesospheric/ionospheric altitudes. For the first time in Indian region we reported rare simultaneous observations of columniform sprites and associated gravity waves (GWs) using the Transient Luminous Events (TLEs) camera and All-sky imager over Prayagraj (25.5° N, 81.9° E, geomag. lat. ~ 16.5° N), India.

On 30 May 2014, an intense MCS occurred over the central India during the period 16-24 UT. Lightning discharges associated with the MCS are shown in Figure 20. During this period, a few hours of clear sky occurred over the Prayagraj station which provided an opportunity for the operation of the TLE camera and Airglow experiments. Figure 21 shows a recorded sprite event, lightning occurrence rate, cloud top area variation and cloud top temperature variation at 17:45, 18:15 UT and 18:45 UT. Figure 22 present OH broadband (705-929 nm) nightglow images recorded during 15:00-18:00 UT (before the TLE event) and 18:00-19:00 UT (around and after the TLE event at ~ 18:13 UT). Figure 23 presents the amplitude variation of JJI VLF transmitter signal (22.2 kHz) recorded at Prayagraj on 30 May (MCS days) and 31 May (Non-MCS day), along with FFT analysis of filtered JJI amplitude signal. To see if GWs observed in the lower ionosphere propagated to the upper F-region ionosphere during the MCS on 30 May 2014, we have used GPS derived total electron content (TEC) data from IGS stations of Lucknow (LCKI) (located in MCS region). The filtered residue (DVTEC) variation for the Lucknow (LCKI) station is presented in Figure 24 for 30 May and 31 May 2014, respectively.

In the study are reported using rare simultaneous observations of columniform sprites and associated gravity waves (GWs) using the Transient Luminous Events (TLEs) camera and All-sky imager over Prayagraj (25.5° N, 81.9° E, geomag. lat. ~ 16.5° N), India. On 30 May 2014, a Mesoscale Convective System (MCS) generated a group of sprites over the north horizon that reached the upper mesosphere. Just before this event, GWs (period ~ 14 min) were seen in OH broadband airglow (emission peak ~ 87 km) imaging that propagated in the direction of the sprite occurrence and dissipated in the background atmosphere thereby generating turbulence. About 9 - 14 min after the sprite event, another set of GWs (period ~ 11 min) was observed in OH imaging that arrived from the direction of the TLEs. Over this site, Very Low Frequency (VLF) navigational transmitter signal JJI (22.2 kHz) from Japan is also recorded. The amplitude of the JJI signal showed the presence of GWs with ~12.2 min periodicities and ~18 min period were observed in the ionospheric Total Electron Content (TEC) variations recorded at a nearby GPS site (LKO). The results presented here are important to understand the physical coupling of the troposphere with the lower and upper ionosphere through GWs.

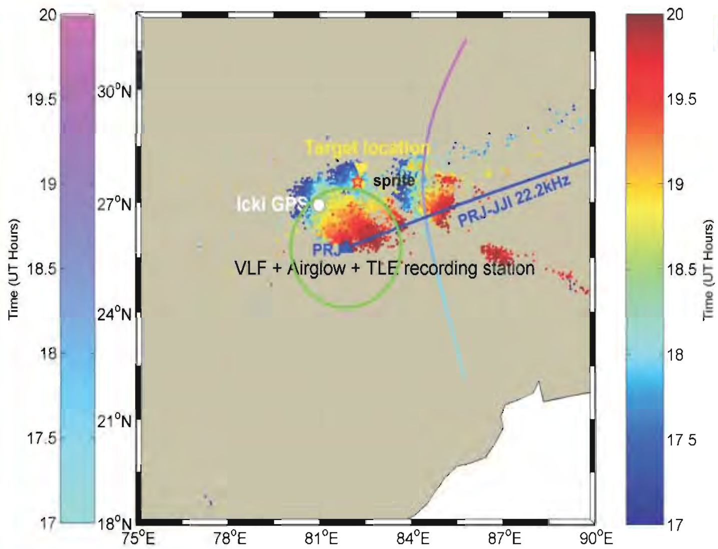

Figure 20 Map depicts the geographic location of Prayagraj (PRJ), India, where VLF experiment, Airglow imager, and TLE camera are located. The green circle represents the field-of-view of the airglow imager at the MLT heights. IGS GPS receiver at Lucknow (LCKI) is shown by the small white circle. Target TLE location indicated by the downward yellow triangle. The sprite location is marked by a yellow-red color star. The JJI (22.2 kHz) VLF signal path to PRJ is shown with the blue line, whereas the satellite path for PRN 26 and lightning activity from GLD360 are depicted color-coded with time in UT during 17-20 UT.

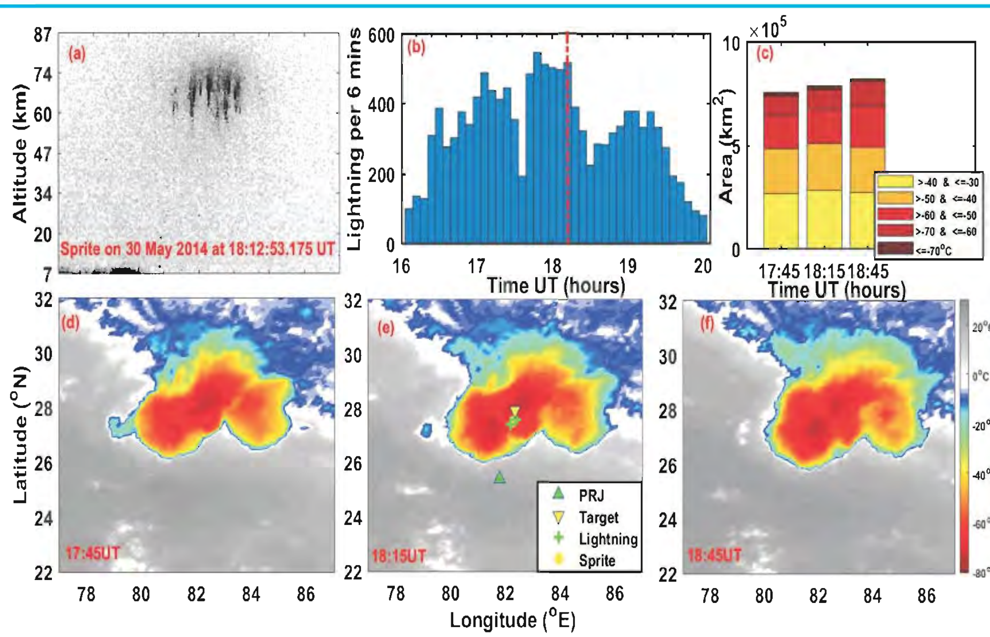

Figure 21 (a) Sprite event recorded on 30 May 2014 at 18:12:53.175 UT. (b) The lightning occurrence rate per 6 mins for +CG and -CG lightning during (16-20 UT) (c) The cloud top area variation for different temperature ranges at 17:45, 18:15 and 18:45 UT. (d) (e) & (f) presents cloud top temperature at 17:45, 18:15 and 18:45 UT obtained from Kalpana1 meteorological satellite IR brightness temperature data. Target TLE location is indicated by the downward yellow triangle.

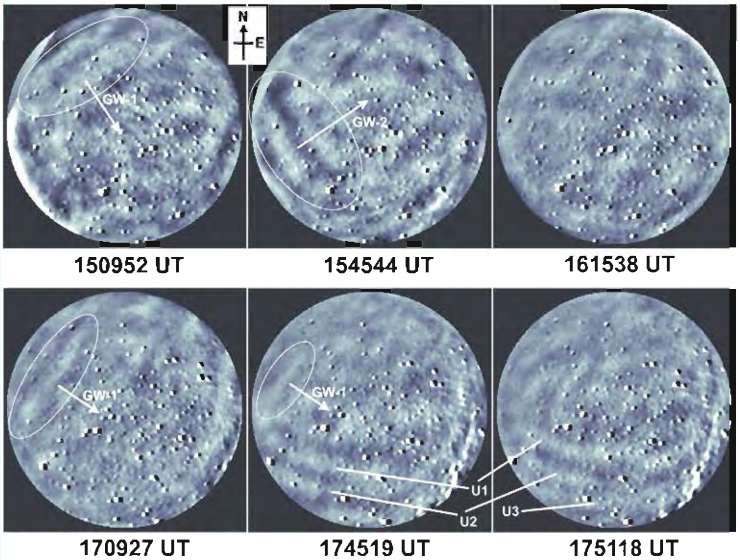

Figure 22

Sample TD OH broadband nightglow images during 15:00 – 18:00 UT featuring small-scale GWs seen over Prayagraj. GWs propagating towards the south-east and north-east are represented by GW-1 and GW-2, respectively. Some detected fronts of GWs that possibly modified the ionization rate and created suitable conditions for sprite initiation are marked as U1, U2, and U3.

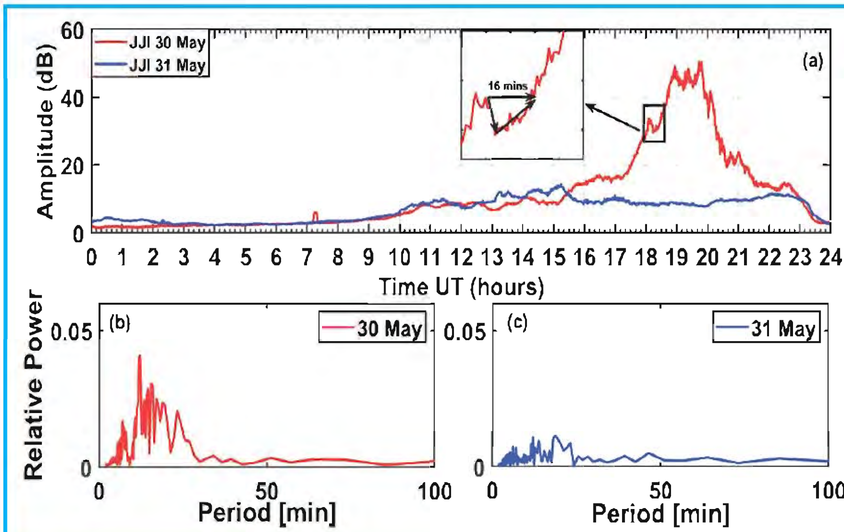

Figure 23

(a) JJI (22.2 kHz) VLF signal amplitude variation on 30 and 31 May 2014 with red and blue colors, respectively. The inset shows the zoomed of signal drop-in and recovery at the sprite occurrence time. (b) FFT of the JJI signal filtered amplitude during 17-20 UT on 30 May 2014. The highest peak shows dominant frequency ~12.2 min. (c) FFT of the JJI signal filtered amplitude during the same period on 31 May 2014.

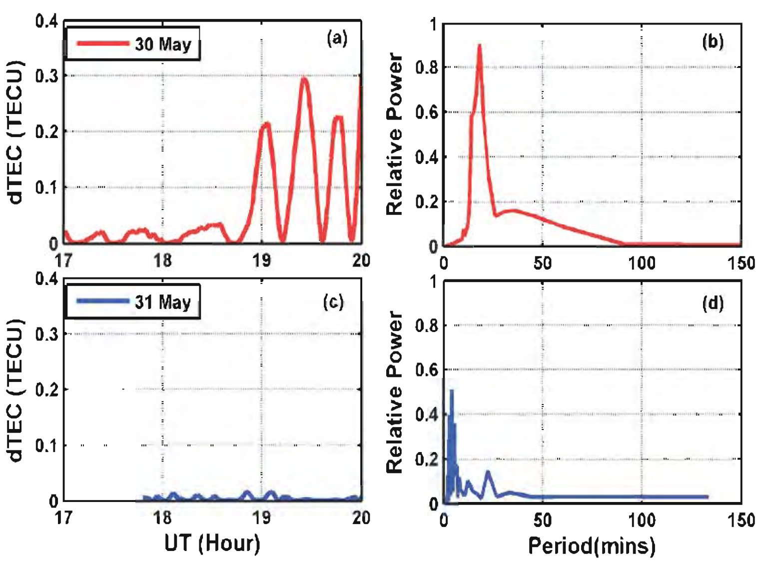

Figure 24

(a) & (c) DVTEC variation for Lucknow (LCKI) on 30 May and 31 May respectively (b) & (d) FFT of DVTEC at Lucknow on 30 May and 31 May 2014, respectively.

Kinetic Alfvén Waves in Space Plasma Environment

The generation of kinetic Alfvén waves (KAWs) is studied through a three component theoretical model considering ion beam as the source of free energy in presence of non-Maxwellian kappa-electrons. It is found that ion beam can excite KAWs for a significant growth rate. Also, the presence of kappa electrons impedes the growth rate of KAWs and narrows down the wave unstable region. The effect of other plasma parameters, such as, ion beam number density, temperature of plasma species, propagation angle, plasma beta etc. are also investigated. The proposed model produces KAWs up to frequency of $\approx$ (6.6–51.2)mHz which falls in the range of observed ultra-low frequency (ULF) waves in different regions of Earth's magnetosphere.

Multipoint analysis of source regions of EMIC waves and rapid growth of subpackets

EMIC wave events are observed in three THEMIS probes A D E (THA, THD,and THE) almost simultaneously. THA, THD, and THE were in the outer magnetosphere (L-shell~8.3). Rapid nonlinear growth is observed which served the EMIC subpackets to grow within one wavelength, which is nearly equivalent to the separation of the spacecraft. The Poynting vector analysis reveals the bidirectional properties of EMIC waves in these regions and confirms the scattered source regions. The strong nonlinear growth of the subpackets within one wavelength is reported for the first time (see Figure 25).

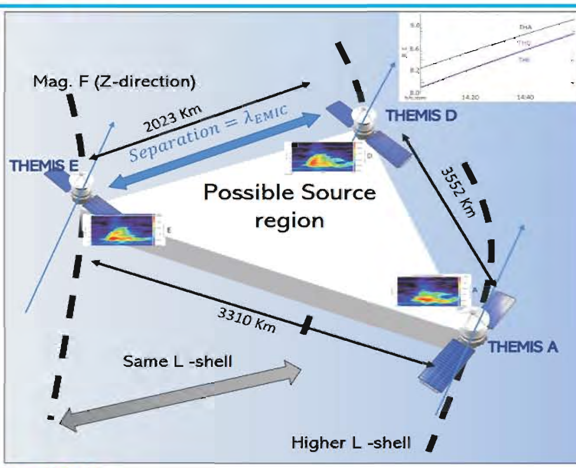

Figure 25

Cartoon of the THEMIS constellation during the observed Electromagnetic Ion Cyclotron waves (EMIC) on September 9, 2010. Inset: Distance from the Earth in RE (Earth radius) for THEMIS A (THA, black), THEMIS (THD, magenta) and THEMIS E (THE, blue). THD and THE are in lower L-shell than THA. Z-direction is along the magnetic field. Dynamic spectra of simultaneously observed EMIC rising tones are shown for each spacecraft. Though we have scattered source regions, the triangular region in white is the possible source region. Separation of THD to THE spacecraft are one EMIC wavelength λ_{EMIC}(~2,023km) at ~14:23 UT suggesting the evolution of the subpacket within one wavelength.

COUPLED LITHOSPHERE - ATMOSPHERE - IONOSPHERE - MAGNETOSPHERE SYSTEM (CLAIMs)

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Paleoseismology (PS)

Paleoseismological Studies in NE region

A field survey in March 2022, was carried out in Kopili Fault Zone, in the meizoseismal areas of 1950 Assam and 1869 Cachar earthquakes to identify the earthquake-induced liquefaction features at the selected sites and collect samples for Radiocarbon (^{14}C) and optically stimulated Luminescence (OSL) dating for chronological constraints. Also collected samples for magnetic and geochemical studies to study palaeo-environmental conditions. Mineral Magnetic and other laboratory experiments are in progress.

Anisotropy of magnetic susceptibility along Krishnai River, Chedrang Fault, Shillong Plateau

More than 139 samples from 5 sites collected from the Krishnai river section (Figure 26) along Chedrang fault were subjected to analyze the anisotropy of magnetic susceptibility (AMS). The bulk susceptibility and anisotropy of magnetic susceptibility of these samples were measured on the MFK1. For each specimen, three principal axes and their magnitudes (referred to as Kmax, Kint and Kmin) describe the ellipsoid of AMS. Orientations of the three principal axes of AMS and its corresponding magnitudes are calculated. Analyzing the orientations of the AMS axes, three different AMS types could be distinguished in our samples (Figure 27). A typical depositional origin referred for the AMS, the axes of minimum susceptibility, Kmin, are tightly grouped near the vertical while the other two axes have rather scattered orientations in the bedding plane. Another typical situation (a-type), is characterized by the probable influence of paleo-current or paleostress resulting in the presence of a magnetic lineation (Sites 1,2 and 5; Figure 27): each of the three sets of principal axes displays a consistent orientation, the Kmin axes being again nearly normal to the bedding plane. In the b-type (Site 3; Figure 27), the Kmin axes are grouped, while the other two axes form a girdle. This distribution also suggests that the sediments may have undergone some horizontal compression, along the trend of the Kmin axes (i.e., N-S in Site 3, (Figure 27). The c-type is characterized by well grouped Kmax axes nearly perpendicular to bedding, the other axes being rather scattered in the bedding plane. This may indicate that the sediments have undergone compression, but the direction of compression is poorly constrained. However, such a pattern may also result from the inversion of fabric caused by the predominance of single domain grains.

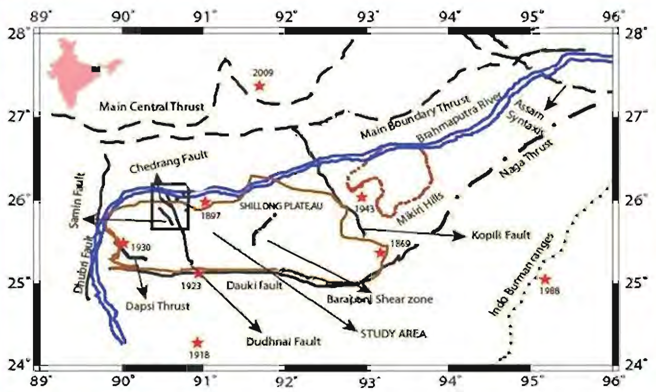

Figure 26

Seismo tectonic map of Shillong plateau and study area

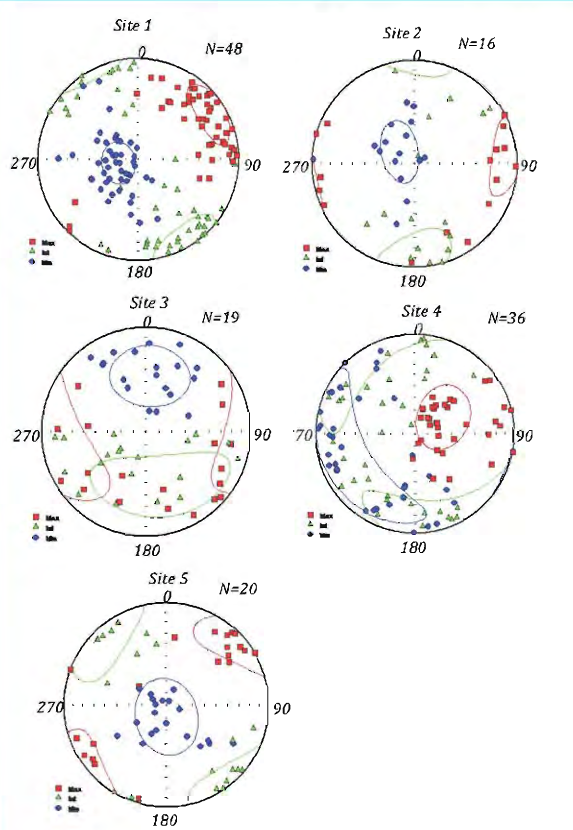

Figure 27

Anisotropy of magnetic susceptibility from different sites along Krishnai River

Earthquake Seismology (ES)

IIG is running a network of Broadband Seismograph (BBS) network consisting of 11 BBS stations spread over the NE Indian region (see Figure 28). BBS network is running continuously and providing good quality seismic data. BBS instrument is also running at Magnetic Observatory Portblair, Andaman & Nicobar region. Broadband seismic network data is being processed and earthquake events (local, regional and teleseismic) are also being archived. These data are being utilised for Noise tomography, Travel-time tomography, and surface wave tomography to achieve a detailed velocity model of the region.

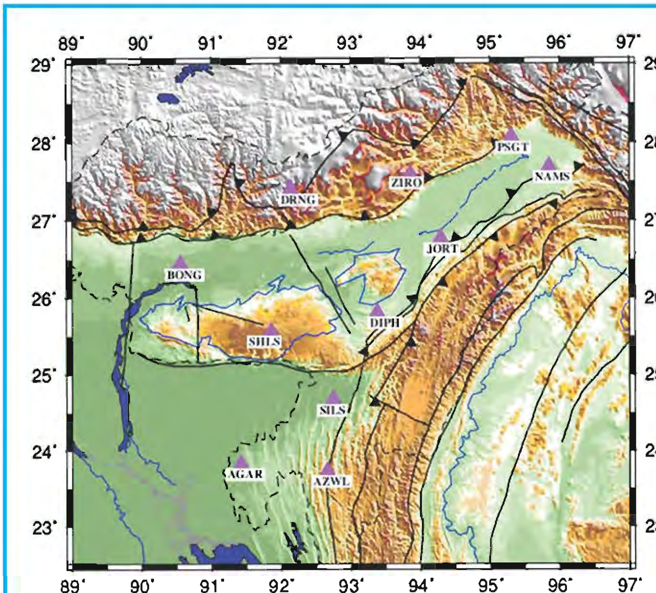

Figure 28

Broadband seismometer network of IIG in the NE Indian region.

Ionospheric Seismology using space and ground based observations (IS)

Terrestrial resonant oscillations during the 11 April 2012 Sumatra doublet earthquake

In addition to the transient co-seismic ionospheric perturbations (CIP), prolonged ionospheric perturbations have been reported after the occurrence of great earthquakes (Mw > 8.0, please see Nayak et al., 2021 for references). The April 2012 Sumatra doublet earthquake sequence has been studied in context of prolonged ionospheric perturbations. Following both the earthquakes, prolonged ionospheric oscillations centered at frequency of ~4mHz were observed in GPS (Global Positioning System) derived total electron content (TEC) towards north-northeast of the epicenters (Figure 29). These oscillations were scrutinized in terms of the manifestations of plausible non-tectonic and tectonic forcing mechanisms surrounding the epicentral region. Non-tectonic forcing such as the geomagnetic field coupling factor and observation geometry played a critical role in determining the amplitude anisotropy of resonant ionospheric signatures. Further, the Rayleigh waves of the first earthquake (Mw 8.6) were already characterized by an excess of energy at ~ 4 mHz. This could make the Mw 8.6 earthquake particularly efficient to excite the 4mHz resonance in the atmosphere. The resonant ionospheric signatures after the second earthquake (Mw 8.2) were observed to be closely associated with the Earth's free oscillations caused by R2 Rayleigh wave train of the Mw 8.6 earthquake event. Together, all the above point to a scenario where the resonant ionospheric signatures during the Sumatra doublet event were indeed related to the seismic source. Therefore, resonant co-seismic ionospheric signatures could provide additional information on the low frequency features of seismic ruptures (Figure 29).

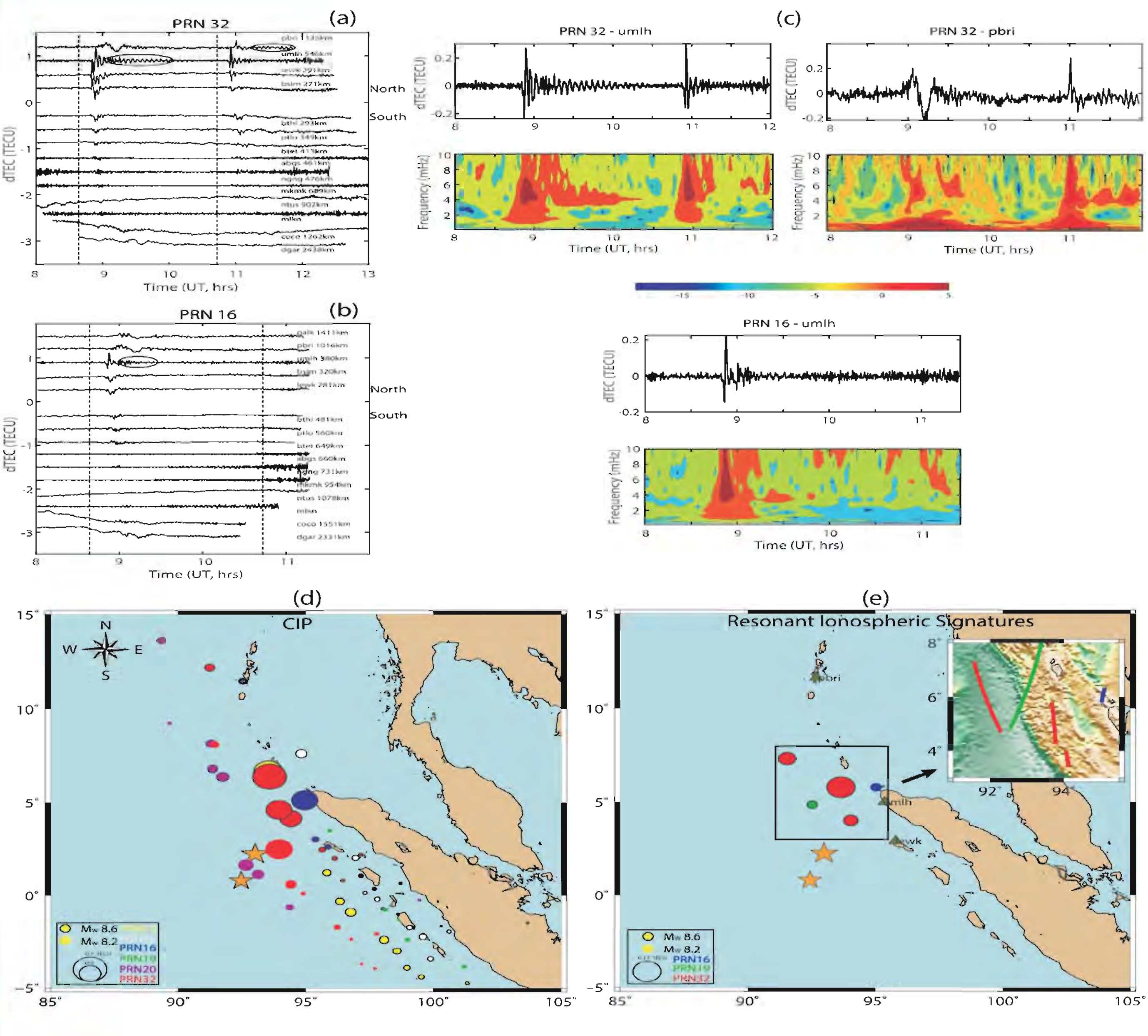

Figure 29 (a-c) Temporal evolution and (d-e) Spatial manifestations of resonant ionospheric signatures during the Mw 8.6 and Mw 8.2 11 April 2012 Sumatra doublet earthquake

Lithosphere-Atmosphere-Ionosphere Coupling - Chemical, Electrodynamical and Mechanical channels (CEM)

Spatial manifestation of resonant ionospheric signatures during the 11 March 2011 Tohoku-Oki earthquake

Earthquake is one of the potential solid earth sources which can trigger the terrestrial resonant coupling. Ionospheric resonant signatures as observed in GPS-TEC during the Mw 9.1 11 March 2011 Tohoku-Oki earthquake (Tohoku EQ) were extensively studied to understand the spatial manifestation of resonant ionospheric signatures around the epicenter. The analysis demonstrated significant north–south asymmetry in spatial distribution of the resonant signatures encompassing the epicenter (Figure 30). This anisotropic behavior has been scrutinized by referring to seismic and non-seismic parameters. The non-seismic parameters mainly of geomagnetic field-acoustic wave coupling and satellite observation geometry largely governed the ionospheric manifestations of seismic energy. This attempt elaborates the role of non-seismic parameters towards efficient understanding of the spatial manifestations of resonant ionospheric signatures during great earthquakes.

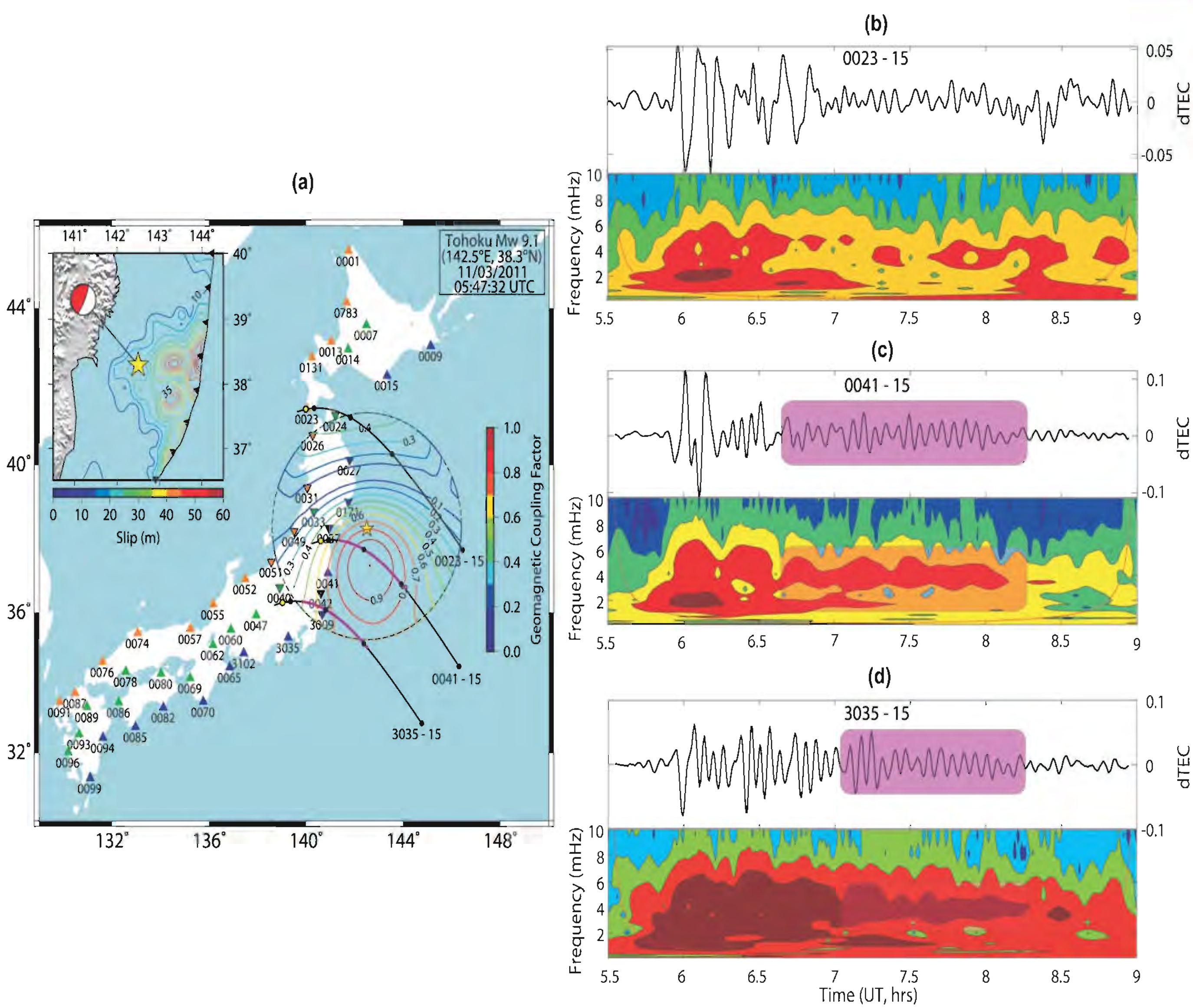

Figure 30 Significant north–south asymmetry in spatial distribution of the resonant ionospheric signatures encompassing the epicentre of the Mw 9.1 11 March 2011 Tohoku earthquake.

Ray tracing model for detection of gravity wave sources

An All-sky Airglow Imager is being operated from Silchar Magnetic Observatory since December 2017 in campaign mode and from January 2020 in continuous mode (moonless, cloud-free, nights). During December 2018 campaign, observations were carried out from 8-11 December 2018. Apart from mesospheric frontal events, small-scale ripple features and gravity waves were also observed. It is important to identify the possible source region for the observed GW events to understand the dynamics behind the generation of GW. A ray-tracing model enables us to trace the GW ray path in the atmosphere. A reverse ray-tracing model traces the GW ray from the point of observation to the possible source region. The ray-tracing model for GW source identification was developed. The model is based on the original work done by Marks and Eckermann.

The model uses wavelength, time period, propagation direction (azimuth) and phase speed along with latitude, longitude and altitude of observed event as input parameters. For tracing the ray in the background atmosphere we have used climatological models such as HWM-14 and NRLMSISE-00 for winds and temperature measurements were used. The model results are in good agreement with results published by others.

Nearly 9 GW events were obtained from December 2018 observations. Out of 9 events only one could be traced back to tropospheric heights while rest of the ray-paths were terminated at mesospheric heights. One of the ray-traced gravity waves is shown in Figure 31. The red line in the map shows the ray path propagation. The ray path terminated at ~15 km altitude in the troposphere.

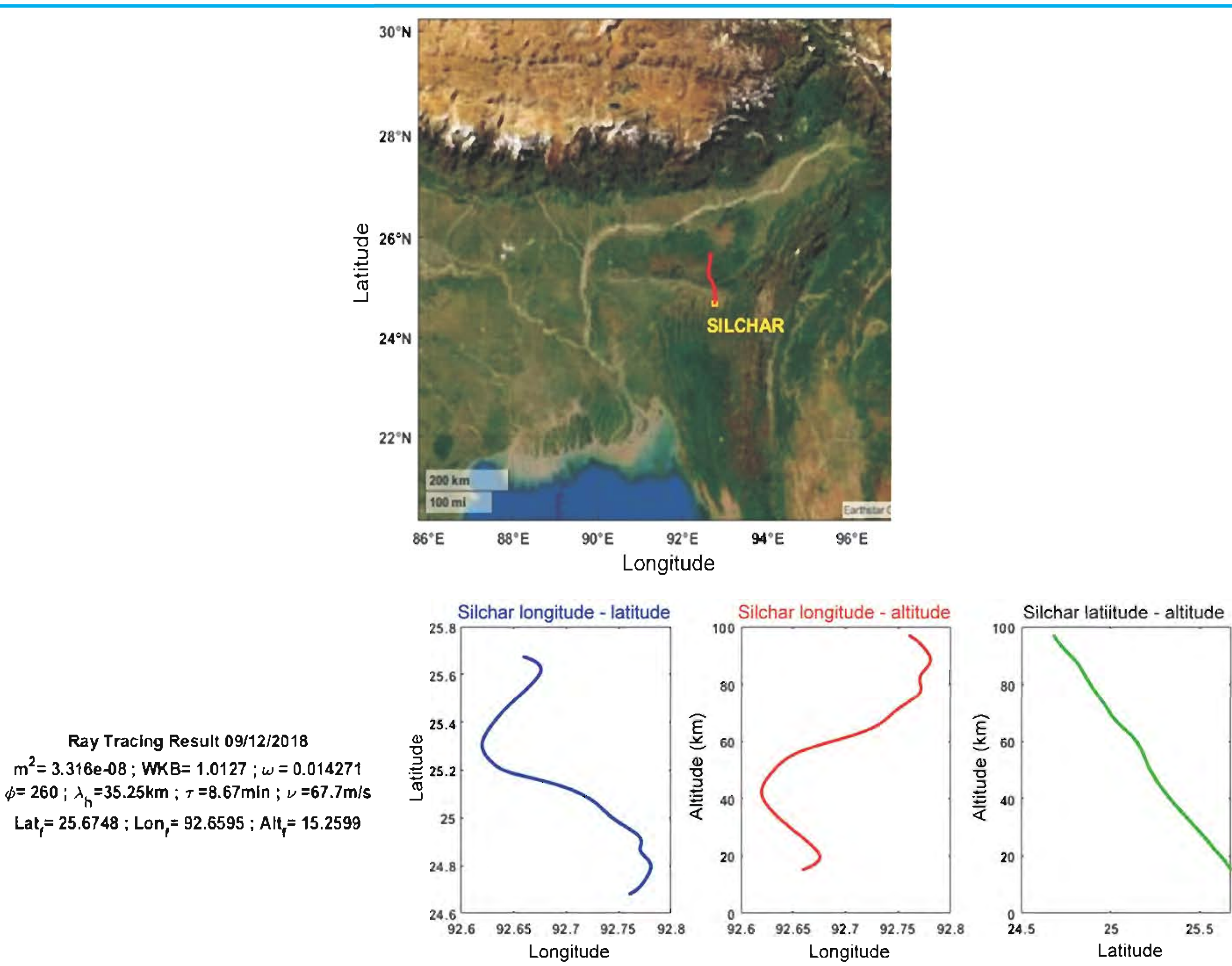

Figure 31 Results from ray tracing model with ray paths in latitude-longitude-altitude frame of reference. The map on the left panel shows the actual ray propagation (red curve).

SOLID EARTH RESEARCH

GEOLOGICAL AND GEOPHYSICAL STUDIES OVER DECCAN TRAPS (GGDT)

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Palaeomagnetic investigations on lamprophyre bodies from the Sarnu-Dandali Alkaline Igneous Complex, Deccan Volcanic Province

Palaeomagnetic experiments have been carried out on 17 oriented lamprophyre samples, which were collected from Sarnu-Dandali alkaline igneous complex. The collected 17 samples were cored in the laboratory and prepared into standard-sized 40 specimens, and all these 40 specimens were subjected to AF and thermal demagnetizations to isolate characteristic remanent magnetization directions (ChRM). Thermal demagnetization data indicated that the majority of the samples depicted overlapping or low-angle relations between primary (ChRM) and secondary components during thermal demagnetizations with gradual decay after 300°C. After removing the specimens with noisy trajectories in AF demagnetizations, the stable components showed steady demagnetization towards the origin after 25 mT. From the isolated ChRM directions the virtual geomagnetic pole (VGP) was calculated as 32.31° N and 298.52° E (dp = 10.43; dm = 18.62) matching very well with the Deccan Super Pole (37° N:311° W; at 65.5 Ma) and supporting the eruption age at c. 65.5 Ma for these studied lamprophyre bodies.

Petrography and Petrogenesis of Malwa Trap

The Petrography and Petrogenesis of Malwa trap from Deccan volcanism, has made an important commitment by proposing for the primary time that parental magma of the entire Deccan Trap locale was tholeiitic in composition. Many workers proposed that there wasan affiliation of antacid olivine-basalt parental magma with the tholeiitic parental magma. The petrological composition of Malwa trap from the Deccan basalt is uniquely uniform and is mainly composed of Clinopyroexene, Plagioclase, and Opaque with accessories of olivine and glass. Clinopyroxene phenocrysts are mostly prismatic and occur in two different varieties. One type is found as medium-sized, subhedral grains, while the other type occurs as microphenocrysts, which cluster together to form tecoblast. Plagioclase phenocrysts are mostly large to medium, euhedral to subhedral, elongated to lath-shaped with the occasional presence of tabular grains. In the groundmass, plagioclase appears to be extremely fine-grained, subhedral, lath-shaped microlites. Smaller grains of opaque minerals remain scattered in the groundmass, mostly occurring as inclusions within phenocrysts grains. Phenocrystal olivines appear to be coarse-grained, showing high R.I. and birefringence. The overall textural pattern is defined by intergranular and interseptal textures with locally developed porphyritic and glomeroporphyritic.

Mineral magnetic properties of sediments from Purna river Basin

Field survey was carried out in Purna basin, to select the sites and collect samples for magnetic and geochemical studies to study paleo-environmental conditions. A total of ~350 oriented and loose sediment samples were collected in 7.65 m sediment section from Parad, 76 samples in 3.7 m section from Andura and 38 samples in ~2 m section from Ghandhigram of Akola District, Maharashtra (Figure 32). Charcoal, bone samples were collected for Radiocarbon (14C) and Optically stimulated Luminescence (OSL) dating for chronological constraints. Mineral Magnetic and other laboratory experiments are under progress.

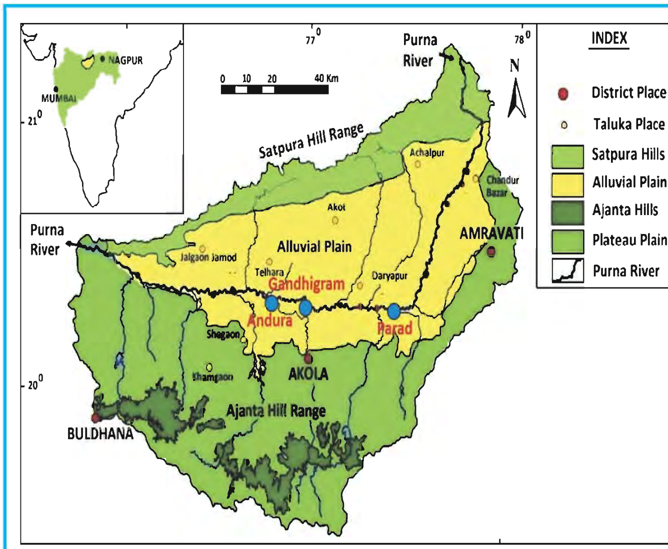

Figure 32

Study area of Parad sediment section, Purna Basin, DVP

Magnetic mineralogy of sediments in and around thermal springs

The behavior of magnetic susceptibility as a function of temperature is a routine method for identifying magnetic minerals. Temperature-dependent magnetic susceptibility (χ-T) measurements can provide information about mineralogy and transformation of magnetic minerals by recognizing the Curie temperature (Tc) and other special features. The χ-T curves from Rajawadi (RW) and Unhavare (UR) springs for selected samples are shown in Figures 33 and 34. All heating curves (red) are characterized by a sharp drop at about 585°C, which is the Tc of magnetite. However, the cooling curves lie above the heating curves due to the formation of new magnetite from other minerals (Fe-bearing silicates and clay minerals) during heating except for the RW3 sample. Unhavare samples are characterized by another sharp drop between 350 and 400°C which is could be Tc of titano-magnetite.

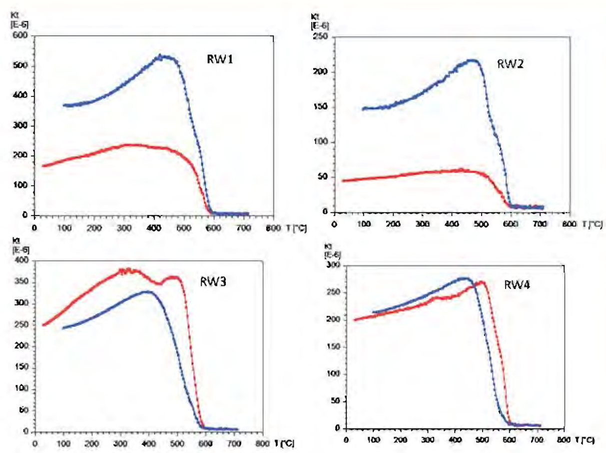

Figure 33

Temperature-dependent magnetic susceptibility (χ-T)curves for representative samples from Rajawadi spring.

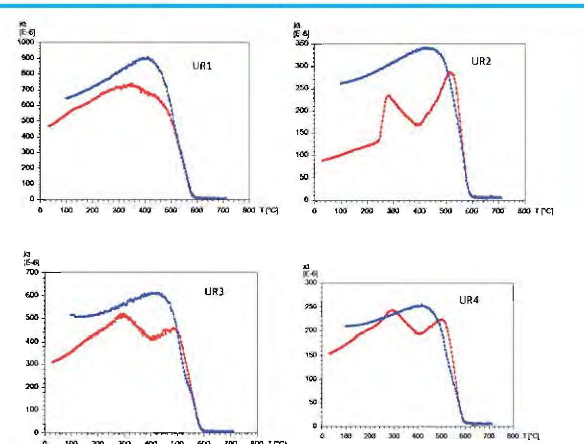

Figure 34

Temperature-dependent magnetic susceptibility (χ-T)curves for representative samples from Unhavare spring

Geochemical signatures of sediments in and around Rajawadi and Unhavare springs

Soil samples were collected from Rajawadi (RW) and Unhavare (UR) springs to study the environmental conditions around Geothermal Springs. Molecular weathering ratios provide an idea about various pedogenic processes acting in the palaeosol and also the climatic conditions during their formation. In the present study, the weathering ratios studied include clayeyness, salinization, calcification, provenance, and weathering index. Clayeyness ranges from 0.31 to 0.5 and 0.64 to 0.71 in RW and UR spring sediments respectively that suggest clayeyness. Salinization of the present samples ranges from 0.05 to 0.24 for the RW sediments and 0.038 to .049 for UR sediments, indicating a slow process of salinization. The average values of the Calcification ratio for RW and UR samples are 0.78 and 0.18 respectively and this low value suggests high precipitation under warm and semi-arid climatic conditions in the area. The Chemical index of alteration (CIA-K) is a tool to understand the rate of weathering and transformation of feldspar to clay minerals. The CIA value having 50 or less represents unweathered rock and soil, whereas, 50-60 incipient pedogenesis, 60-80 moderate pedogenesis, and 80-100 intense pedogenesis. In the studied samples, the CIA values are high in the sediments around UR spring i.e., 83.6-99.7 compared to RW sediments i.e., 50.6-74.6 indicating that the sediments were subjected to intense weathering and pedogenesis, whereas, RW sediments were moderately affected.

Pre-historic geomagnetic field variations using archaeological artifacts

Archaeomagnetism is the magnetic study of baked clay samples collected from historical sites. The purpose of these studies is to add data to the secular variation curve, if independent dating evidence is available, or to provide a date of last heating if the secular variation is well known. Instrumental geomagnetic records have been available since 1841 from IIG, prior to which geomagnetic field changes could be indirectly deciphered from archaeomagnetic studies.

Rock-magnetic studies carried out in detail on the Keeladi archaeological artefacts are seen to reflect the magnetic mineralogy and their grain size. Thermal stability test results are important for the accomplishment of precise archaeointensity from Keeladi artefacts. The majority of samples show the dominance of the magnetically soft fraction with unblocking temperatures close to 600°C in SIRM demagnetization. Magnetic susceptibility curves were stable in entire thermal steps, except KL21. After 350°C, the major alteration was acquired in KL21, this sample needs to be excluded from the archaeointensity calculation (Figure 35). These results suggest that the Keeladi artefacts are suitable for reliable ancient geomagnetic field intensity investigation.

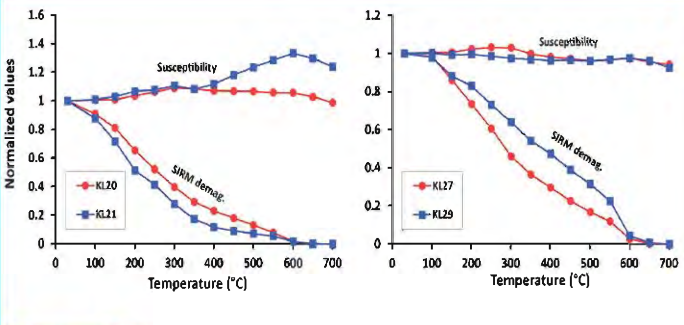

Figure 35

Representative thermal stability curves from Keeladi (KL) archaeological artefacts.

The new uncorrected archaeointensity value calculated for the Keeladi individual sample is Banc= 49.0 μT for KL10a (Figure 36). The cooling rate correction and anisotropy of thermal remanent magnetization correction experiments are in progress, to get the mean archaeointensity value for the Keeladi site.

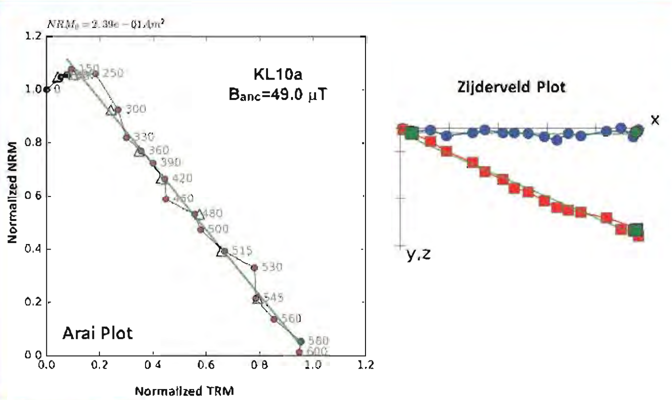

Figure 36

Keeladi artefact (KL10) Arai plots of successful palaeoinetnsity experiments (left column) with their associated orthogonal Zijderveld diagrams (right column).

Morphometry dominates the groundwater recharge process

Eleven influential morphometric parameters are considered to prioritize the nine sub-basins of the Mann River basin in south-eastern Maharashtra by performing the weighted sum analysis (WSA) technique, wherein weights are assigned to individual morphometric parameters based on their importance. The analysissuggests that 42% of the area spread over sub-basins is of very good to good priority type. Principal component analysis has been performed to identify the most influencing morphometric parameters for groundwater recharge in basaltic aquifers. The PCA results show that the relief ratio, basin relief, and ruggedness number showcasing the relief aspect of morphometry dominates the groundwater recharge process. It is suggested to adopt conservation measures in high-priority areas, like rainwater harvesting, aquifer recharge, and resource management for effective land and water management (Figure 37).

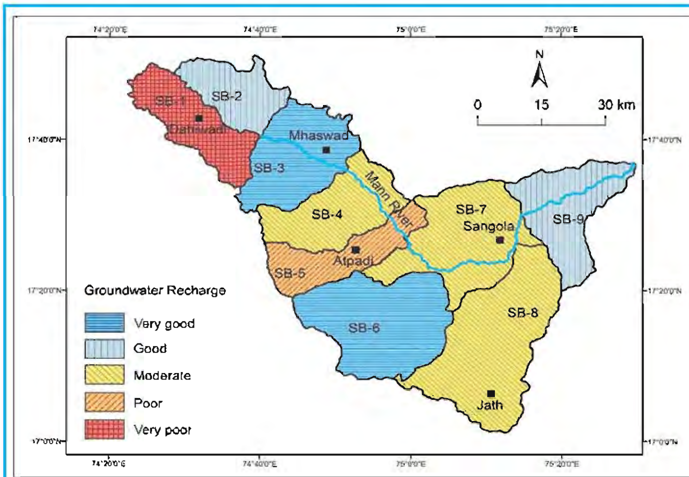

Figure 37

Priority-wise classification of sub-basins for groundwater recharge.

Protective capacity and anisotropic nature of aquifers via electrical resistivity data

Electrical resistivity data were acquired to understand the protective capacity of aquifers, anisotropic nature, and fracture geometry of dyke infested terrain in parts of the Nandurbar region, Maharashtra. The Dar-Zarrouk and other geoelectric indices suggest that the area has poor to moderate aquifer protective capacity,indicating that weaker zones may be prone to infiltrating contaminants. The high electrical anisotropy (λ) signifies EW and NS-oriented dykes, suggesting the heterogeneous and anisotropic nature of the subsurface. Two-dimensional (2D) electrical resistivity imaging (ERI) was used to generate subsurface resistivity models for delineating the availability of groundwater in this region. The available dug well/borehole lithology suggests that the top layer is comprised of red bole, laterite, or black soil followed by weathered/fractured rock. Results from the 2D inverted models of resistivity variation with depth (Figure 38) suggest the occurrence of aquifers mostly in weathered/fractured zones within the traps or beneath it. The resistivity models suggest that the northern part of the study area represents a promising aquifer zone with a reasonable thickness of weathered formation.

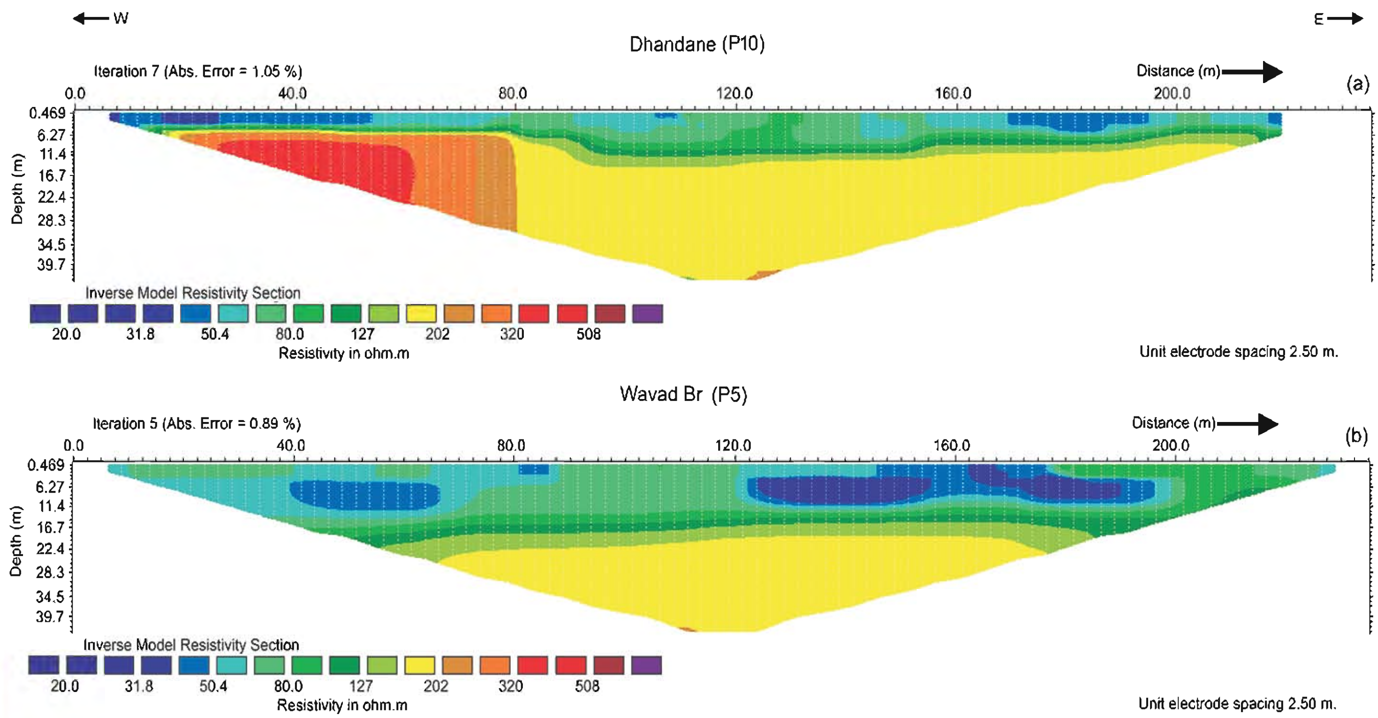

Figure 38 Inverted resistivity models at (a) P10 (Dhandane) and (b) P5 (Wavad Br).

AMT/ MT studies across Aravali and Tural geothermal zones, western Maharashtra, India

Integration of AMT and MT data across Aravalli and Tural geothermal zones (in the Konkan region of Deccan Volcanic Province (DVP) has brought out the sub-surface electrical conductivity structure as shown in Figure 39. Dimensionality analysis carried out by Phase tensor ellipses denotes the 1D and 2D nature of the data with regional strike oriented in NE-SW direction Figure 40. 2D inversion of data brings out two different conductivity anomalies (a) shallow conductivity anomaly related to upward propagation of meteoric water through faults/fracture zones, (b) a conductive deep-seated fracture/fault zone sandwiched between resistivity blocks through which Deccan volcanism might have erupted Figure 41. This conductivity anomaly has been related to trapped carbonate fluids that are linked to basaltic magmatic intrusions at the base of the crust.

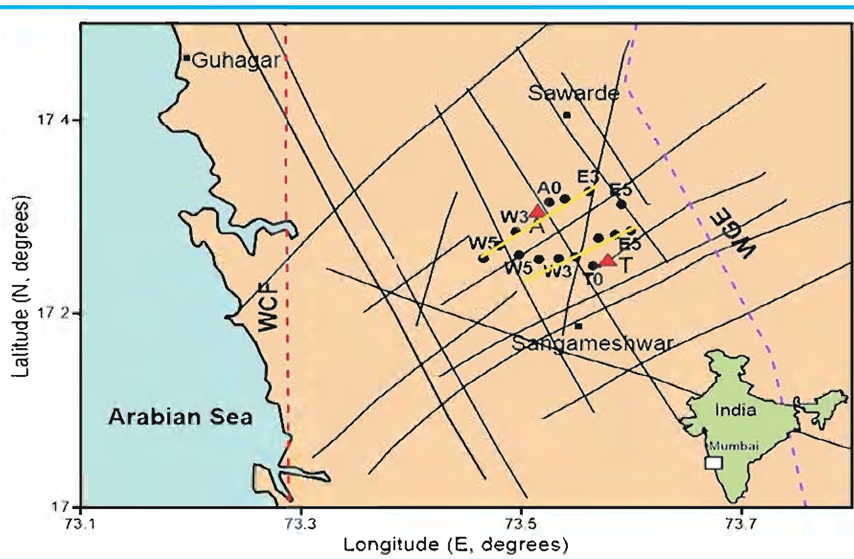

Figure 39

Hot springs Aravali (A) and Tural (T) located in western part of Maharastra along with AMT/MT sites are shown. Regional lineaments of study area (after Arora et al., 2018) are also superimposed. It also shows west coast fault (WCF), Western Ghats escarpment (WGE) and geothermal zones (A & T) that are located to the west of WGE.

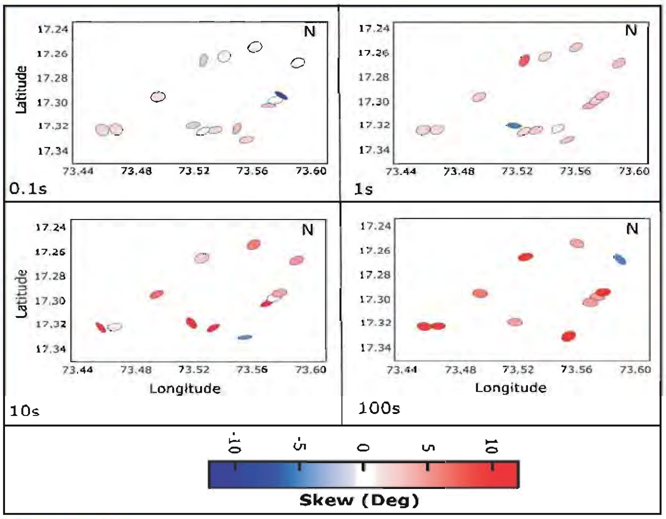

Figure 40

Phase tensor ellipses for both Aravali and Tural profiles for 0.1-100 s. Major axes of the ellipses are oriented in NE-SW direction with $|\beta| \leq \pm 5$ suggesting 2D in nature.

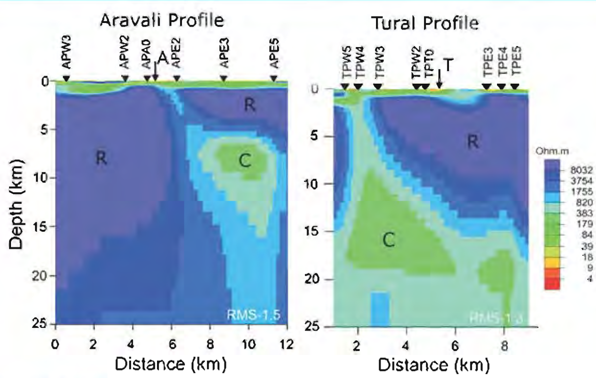

Figure 41 2-D Geoelectric depth section (TE + TM mode) across Aravali and Tural profiles. (a) shallow section showing high conductivity anomaly beneath hot springs. (b) deep seated conductivity anomalies (C1 & C2) are related to mid-lower crustal conductivity anomalies are related to carbonate fluids released/trapped due to partial melting of basaltic magma at the base of the lower crust.

Lithospheric anomaly map over the Indian subcontinent and adjoining oceans

Data from the Swarm satellite constellation and geomagnetic observatories distributed throughout the length and breadth of India is being utilized to develop a lithospheric anomaly map over the Indian subcontinent and adjoining oceans. Elimination of external and internal sources is necessary which masks the lithospheric source/features. For this, the geomagnetic quiet condition night-time data were considered to minimize the contribution from the external sources. A two-dimensional lithospheric magnetic model was derived from the Legendre polynomial expansion of harmonic terms 6-50 and the damped least square method was used to estimate the model coefficients. The 2D lithospheric model thus generated was compared with the existing lithospheric models like MF7, Chaos, etc. It is found that the generated 2D model could map intermediate wavelength structures compared to the existing models. It is also planned to develop a regional model using the magnetic observatory data to represent the main field over the Indian region.

Gravity, magnetic, and GPS data acquired along two ~300 km long east-west profiles running from the west coast and cutting across the Western Ghat escarpment was processed and preliminary qualitative interpretations were carried out. The objective of this study was to understand the subsurface density and magnetization distribution in this part of the Deccan Volcanic province. Preliminary interpretations of magnetic and magnetic gradiometer data have helped to delineate several subsurface lineaments. In addition, the magnetic gradient data could map the polarity reversal of the different formations, laterally. A comparative study of the effective elastic thickness (Te), geoid to topography (GTR) ratio, and the Curie isotherm depth along the Greater Maldive Ridge (GMR) has been attempted, consisting of the Maldive Ridge (MR) and Deep Sea Channel (DSC) region, to throw light on the plume-ridge interaction. It is observed that there exists an inverse correlation between the Curie depth and the effective elastic thickness along the ridge. From these observations, it is postulated that Curie isotherm depth in combination with excess crustal thickness can be used as a proxy to throw light on the duration of plume-ridge interaction.

Revealing the Contemporary Kinematics of Antarctic Plate Using GPS and GRACE Data

Revised horizontal and vertical plate velocities of the Antarctic continent in ITRF2008 and the impact of elastic and viscoelastic deformations over the continent due to Antarctic Ice Sheet (AIS) variations are simultaneously estimated using GPS and GRACE data for the period 2005–2015. The improved GPS time series and resulting horizontal and vertical velocities indicate that East Antarctica is subsiding significantly, whereas West Antarctica is experiencing uplift with transitional subsidence along the Trans-Antarctic Mountain ranges. According to the ongoing elastic deformation and AIS mass variations from GRACE data, the East Antarctic area is subsiding at a rate of 1 mm/yr. The elastically corrected or GRACE corrected vertical deformation also exposes the deformation patterns associated with the viscoelastic vertical deformation in terms of East Antarctica subsidence and West Antarctica upliftment. The glacial isostatic adjustment (GIA) model values also agree well with elastically corrected vertical motions when validated with elastically uncorrected and corrected GPS vertical velocities. It is thus suggested that the outcome of the elastically corrected vertical deformation in the Antarctic region is very well connected to the long-term viscoelastic changes akin to AIS mass variations.

FIELD SURVEYS

1. Ground magnetic survey was carried out to understand the magnetization variations within the Deccan Trap, map the lineaments, and prepare a crustal magnetic anomaly map of the Deccan Volcanic Province of Maharashtra. The areas surveyed were Dhule, Nasik, Malegaon, and the surrounding regions of Maharashtra, from March 7 to April 1, 2022.

2. Two field surveys were conducted in the Palghar seismic swarm region to establish three permanent GPS sites and six campaign sites. The first fieldwork during October 2021 was carried out to identify the permanent sites and permission acquired from Governmental institutions. In the second field tour from March 23 to April 4, 2022, monumentation and installation of the permanent site were completed. Also, campaign observation data were collected during this period.

3. Acquired geological and historical archive samples from the Purna River basin for Environmental magnetic and Archaeomagnetic studies during November 9-19, 2021.

4. Field survey was carried out in the Purna basin, to select the sites and collect samples for magnetic and geochemical studies to study palaeoenvironmental conditions. A total of ~350 oriented and loose sediment samples were collected in 7.65 m sediment section from Parad, 76 samples in 3.7 m section from Andura and 38 samples in ~2 m section from Ghandhigram of Akola District, Maharashtra. Charcoal and bone samples were collected for Radiocarbon (14C) and Optically stimulated luminescence (OSL) dating for chronological constraints. The survey was carried out during November 9-19, 2021.

5. Field surveys were carried out in Assam, with the objective of identification of palaeo earthquakes using liquefaction features in NE India. The survey was carried out during March 11-28, 2022.

6. AMT and MT data were acquired from the thermal springs of western Maharashtra, DVP during February 23-March 14, 2022. The objective of the survey is to image the subsurface geoelectrical structure of Rajapur hot spring, Western Maharashtra, India.

7. VLF-EM survey was carried out over and around five thermal springs of Jalgaon district, north Maharashtra with the objective of delineating the subsurface structure, fracture pattern, and extent of conductive zones. Also, 10 soil samples and 14 water samples were acquired from the survey area to study the Physico-chemical characteristics. The survey was carried out during November 21-28, 2021.

8. A state-of-the-art All-Sky Airglow Imager (ASAI) has been operated in a campaign mode at Panhala, Kolhapur, to study the equatorial plasma bubbles and their drift motion. Students and Scientific/Technical Staff at IIG/MF radar facility were involved in operating the newly acquired All Sky Imager (Keo Scientific Ltd. 1024*1024 Pixels CCD, working in Window 10 operating system, New Synopticx software 1.4.18 version) at Panhala. This campaign was conducted during November 2021-March 2022 in three intervals: (27 November-09 December 2021; 29 December 2021-09 January 2022; 26 February-09 March 2022). The data collected on clear sky conditions are of good quality and are currently being analyzed.

9. Installation of new broadband seismograph (BBS) at Rain Forest Research Institute (RFRI) campus, Jorhat, Assam, and periodic servicing and data retrieval of BBS stations at Bongaigaon, Diphu, and Namsai during November 7-23, 2021.

10. Servicing and data retrieval of BBS stations at Jorhat, Assam; Pasighat, Arunachal Pradesh Agartala, and Aizawl during January 5-9, 2022.

11. Installation of new broadband seismograph (BBS) at Jorhat, Assam and Govt. Polytechnic College campus, Pasighat, Arunachal Pradesh.Servicing and data retrieval of BBS stations at Pasighat, Ziro and Dirang during January 2-24, 2022 .

Installation of new broadband seismograph (BBS) at Rain Forest Research Institute (RFRI) campus, Jorhat, Assam.

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On the latitudinal variation in OI 630.0 nm day glow emissions in response to the equatorial electrodynamic processes and neutral winds. *Adv. Space Res.,* **69(2),** 926-938, 2022, https://doi.org/ 10.1016/ j.asr. 2021. 10. 034.

55. **Tahama,** K., A. Baride, **G. Gupta, V.C. Erram** and M.V. Baride
Spatial variation of sub-surface heterogeneities within the dyke swarm of Nandurbar region, Maharashtra, India, for groundwater exploration using Inverse Distance Weighted technique. *Hydroresearch,***5, 1-12,** 2022, https://doi.org/10.1016/j.hydres.2021.12.001.

56. **Tahama, K., G. Gupta** and J.D. Patil
Geoelectrical survey for evaluation of groundwater potential within the basaltic terrain of Chikotra River basin, Maharashtra. Hydrospatial Analysis, **5(2),** 72-84, 2021, https://doi.org/10.21523/gcj3.2021050203.

57. **Tahama, K., G. Gupta, V.C. Erram,** A. Baride and M.V. Baride
Electrical Resistivity Imaging in Parts of Nandurbar District, Deccan Volcanic Province, Maharashtra, India. *J. Geol. Soc. India,* **98,** 305-313, 2022, https:// doi.org/ 10.1007/s12594-022-1981-6.

58. Thammavongsy, P., P. Supnithi, L.M.M. Myint, **S. Sripathi,** K. Hozumi, D. Lakanchanh
Comparison of Observed Equatorial Spread-F Statistics between Two Longitudinally Separated Magnetic Equatorial Stations and the IRI-2016 Model during Low and High Solar Activities. *Adv. Space Res.*, 2021, doi: https://doi.org/10.1016/j.asr.2021.12.050.

59. Tripathi, G., S.B. Singh, S. Kumar, As. K. Singh, **Rajesh Singh** and A.K. Singh
Effect of 21 June 2020 solar eclipse on the ionosphere using VLF and GPS observations and modelling. *Adv. Space Res.,* 2021, https://doi.org/ 10.1016/ j.asr. 2021.11.007.

60. Tsurutani,B.T., L. Shan, **G.S. Lakhina**, C. Mazelle, X. Meng, A. Du and Z. Liu
Comment on "Non-interacting coronal mass ejections and solar energetic particles near the quadrature configuration of solar terrestrial relations observatory": CME shocks are fast magnetosonic shocks and not intermediate Alfvén shocks.*Astron. Astrophys.*, **656**, 2021, https://doi.org/10.1051/0004-6361/202141029.

61. Vankadara, R.K., S.K. Panda, C. Amory-Mazaudier, R. Fleury, V.R. Devananboyina, T.K. Pant, P. Jamjareegulgarn, M.A. Haq, D.I. Okoh and **G.K. Seemala**
Signatures of Equatorial Plasma Bubbles and Ionospheric Scintillations from Magnetometer and GNSS Observations in the Indian Longitudes during the Space Weather Events of Early September 2017. *Remote Sensing*, **14(3),** 652, 2022, https://doi.org/ 10.3390/rs14030652.

62. **Vijaya Kumar, P.V., P.B.V. Subba Rao, A.K. Singh, Amit Kumar** and P. Rama Rao
Dimensionality and directionality analysis of magnetotelluric data by using different techniques: A case study from northern part of Saurashtra region, India. *J. Earth System Science,* **130(2)**, 1-16, 2021.

63. Yadav, S., A.K. Yadav, D. Singh and **M. Lal**
Variability and Changes in Rainfall Observed Across Jharkhand Region (India). Int. *J. Res. Appl. Sci. Engg. Tech.*,**9(XII)**, 2021.

64. Yadav, S. and **M. Lal**
Investigation of Decadal Changes of Temperature over Bihar Region (India). *Int. Res. J. Engg. Tech.*,**9(1)**, 2022.

CHAPTERS IN BOOKS/ BOOKS EDITED

1. **Basavaiah, N.**, J. Seetharamaiah, E. Appel, N. Juyal, S.A Prasad, K. Nageswara Rao, A.S. Khadkikar, N. Nowaczyk and A. Brauer
Holocene environmental magnetic records of Indian monsoon fluctuations. In: Navnith Kumaran, Padmalal Damodara (eds.), Holocene Climate Change and Environment, Elsevier, 229-247, 2022, ISBN 9780323900850, https://doi.org/10.1016/B978-0-323-90085-0.00004-8.

2. **Gawali, P.B., B.V. Lakshmi,** P. Hanamgond, S. Aher, P. Deshmukh, M. Herlekar, S.J. Sangode and P. Kamble
Monsoon Impacted Magnetic and Geomorphological Changes Along the Redi Beach, Sindhudurg District, West Coast of Maharashtra, India. In: Singh, R.B., Kumar, M., Tripathi, D.K. (eds.) Remote Sensing and Geographic Information Systems for Policy Decision Support. Advances in Geographical and Environmental Sciences. Springer, Singapore, https://doi.org/10.1007/978-981-16-7731-1_5.

3. Kar, R., A.K. Mishra, A. Mazumder, K. Mishra, **S.K. Patil**, P. S. Ranhotra, R. Bajpai and K. Singh
Deciphering the changing climate and environment around Ny-Ålesund, Svalbard, since the Last Glacial Maximum: a multiproxy approach. (Chapter 4 of the Book: Understanding Present and Past Arctic Environments, pp: 49-78, Elsevier Inc., 2021), DOI: https://doi.org/10.1016/B978-0-12-822869-2.00020-7.

4. Patil, S.N., A.V. Deshpande, A.M. Varade, P. Diwate, A. A. Kokoreva, R. B. Golekar and **P.B. Gawali**
Magnetic Susceptibility and Heavy Metals Contamination in Agricultural Soil of Kopargaon Area, Ahmadnagar District, Maharashtra, India. In: Rai, P.K., Mishra, V.N., Singh, P. (eds.) Geospatial Technology for Landscape and Environmental Management. Advances in Geographical and Environmental Sciences. Springer, Singapore, https://doi.org/ 10.1007/978-981-16-7373-3_21.

5. Resmi, T. R., G. Gopinath, **P. S. Sunil**, M. Praveenbabu, P. Arjun and R. Rawat
Chemical and Isotopic Characterization of Lakes in the Larsemann Hills, East Antarctica. In: Khare N. (ed.) Assessing the Antarctic Environment from a Climate Change Perspective. Earth and Environmental Sciences Library. Springer, Cham., https://doi.org/ 10.1007/ 978-3-030-87078-2_10.

6. Roy, I., P. Singh, R. N. Tomar, M. Shekhar, S. Agrawal, A. Bhattacharyya, P. Kumar, **S.K. Patil** and R. Sharma
Reconstruction of the Late Holocene climate variability from the Summer Monsoon dominant Bhagirathi valley, western Himalaya. J. Asian Earth Sci., 105080, 2022, https://doi.org/10.1016/j.jseaes.2022.105080.

7. Sudarshan, R., B. Madhusudan Rao, B. Nagaraju, **S.K. Patil** and K. Lohith Kumar
Magnetic Properties of Road Dust Using Environmental Magnetism Settings in Greater Hyderabad Municipal Corporation (GHMC), Telangana State, India. H. Chenchouni et al. (eds.), New Prospects in Environmental Geosciences and Hydrogeosciences, Advances in Science, Technology & Innovation, 2022, https://doi.org/10.1007/978-3-030-72543-3_60.

8. **Sunil P. S., A. P. Saji, K. VijayKumar, M. Ponraj, S. Amirtharaj** and **A. Dhar**
Revealing the Contemporary Kinematics of Antarctic Plate Using GPS and GRACE Data. In: Khare N. (ed.) Assessing the Antarctic Environment from a Climate Change Perspective. Earth and Environmental Sciences Library, Springer, Cham., 2022, https:/ /doi.org/ 10.1007/978-3-030-87078-2_18.

IMPACT FACTOR OF PUBLICATIONS DURING 2021-2022

Journal Name	Impact Factor	No. of Papers
Advances Space Research	2.611	14
Applied Geomatics	2.357	1
Astron. Astrophys.	5.802	1
Astrophys. J.	5.874	1
Earth Planet. Phys.	NA	2
Environ. Dev. Sustain.	4.080	1
Environ. Earth Sci.	3.119	1
Front. Earth Sci.	3.498	1
Geophys. J. Int.	2.934	1
Geol. Soc. London (Special Publ.)	0.85	1
Gondwana Res.	6.151	1
Hydroresearch	NA	1
Hydrospatial Analysis	NA	1
Int. Advanced Res. J. Sci. Engg. Tech.	7.105	1
Int. J. Res. Appl. Sci. Engg. Tech.	7.538	1
Ind. J. Sci. Tech.	NA	1
Int. Res. J. Engg. Tech.	7.529	1
J. Appl. Geophys.	2.121	1
J. Asian Earth Sci. X	3.374	1

Journal Name	Impact Factor	No. of Papers
J. Atmos. Solar-Terr. Phys.	2.119	1
J. Cosmol. Astropart. Phys.	5.839	1
J. Earth System Sci.	1.912	3
J. Geophys. Res. (Space Physics)	3.11	6
J. Ind. Geophys. Union	NA	1
J. Geol. Soc. India	1.466	2
J. Geosci. Res.	NA	1
Marine Petroleum Geology	5.361	1
Meteorit. Planet. Sci.	2.890	1
Monthly Notices Royal Astron. Soc.	5.235	2
Phys. Scripta	3.081	1
Planet. Space Sci.	2.085	1
Plasma	NA	2
Precambrian Res.	4.261	1
Pure Appl. Geophys.	2.641	1
Remote Sensing	5.349	1
Results Phys.	4.565	1
Scientific Reports	4.380	2
Tectonophysics	3.66	1
Waves Random Complex Media	4.853	1

INVITED TALKS AND LECTURES

Dr. S.P. Anand
Invited by Marine & Coastal Survey Division (M & CD), Geological Survey of India, to deliver an e-lecture as a part of their online training course entitled "Course on Marine Geology and Marine Geophysics" on the topic ´Crustal Structure of Asesimic Ridges in the Northwestern Indian Ocean-A Geopotential Appraisal' on June 19, 2021.

Delivered one day e-lecture as a part of the 13th Orientation Course for the newly recruited Geophysicist at Geological Survey of India Training Institute Hyderabad, on the following topics a) Potential Field Data Enhancement and Filtering Techniques b) Interpretation of Magnetic Data and Modelling.

Ghodpage, R.N.
Delivered an invited lecture on "Study of upper atmosphere using Airglow technique" at ACS College Paluse, Sangali on 23 March, 2022.

Dr. Geeta Vichare
Invited to deliver a talk on "Impact of Extreme Space Weather Events" at ISWI Workshop on Space Weather: Science & Applications, held during November 2-3, 2021, which was jointly organized by the United Nations Office of Outer Space Affairs (UNOOSA) and VSSC, ISRO.

Bagiya, Mala S.
Invited to deliver a talk on "Tsunamigenic energetics in the ionosphere and possible early warning scenario", by Bagiya, Mala S., A. S. Sunil, P.S. Sunil and S. Nayak, held during NSF workshop on Bringing Land, Ocean, Atmosphere and Ionosphere Data to the Community for Hazards Alerts, May 24-28, 2021.

Dr. Amar Kakad
Delivered an invited Talk on "Fluid simulation of the new subclass of solitons "Supersolitons" in plasma at Khalifa University, Abu Dhabi onDecember 16, 2021.

Dr. Rajesh Singh
Delivered an invited talk on "Global Climate Change and its impact on Earth's Upper Atmosphere", UGC Refresher course on "Climate Change" at K. Banerjee Centre of Atmospheric and Ocean Studies, University of Allahabad, January 19, 2022.

PARTICIPATION IN CONFERENCES/MEETINGS/SEMINARS

NATIONAL

1st Venus Science Conference 2021 (Venus-SC-2021), Physical Research Laboratory, Ahmedabad, September 23-24, 2021

Kamalam, T., S.V. Singh, G.S. Lakhina and R. Rubia
Kinetic study of ion acoustic waves in Venus's dawn dusk meridian region in ionosphere.

Rubia, R., **Devanandhan, S., S.V. Singh** and **G.S. Lakhina**
Electrostatic Solitary waves observed at Venus.

6th Shear Zones and Crustal Blocks of Southern India, Department of Geology, University of Kerala, Trivandrum, November 5-10, 2020 (Virtual)

Anand. S.P.
Aeromagnetic Signatures of Peninsular India.

Virtual National Conference on Plasma Science and Application (PSA-2021), organized by Sardar Vallabhbhai National Institute of Technology, Surat, India, December 20-21, 2021.

Barik, K.C., S.V. Singh and **G.S. Lakhina**
Ion beam driven kinetic Alfvén waves in space plasmas.

Kakad, A.
Ion Holes in Collisionless Space Plasmas
(Plenary Invited Talk)

Indian Space Weather Conference (ISWC- 2022), Physical Research Laboratory, India, January 11-12, 2022 (Virtual).

Saranya, P., N. Parihar, S. Sau, A. Taori, **S. Sripathi, R. Rawat, K. Emperumal,S. Sathishkumar** and T.R. Mudgal
A case study of equatorial spread-F associated airglow depletions near the crest of ionization anomaly in India on 16 April 2012.

Trunall, S., B. Veenadhari and M. Pandya
Energetic Ion variations at near Earth plasma sheet during Substorm events and associated magnetic field Dipolarization using Van Allen Probes observations.

Indian Quaternary Congress (IQC) BSIP, Lucknow, January 18-21, 2022

Mujahed Baba, B.V. Lakshmi, Pravin B. Gawali and **K. Deenadayalan**
Geochemical characteristics of river sediments near Dauki Fault, Shillong Plateau, NE India: An emphasis on environmental changes.

21st National Space Science Symposium (NSSS-2022), IISER Kolkata, India, 31 January-4 February 2022 (Virtual)

Ghodpage, R.N., Alok Taori, O.B. Gurav, **P.T. Patil** and M.K. Patil
Interesting Airglow Observations during COVID 19 Pandemic over Indian Sector.

Gurav, O. B., **R. N. Ghodpage,** A. Taori, S. Sau, **P. T. Patil, V. C Erram** and **S. Sripathi**
A study of Fascinating Equatorial Plasma Bubble Event Imaged through All-Sky Imager over Indian Sector.

Naniwadekar, G.P., **S. Gurubaran, R. N. Ghodpage, P. T. Patil** and D.S. Burud
Long-term variability in the mesospheric mean winds observed by MF radar over Kolhapur (16.8°N, 74.2°E).

Sripathi S. and Ram Singh
On the seasonal response of the equatorial and low latitude ionosphere to major geomagnetic storms: A comparative study.

58th Annual Convention Indian Geophysical Union (IGU), North-Eastern Hill University (NEHU), Shillong,February 2-4, 2022(Virtual)

Bagiya, Mala S., S. Nayak and Surendra Sunda
GNSS measured tsunamigenic wave perturbations in ionosphere and possible early warning scenario.

Das, R., S. Mukhopadhyay, **Mala S. Bagiya** and **Nava K. Hazarika**
Recent Seismicity and Minimum 1-D Velocity Models of North-East India Region.

Nayak, S. and **Mala S. Bagiya**
Ionospheric resonance oscillations during Great earthquakes.

Pradhan, S.K., Nava K. Hazarika, Mala S. Bagiya and Damepaia S.M. Pdah
Neo-tectonic study of a North Brahmaputra River basin: Insights from Remote sensing study

INTERNATIONAL

NSF workshop on Bringing Land, Ocean, Atmosphere and Ionosphere Data to the Community for Hazards Alerts, May 24-28,2021(Online everywhere)

Nayak, S., Mala S. Bagiya, Satish Maurya, **Nava K. Hazarika,** A.S. Sunil Kumar, D.S.V.V.D. Prasad and D.S. Ramesh
Terrestrial resonant oscillations during the 11th April 2012 Sumatra earthquake.

Joint scientific General Assembly IAGA-IASPEI 2021 conducted by NGRI, Hyderabad, 21-27 August, 2021(Virtual)

Bagiya, Mala S., A. S. Sunil, P. S. Sunil, S. Sunda and **D. S. Ramesh**
Tracing of Ionospheric Signals for Tsunami Early Warning using GNSS data.

Bagiya, Mala S., A.S. Sunil, L. Rolland, **S. Nayak** and **D.S. Ramesh**
On the Effects of Non-Tectonic Forcing Mechanisms on GPS measured Coseismic Ionospheric Perturbations: a Geometrical Modelling Approach.

Barad, Rajesh K. and **S. Sripathi**
Investigation of ionospheric response to 26 December 2019 solar eclipse using observations and SAMI2 model simulations.

Bhaskar, A., D. Sibeck, Suk Bin Kang, Mei Ching Fok, D. Oliveira, S. Kanekal, T.K. Pant and **Geeta Vichare**
Investigating magnetospheric particle injections and associated drift echos induced by interplanetary shocks.

Chauhan, N., S. Gurubaran, K. Sarkar, S. Moulik and **P.K. Das**
All-sky imaging observations of mesospheric frontal events over low latitudes.

Datar, G. and **Geeta Vichare**
Study of thunderstorm ground enhancement events from Tirunelveli, India.

Gurubaran, S., Ashish P. Jadhav, P.T. Patil, R. Ghodpage and R.S. Vhatkar
Day-to-day variabilities of Equatorial Electrojet caused by Planetary Waves in the Mesosphere-Lower Thermosphere Region.

Jethva, C., **Mala S. Bagiya** and H.P. Joshi
GPS-TEC Variability in Comparison with IRI-2016 Model at Northern EIA Crest during Solar Cycles 23-24 (2005-2019).

Lakshmi, B.V., K. Deenadayalan and **P.B. Gawali**
Reconstruction of paleoenvironmental changes from Chandanpuri formation, Deccan Traps: Magnetic and geochemical approaches.

Mujahed Baba, B.V. Lakshmi, P.B. Gawali, K. Deenadayalan and **D.S. Ramesh**
Magnetic fabric characteristics of sediments in and around Dauki fault region, Shillong, India.

Nayak, S., Mala S. Bagiya, A.S. Sunil and **D.S. Ramesh**
Spatial extent of the resonance ionospheric signatures during the 11 March 2011 Tohoku earthquake.

Nilam, B. and **S. Tulasi Ram**
Forecasting geomagnetic activity (Dst index) using an Ensemble Kalman Filter.

Singh, R.
D-,E-,F-region ionosphere coupling due to Mesoscale Convective System (MCS) generated lightning discharges.

Sreelakshmi, J. and **Geeta Vichare**
Characteristics of Equatorial Counter-Electrojet.

Sripathi, S., Rajesh K. Barad, Ram Singh, S. Banola and **Prabhakar Tiwari**
Ground and Space based observations of the pre and post atmospheric and ionospheric anomalies as investigated using 2015 Nepal earthquake.

Sripathi, S., Ram Singh and **Rajesh Kumar Barad**
A study on the sources for the excitation of F3 layers at Allahabad (25.3° N, 81.5° E) near anomaly crest region over India during 19-21 December 2015 geomagnetic storm.

Trunali, S., M. Pandya and **B. Veenadhari**
Study of Energetic Ion variations at near Earth plasma during Substorm events and associated Dipolarization using Van Allen Probes data.

Tulasi Ram, S. and K. K. Ajith
Early development of 3-meter scale irregularities in the topside region of a rapidly rising Equatorial Plasma Bubble.

Vichare, Geeta and D. Hui
Simulation of storm time equatorial ionospheric plasma drifts: IMFBy effects.

5th Asia Pacific Conference on Plasma Physics, Kyushu University, Japan, September 26- October 1, 2021, (Online)

Kakad, A.
Formation and Dynamics of Solitary Waves in Plasmas **(Plenary Invited Talk)**

Singh, S.V.
Nonlinear electrostatic waves in the auroral plasma **(Invited)**

AGU Fall Meeting, USA, 13- 17 December, 2021 (Virtual)

Barik, K.C., S.V. Singh and **G.S. Lakhina**
Generation of ultra-low frequency Waves: Kinetic Alfvén waves Perspective.

Nilam,B. and **S. Tulasi Ram**
Forecasting geomagnetic activity (Dst index) using an Ensemble Kalman Filter.

15th Quadrennial Solar-Terrestrial Physics (STP-15) Symposium, Indian Institute of Geomagnetism, India, 21- 25 February, 2022 (Virtual)

Barik,K.C., S.V. Singh and G.S. **Lakhina**
A comparative study of ion beam and velocity shear driven resonant instability of kinetic Alfvén waves with κ-electrons.

Chauhan, N., S. Gurubaran and V. Lakshmi Narayanan
Investigation of sources of gravity waves observed over Indian low latitude region.

Jadhav, Ashish P., S. Gurubaran, P.T. Patil and R.S. Vhatkar
Quasi-2-day Wave Coupling of Atmosphere-Ionosphere System at low to mid-latitudes.

Jyoti, K. Atul, S. Sripathi, S.V. Singh and Rameswar Singh
Nonlinear Evolution of Equatorial Plasma Bubbles.

Liow, Y.Y., S.M. Buhari, M. Abdullah, T.J. Musa and **S. Tulasi Ram**
The relation between large-scale wave structure and equatorial plasma bubbles.

Nilam, B. and **S. Tulasi Ram**
Extremely large and rapid decrease of equatorial geomagnetic field due to sudden decrease in the solar wind density.

Ojha, B., Y. Omura, **S.V. Singh** and **G.S. Lakhina**
Investigating the fine structures of EMIC waves: Simultaneous rising and falling tones.

Ojha, B., Y. Omura, **S.V. Singh** and **G.S. Lakhina**
Rapid growth of EMIC wave subpackets: Multipoint observations.

Rajesh Singh, A.K. Maurya and **Navin Parihar**
Study of Gravity Waves in Atmosphere-Ionosphere Coupling.

Shipra Sinha, B. Nilam, Geeta Vichare, S. Tulasi Ram and **Ashwini K. Sinha**
Low latitude geomagnetic H-component variations during impulse induced storm time substorms.

Singh, S.V., B. Ojha and **G.S. Lakhina**
Observation of Magnetosonic waves in outer magnetosphere associated with EMIC waves by THEMIS probe.

Sreelakshmi, J. and **Geeta Vichare**
Gravity And Pressure-gradient Currents In The Earth's Ionosphere.

Sripathi, S., Rajesh K. Barad, S. Banola, P. Tiwari, K. Emperumal and **C. Selvaraj**
Characteristics of plasma irregularities at equator and anomaly crest region under varied space weather conditions and their causative mechanisms

Trunali, S., B.Veenadhari, M. Pandya, Y. Miyoshi and M. Nosé.
Substorm and associated magnetic field dipolarization signatures in inner magnetosphere and related ion flux variations using Van Allen Probes and Arase observations.

Virtual THEMIS-ARTEMIS SWT meeting, February 23-24, 2022

Ojha, B., S.V. Singh and **G.S. Lakhina**
Observation of Low-frequency Magnetosonic waves associated with EMI Crising tones by THEMIS spacecraft.

STUDENTS CORNER

Shri Srinivas Nayak
Best Young scientist presentation at IAGA-IASPEI General Assembly – 2021, Virtual Meeting, August 21-27, 2021.

Participated in the workshop on "NavIC/GNSS Technique and Applications", August 3-5, 2021 (Virtual meeting).

Shri Krushna Chandra Barik
Received Young Researcher Award at Virtual National Conference on Plasma Science and Application (PSA-2021), organized by Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat, India, 20-21 December, 2021.

Ms. Monica Rawat and Shri Tabish Khan
Participated in the e Training program "Fundamental of Geological Mapping organized by Geological Survey of India Training Institute, Hyderabad from June 10-11, 2021.

Ms. Monica Rawat
Participated in African Geophysical Society, a conference on Solid Earth Geophysics and Atmospheric Physics Organized by National Space Research and Development Agency held during October 19-21, 2021.

Participated in the STEPSYS workshop organized by Indian Institute of Geomagnetism during February 19-20, 2022.

Participated in the 15th Quadrennial Solar-Terrestrial Physics (STP-15) symposium organised by Indian Institute of Geomagnetism during February 21-25, 2022.

Shri Tabish Khan
Attended workshop on Navic/GNSS: Techniques and Application organized by NARL, Gadanki from June 3-5, 2021.

Shri Harikrishnan A.,
Ph.D. Degree Awarded by University of Mumbai, March 2022.

Ms. T. Kamalam's
Ph.D. Viva was completed on 25th March 2022 and received Ph.D. result notification letter from University of Mumbai on 19th April 2022.

Shri Krushna Chandra Barik
submitted Ph.D. Thesis entitled **"Generation of low-frequency electromagnetic waves in the magnetosphere"** to University of Mumbai on 17th September 2021 under the supervision of Dr Satyavir Singh.

Ms. T. Kamalam
Received "best paper presentation award" among young researchers in the 1st Venus Science Conference 2021 (Venus-SC-2021), Physical Research Laboratory, Ahmedabad, 23-24 September 2021 on the paper "Kinetic study of ion acoustic waves in Venus's dawn dusk meridian region in ionosphere", **T. Kamalam, S. V. Singh, G. S. Lakhina** and R. Rubia.

DEPUTATIONS/VISITS ABROAD

Name	Country visited	Duration	Conference/workshop/symposium
Dr. Amar Kakad	Abu Dhabi	December 10-26, 2021	Visiting Professor at Khalifa University
Dr. Remya Bhanu	USA	November 30, 2020 - November 29, 2021	NASA Postdoctoral Fellow at NASA Goddard Space Flight Center, Maryland

Antarctic/Arctic Expeditions

Name	Country visited	Duration	Expedition
Shri Ramana Murthy	Maitri, Antarctica	41 ISEA	Winter member
Shri Anoop K. Soman	Bharati, Antarctica	41 ISEA	Station Leader & Winter member
Shri Pritimay Patro	Maitri, Antarctica	41 ISEA	Summer member

DISTINGUISHED VISITORS

Mrs. Renuka Mukadam, POSH Consultant, delivered a talk on "Sexual Harassment of Women at Workplace (Prevention, Prohibition and Redressal) Act 2013", on December 9, 2021.

Ms. Ishita Gulati from New Castle University, UK, delivered a talk on "Modelling the Impact of Ionospheric Scintillation on GNSS Receivers in the Indian Low-Latitude Region" on September 24, 2021.

Mrs. Renuka Mukadam, POSH Consultant, delivering a lecture on "Sexual Harassment of Women at Workplace (Prevention, Prohibition and Redressal) Act".

HONOURS AND AWARDS

Dr. Gautam Gupta
Member, Board of Studies, Department of Geotechnology, Manonmaniam Sundaranar University, Tirunelveli, 2022.

Member of the National Advisory Committee of the Multidisciplinary National Conference on "Socio-Economic and Ecological Impacts of the Climate Change with Reference to Indian Subcontinent", February 2022.

Associate Editor, Journal of Ground Water Research, ISSN Number (ISSN 2321-4783), 2021-2023.

Member, Editorial Board, Bulletin of Pure & Applied Sciences (Geology), eISSN: 2320-3234, 2021-2023.

Dr. Geeta Vichare
Appointed as a member of Subject Expert Committee (SEC) on Earth &Atmospheric Sciences for Women Scientists Scheme-A (WOS-A) of DST.

Marking Golden Jubilee year of IIG, organized a Special Session on "Geomagnetism - The Connecting Link between Sun and Earth" during STP-15, February 2022.

Dr. Satyavir Singh
Chaired two sessions (February 22 and 24, 2022) on PRESTO Pillar 2: Space Weather and Earth's Atmosphere in Virtually held "15th Quadrennial Solar-Terrestrial Physics (STP-15) symposium" during February 21-25, 2022 at Indian Institute of Geomagnetism, Navi Mumbai.

Convener of STEPSYS (Solar-Terrestrial Physics for Students and Young Scientists), February 19-20, 2022 held virtually at Indian Institute of Geomagnetism, Navi Mumbai.

Dr. Amar Kakad
Jury member for the ORAL session and the Emerging Scientist award presentations in Virtual National Conference on Plasma Science and Application (PSA-2021), organized by Sardar Vallabhbhai National Institute of Technology, Surat, India, 20-21 December 2021.

Dr. Remya Bhanu
Awarded NASA Postdoctoral Program (NPP) fellowship for two years.

A proposal titled "Geomagnetic activity and solar cycle dependence of Electromagnetic Ion Cyclotron (EMIC) wave activity and wave parameter in the Earth's magnetosphere" submitted to the "International Space Science Institute (ISSI) - 2021 International Teams in Space and Earth Sciences" was approved for implementation. Dr. Remya Bhanu is the team lead of the project with 11 other international team members, one external science expert and two early-career scientists.

Dr. Rajesh Singh
Co-Convener of Session D5- "Relativistic electrons: Their emergence and loss in geospace, their impact on the upper atmosphere and the role of the cold plasma background" at Joint Scientific Assembly, IAGA-IASPEI-2021, Virtual Conference, Hyderabad, India, August 21-27, 2021.

TRAINING IMPARTED

Dr. B.V. Lakshmi

Saurabh Santosh Sawant, JRF, IIG has done his dissertation as a part of Ph.D. course work on "Application of Mineral magnetism in assessing Paleoenvironmental changes: Preliminary investigations from Parad sediment section, Purna Basin, DVP" during January-March, 2022.

Rama Pandey, JRF, IIG has done her Ph.D. course work project on "Environmental magnetic properties of sediments from NE India" during January-March, 2022.

Dr. S. Sripathi

Ms. Ishita Gulatifrom New Castle University, UK visited IIG during July-September 2021 under the SCOSTEP Visiting Scholar (SVS) student exchange program. She worked on performance of GNSS receivers under severe scintillation environment under St Patrick's Day geomagnetic.

Dr. K. Deenadayalan

Ms. Pradnya Ramesh Mohite, JRF, IIG has done her dissertation work on "Rock-magnetic studies of archaeological artefacts from Parad, Purna River, Maharashtra"during January-March, 2022.

PARTICIPATION IN SPECIALIZED WORKSHOPS/TRAINING COURSES

Dr. Geeta Vichare

Attended the workshop on "Prevention of Sexual Harassment of Women at Workplace" at Ramnagar, Uttarakhand, during November 23-26, 2021.

Dr. A.K. Singh

Participated in the 3rdAOGS-EGU Joint Conference: NatHazards 2021, on "New Dimensions for Natural Hazards in Asia", September 20- 22,2021(Virtual).

Participated in the 18th Annual Meeting of the Asia Oceania Geosciences Society (AOGS 2021), Singapore, August1-6, 2021.

Participated in the International Virtual Workshop on "Global Seismology & Tectonics (IVWGST-2020)", Geoscience & Technology Division, North East Institute of Science & Technology (CSIR) Jorhat, Assam, India,September 14-25, 2020.

Dr. Anand, S.P.

Nominated to attend NIAS-DST Online Training Programme on "Science, Technology and Innovation Policy"from March 7-18, 2022. He also presented a paper entitled "Sharing of Research Experience- Challenges & Achievements".

Dr. K. Vijay Kumar

Participated in the annual International virtual Workshop, on "Global Seismology & Tectonics" (IVWGST) organized by Geoscience & Technology Division (GSTD) of CSIR-NEIST, Jorhat from September 20-30, 2021.

Dr. S. Pandey

Participated in the International Webinar Series on the Topic "Advances in Earth and Environmental Geosciences", March10-11, 2022,Department of Geophysics, Institute of Science, Banaras Hindu University in association with Distinguished Lecture Series Programme, American Geophysical Union.

Participated in the International Virtual Workshop on "Global Seismology & Tectonics (IVWGST-2020)", Geoscience & Technology Division, North East Institute of Science & Technology (CSIR) Jorhat, Assam, India,September 14-25, 2020.

Dr. Navin Parihar

Participated in Eastern Africa GNSS and Space Weather Capacity Building Workshop Advanced School/Workshop [Organizer: International Centre for Theoretical Physics, Trieste, Italy, 21-25 June 2021; Online Mode.

Dr. Amar Kakad

Participated in CDAC's Government Officials Training Program on "Artificial Intelligence" under "Future Skills PRIME: program (16-30 June 2021).

Participated in NIAS-DST Online Training Program on "Science, Technology and Innovation Policy" during 7-18 March 2022.

Dr. Satyavir Singh

Participated online programme on "Managing Technology Value Chain"' organized by Administrative Staff College of India, Hyderabad, Sponsored by the Department of Science and Technology, GoI (October 25-29, 2021).

Shri Krushna C. Barik
Attended workshop on Solar-Terrestrial Physics for Students and Young Scientists (STEPSYS), February19-20, 2022 organized by Indian Institute of Geomagnetism as a part of 15TH QUADRENNIAL SOLAR-TERRESTRIAL PHYSICS SYMPOSIUM (STP-15).

Attended international Space Weather Initiative Workshop on Space Weather: Science and Applications, November2-3, 2021, jointly organized by the United Nations Office for Outer Space Affairs and the Vikram Sarabhai Space Centre of Indian Space Research Organization, India.

Attended AAPPS-DPP 2021, September 26- October1, 2021.

Attended Virtual GEM 30 Workshop, July 25-30, 2021.

Attended Online Cold Plasma Seminars, organized by Los Alamos National Laboratory (LANL), USA.

Attended Heliophysics 2050 Workshop, May 3-7, 2021 [Virtual Mode].

Attended Parker Solar Probe (PSP) Scholars Meeting, April 27-28, 2021 [Virtual Mode].

OFFICIAL LANGUAGE (HINDI)

Rajbhasha Adhikari	:	Amar P. Kakad
Asst. Director (Official Language)	:	J. Kamra
Hindi Advisor	:	Manju J. Singh
L. D. C	:	K. Shelatkar

In compliance with the provisions of the Official Languages Act, Rules made thereunder, the Annual Programme, and other directives issued from time to time by the Department of Official Language, the Institute regularly undertakes important and special activities to enhance the progressive use of official language Hindi among its staff members.

The Institute has organized 'Hindi Mah' during September-October, 2021. The Hindi competitions organized during this period included Essay Writing, General Knowledge, and Crossword, which were well attended by the staff members & research scholars. A total number of 48 prizes were given in these competitions. These competitions were conducted during the re-open period in Seminar Hall with considerable physical distance in the wake of the COVID-19 pandemic.

The Institute celebrated World Hindi Day on January 10, 2022 and organized Hindi Dictation and Word Formation competitions, which received an overwhelming response with more than 25 participants in each competition. A total number of 17 prizes were given in these competitions.

During the year, the Institute actively participated in various competitions organized by Navi Mumbai Town Official Language Implementation Committee (TOLIC). Under these competitions, the Institute bagged 2nd prize for implementation of Official Language Policy. Prof. Gautam Gupta bagged the 2nd prize in the Scientific Article competition, Miss Shivangi Rawat D/o Shri Rahul Rawat, Technical Officer-III of the Institute bagged 3rd prize in short story competition and Dr. Vinit Erram, Technical Officer-IV was awarded consolation prize in the Hindi Article competition. The winners shall be awarded with a cash prize in the forthcoming half-yearly meeting of the TOLIC to be held during June/July, 2022.

The Hindi House Magazine "SPANDAN" was published on a six-monthly basis (2 issues annually), which included both scientific and technical articles. The magazine is sent to various scientific and educational institutes in the country.

During the year, four Hindi Workshops (1 virtual mode and 3 with physical distancing) were organized on different topics for the staff of the Institute, in which around 65 members participated. The first 3 workshops were conducted by Asstt. Director (OL) of the Institute and the last workshop was conducted by Dr. Sushmita Bhattacharya, Dy. Director, Regional Implementation Office, Deptt. of Official Language,so as to provide guidance to the academic staff of the Institute.

Under the annual incentive scheme, a total of 16 staff members of the Institute were awarded with cash prizes for doing their official work in Hindi, and one officer was awarded with a prize for working as a major checkpoint. Apart from this, 7 children of employees were awarded with cash prizes for scoring very good marks in the Hindi/Sanskrit subjects. The awards were given during the Annual Day Celebrations, 2022.

The Director, Rajbhasha Adhikari, and Asstt.Director (Official Language) of the Institute attended various meetings /seminars held under the aegis of TOLIC, Navi Mumbai and other organizations.

Novels on display at Library during Hindi Mah.

Participants of the Hindi cross-word competition.

Dr. Sushmita Bhattacharya, Dy. Director, Regional Implementation Office, Deptt. of Official Language, addressing the academic staff at IIG.

SCIENCE OUTREACH ACTIVITIES

NATIONAL SCIENCE DAY 2022

National Science Day is being celebrated in our country on February 28 every year in commemoration of Sir C. V. Raman's discovery of the Raman Effect on February 28, 1927. The theme for National Science Day 2022 is "Integrated Approach in Science and Technology for a Sustainable Future". A popular talk was arranged on the topic "Cloud infra, security and services" and delivered by Ms. Prasanna Lakshmi, Scientist 'F', National Informatics Centre (NIC), Maharashtra. The talk was arranged in a virtual mode on February 28, 2022 at IIG HQ. The lecture was attended by staff members and students of IIG HQ, its Regional Centers and Magnetic Observatories.

Ms. Prasanna Lakshmi, Scientist 'F', National Informatics Centre (NIC), Maharashtra, delivered the Science Day talk in a virtual mode on February 28, 2022.

Ms. Prasanna Lakshmi, Scientist 'F', National Informatics Centre (NIC), Maharashtra, delivered the Science Day talk in a virtual mode on February 28, 2022.

7TH INDIA INTERNATIONAL SCIENCE FESTIVAL – 2021

IIG participated in the 7th India International Science Festival (IISF) 2021 conducted from December 10 to 13, 2021 at Campal Ground, Panaji, Goa. The Ministry of Earth Sciences, Ministry of Science & Technology, and Government of Goa in association with Vijnana Bharati (VIBHA) were the organizers. The National Centre for Polar and Ocean Research (NCPOR) of the Ministry of Earth Sciences, an institution situated in Goa, was the nodal agency to organize the IISF 2021.

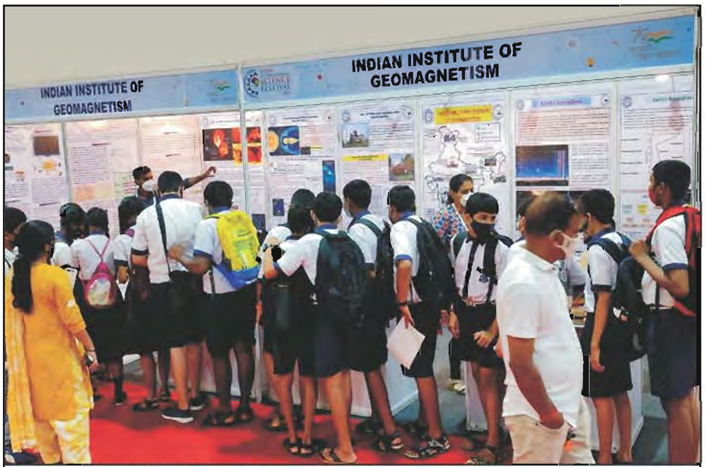
The theme of IISF 2021 was 'Celebrating Creativity in Science, Technology and Innovation for Prosperous India'. Apart from the Mega Science Expo, a total of 12 events were organized to engage creative and imaginative minds in India and across the globe to celebrate science through various programs which reflected the spirit and idea of Aazadi ka Amrit Mahotsav.

IISF 2021 Mega Science Expo was officially inaugurated on December 11, 2021 by the Hon'ble Minister of Ministry of Science & Technology and Earth Sciences Shri Jitendra Singh in the esteem presence of Secretary, MoES, Dr. M. Ravichandran, and Dr. Shekhar C. Mande, Secretary, DSIR & DG CSIR.

The Expo was one of the main events of the Science festival, with more than 174 stalls comprising academic institutions, R&D organizations, Science & Industrial councils, S&T organizations, traditional arts & crafts, etc. The total number of visitors for the expo (including the participants in the Guinness world record) was approximately 1 lakh. Around 250 govt. institutes, organizations, and autonomous bodies have participated in the IISF.

A large audience visited the IIG kiosk and was enamored with the scientific models. This helped in taking geomagnetism to the masses. Using the posters it became quite easy to explain complex concepts in an easy-to-understand language to lay public. The IIG-built magnetometer was also very well explained to the public till they understood the entire meaning of what is done with a magnetometer.

After the successful conduction of the Mega Expo, it was concluded on December 13, 2021. Dr. Shekar C. Mande, Secretary, DSIR & DG CSIR, Smt. Indira Murthy, Joint Secretary, MoES, and Shri Hari Babu Srivastava, Director General - Technology Management (TM), DRDO, delivered the valedictory address.



School students being explained the science of Geomagnetism at IISF 2021, Goa


Scientific models being explained to the students during the IISF 2021, Goa.

SHINING MAHARASHTRA 2022

'Shining Maharashtra 2022' event was held at Phaltan in Satara district, Maharashtra, during March 25-27, 2022. During this event, IIG showcased its research activities through colourful posters. The geophysical science for society, particularly the poster explaining the groundwater potential zones in Mann River Basin, Satara Dist. Maharashtra generated a lot of queries and appreciation by politicians and the local public. The opportunities and services offered by IIG were explained to the school and college students and other stakeholders in detail.

Several scientific models were demonstrated to the curious students and general public. Working models of the atmosphere along with a plasma globe and levitating earth, which explained basic physics principles, were a major attraction. Several eye-catching rocks and mineral samples were displayed along with a Geological time clock, which drew lots of crowds.

The footfall at 'Shining Maharashtra 2022' was both amazing and heartening as several thousands of laity of common people, school & college students, professionals and experts visited the IIG stall and were explained the intricacies of Geomagnetism and allied fields.


School students being explained the intricacies of geology and geophysics at Shining Maharashtra event 2022, Phaltan.


Posters and models depicting the science of geomagnetism being explained to the students during Shining Maharashtra event 2022, Phaltan.

ERP & COMPUTER SERVICES

Chief Coordinator : Ajay K. Singh
Member : Susheel Kumar, Mahendra Doiphode, Sayali Nalawade, Tejashri Bari, Nanda S. Shah

Chief Coordinator:
Member: ERP and Computer services, is providing IT infrastructure support, services and cyber security to the IIG staff members at its HQ, regional centers and magnetic observatories. Server level support is provided to various departments like library, accounts and ERP cell. It also looks after the implementation of SSL certification for IIG and ERP web portals. Real-time data transfer services for DFM using IPsec and SSLVPN technologies are implemented for the magnetic observatories.

Under the Equipment replacement/procurement plan (as per National IPv6 Deployment Plan: to phase out non-compliant hardware and software) procurement of new IPv6 compliant Firewall units along with analyser and manager functionality is initiated. This will further improve the network security at the remote offices.

IIG ERP (Enterprise Resource Planning) System envisages automation and integrationof the works of the administration towards a paperless office. Development & testing of various modules related to HRD, Accounts, Stores, and Establishment section have been completed, including CERT-IN security audit and SSL certification of the ERP portal. Module-wise role delegation and training as required under various modules have been completed. ERP system is ready to go live in two phases.

Renovation of the computer center and development of Video Conference room by CPWD is underway.

As a major achievement, the "15th QUADRENNIAL SOLAR-TERRESTRIAL PHYSICS SYMPOSIUM (STP-15) virtual international conference" has been successfully hosted during February 21-25, 2022, with the available IT resources at HQ.

LIBRARY AND DOCUMENTATION

Chief Coordinator : Ashwini K. Sinha/ Anand, S.P.

Coordinator : Smita Chandra

Members : B.I. Panchal, Sachin Jadhav

Library

The IIG Library continued to render its services of knowledge dissemination to the scientists, students, and technical staff at its headquarters, regional centers, and observatories by means of acquisition, collection management, and dissemination of the library resources. The Library staff with the help of the IIG management delivered quality services both via the online medium during Covid-19 times and offline, physically, after the Covid-19 restrictions.

The collections added during the period is as follows:

Sr.No.	Collection	Added during 2021-2022
1.	Books, Thesis, Hindi Books, Project Reports	90
2.	*Journals/e-Journals subscribed by Library	83
3.	Scientific Publications of IIG	78
4.	**Total**	**251**

***(The above list excludes the list of e-journals subscribed by the DST-NKRC Libraries consortia for the library.)**

Besides rendering library help on a daily basis, some of the important services provided by the library during this period are as follows:

1. Generation of Research metrics figures related to number of publications, the impact factor, the h-index, citations of papers produced during the year, etc. The trends analyzed for the top authors of the institute, the top publishers the scientists chose to publish their article with, and the top journals the scientists chose to publish in for the year were collected, the number of Open Access articles published, etc was prepared by the library using tools like the Web of Science and in-house data collected by the library.

2. Scientists were informed and guided to save on the Article Processing Charges (APCs). The library with the help of the scientists and the IIG management would like to further explore the various Open Access models that would enable Gold OA with minimal costs to the institute.

3. New Current Awareness Service were provided for wider dissemination of the scientific activities covered by the library to all its regional centers and observatories.

4. The library continued to contribute to the "National Digital Library" mentored by Ministry of Education, Government of India, through its National Mission on Education through Information and Communication Technology (NMEICT). The IIG Institutional Repository <http:// library.iigm.res.in:8080/xmlui/> served this purpose along with the DST/DBT purpose of enabling Open Access to scientific publications.

5. Library orientation to new students covered topics like the collection, services, facilities, etc both online as well as physical.

6. An awareness was raised for better usage of campus subscribed resources via technologies enabled by Google, for the IIG library users, anywhere, anytime, any day, and on any device of their preference.

7. Library contributed to the Hindi Mah (September 14-October 13, 2021) by displaying books in the library on the topics of: "Science and Technology Books in Hindi" and "Great Hindi Writers/Poets". Besides these, efforts on a daily basis were made for the implementation of Rajbhasha.

Display of Hindi Books in the Library during Hindi Mah.

Library Usage during 2021-2022

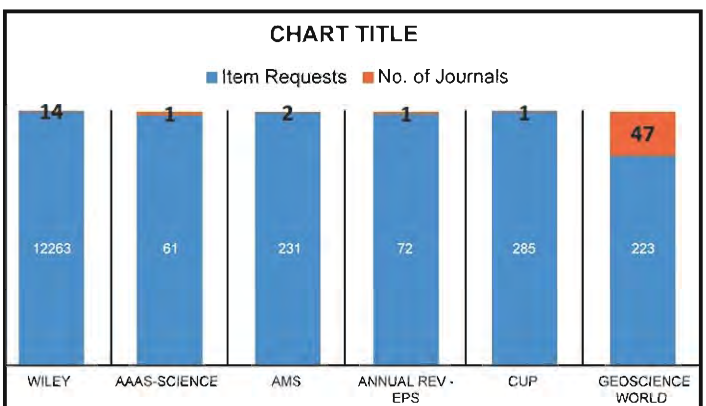
1. Following are the figures of usage of the library and some of the other services by the HQ library :

Sr.No.	Library Service	Usage Figures
1.	Average Daily HQ Library Footfall	26
2.	Issue/Return Transactions or Circulation Desk Transactions	800
3.	Number of Xerox copies provided	1386
4.	Number of binding work done	34
5.	Number of Abstracts Processed and Displayed	85
6	Number of ILL Article requests handled	4

2. The library used for the e-resources facilities provided by the library to the HQ, regional centers, and observatories are as follows :

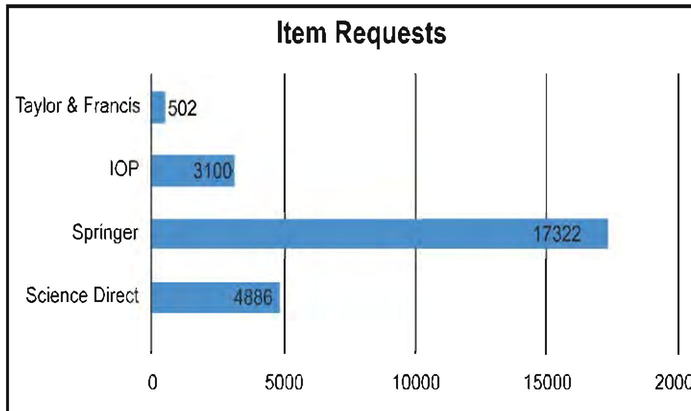
Sr.No.	E-resource service provided	Usage Figures
1.	RemoteXs services for e-resources (Data available : Apr-Dec 2021)	Logins : 145 Downloads : 166
2.	Daily Average Web-OPAC Hits	43
3.	i-Thenticate Plagiarism Checks	128 document count

3. Usage Statistics of e-Journals Subscribed by the library for the period :



Usage Statistics of e-Journals Subscribed by the library.

4. Usage Statistics of some of the Publishers subscribed by the DST-NKRC Consortium for the IIG Library



Usage Statistics of some of the Publishers subscribed by the DST-NKRC Consortium.

Documentation

The Documentation section designed and prepared the banners for all office events like, Vikashan, Yoga Day, SCOSTEP-15, Science Day, Hindi Mah, Hindi Diwas, Shining Maharashtra, Azadi ka Amrit Mahotsav, Vigilance Awareness Week, World Water Day, Plastic boycott etc. The designing and printing of a Coffee Table Book,specially prepared for SCOSTEP-15 symposium, was done in-house by the documentation. The section was involved with making various types of brochures in Hindi showing the achievements of IIG for the requirement of the Department of Science and Technology. The cover page and back-cover page of IIG's Golden Jubilee book was also designed and created. The documentation was involved with the Memento designing. The documentation was also involved with the designing of the identity cards for retired employees. Helping with figures and plot creation of various kinds of scientific figures and diagrams for the Scientific and Technical staff is an ongoing activity of the section that was continued for the year as well. The Intermagnet Observatory Map was designed as per the requirement of the user. In keeping with the ongoing services, the documentation continued to provide photographing all official events. This also included taking and editing photographs of all employees for use in the ERP department, as well as taking photos of the entire campus. The documentation staff also helped with the library work. This included any work assigned by the library including updating serials records in the library database, proposals items, and the digitization of some reprints in the Library.

SPECIAL EVENTS

15TH QUADRENNIAL SOLAR-TERRESTRIAL PHYSICS SYMPOSIUM (STP-15)

The year 2021-2022 is a momentous year for IIG which is celebrating its Golden Jubilee coinciding with the Semisesquicentennial of Indian Independence (Azadi Ka Amrit Mahotsav). During this ceremonial year, IIG hosted the SCOSTEP's 15th Quadrennial Solar-Terrestrial Physics (STP-15) Symposium in India during February21-25, 2022 in a fully online mode. The Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) organizes the Solar-Terrestrial Physics (STP) symposium once every four years. SCOSTEP is engaged in three major activities: long-term scientific programs, capacity building and public outreach. The scientific programs of SCOSTEP are designed to advance our understanding of the solar-terrestrial relationship using space- and ground-based observations, cutting-edge models and theory. Under what ways the Sun affects the Earth and its environment over various time scales is the underlying theme of the scientific programs pursued under SCOSTEP. The main objective of STP-15 is to gather eminent scientists in solar, magnetospheric, ionospheric, and atmospheric physics communities across the globe to discuss and deliberate on the cutting-edge sciences pertaining to STP.The official website of STP-15 (https://stp15.in) was launched in July 2021 to provide all the necessary information about STP-15 and to facilitate a virtual platform to all the domestic and international participants to join the symposium.

STP-15 official website (https://stp15.in).

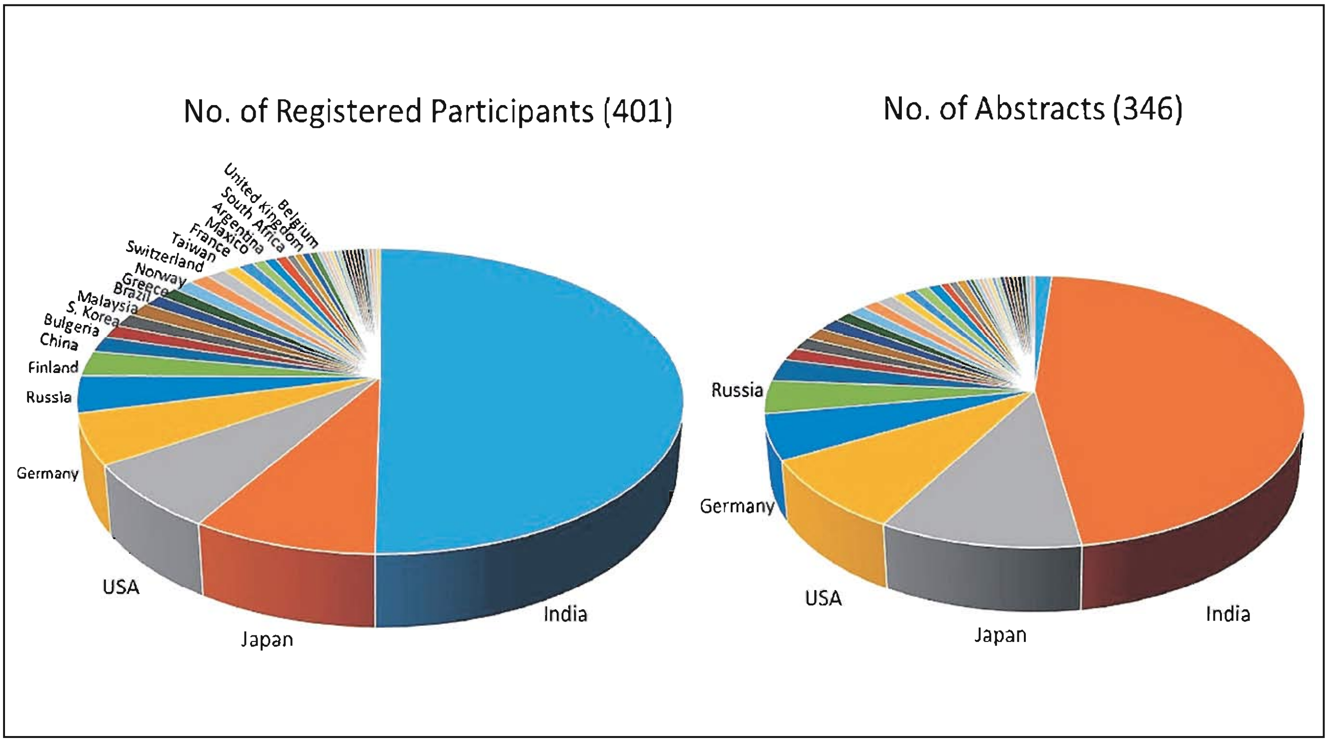
The STP-15 symposium was organized into the following eight thematic scientific sessions and both invited and contributory papers are invited from participants all over the globe.

1. Overarching Topics in the Sun-Earth Connection
2. PRESTO Pillar 1: Sun, Planetary Space, and Geospace
3. PRESTO Pillar 2: Space Weather and Earth's Atmosphere
4. PRESTO Pillar 3: Solar Activity and its Influence On Climate
5. Space Weather Prediction and Implementation
6. Modelling, Database and Data Analysis Tools for Solar -Terrestrial Physics
7. New ground- and space-based initiatives for Solar -Terrestrial Physics
8. Special Session on "Geomagnetism - The Connecting Link between Sun and Earth".

The STP-15 symposium received an overwhelming response from the STP scientific community. About 400 participants from nearly 40 countries registered and 346 abstracts were submitted for presentation at STP-15.

The 5-day STP-15 symposium was formally inaugurated by Dr. S. Chandrasekhar, Secretary, Department of Science and Technology, Government of India. A total of 4 keynote talks, 29 invited papers and 313 contributed papers were presented orally in STP-15, making it the largest symposium of SCOSTEP's STP symposia. The scientific deliberations were conducted in two time zones GMT 0300 – 0640 hrs and GMT 1100 – 1630 hrs for the convenience of participants from different parts of the globe. The thematic scientific presentations were organized into three parallel sessions and conducted in three virtual halls (JC Bose hall, vanAllen hall and Akasofu hall) simultaneously using WebEx virtual platform.

Inauguration of STP-15 by Dr. S. Chandrasekhar, Secretary, DST.



Registered Participants and Abstracts Submitted to STP-15 international symposium.

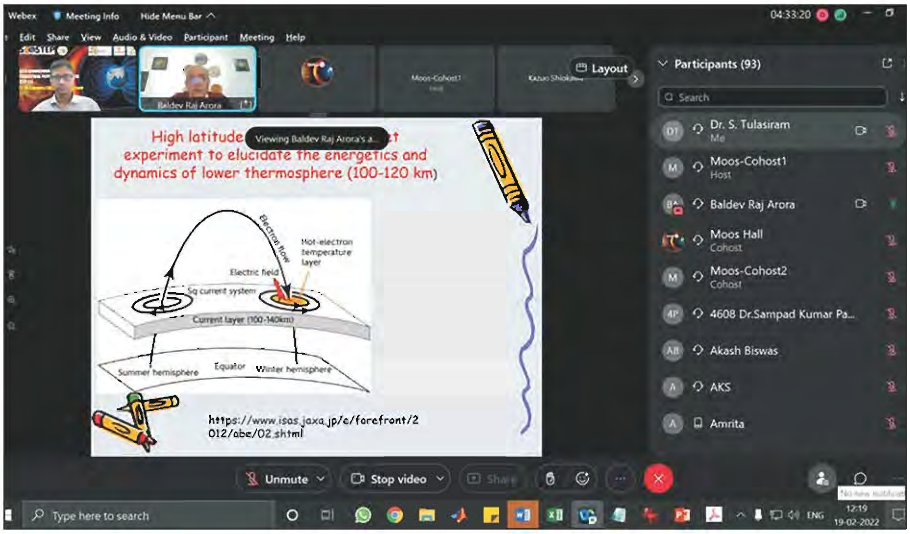


Photo from the popular lecture by Prof. B. R. Arora during the STEPSYS workshop.

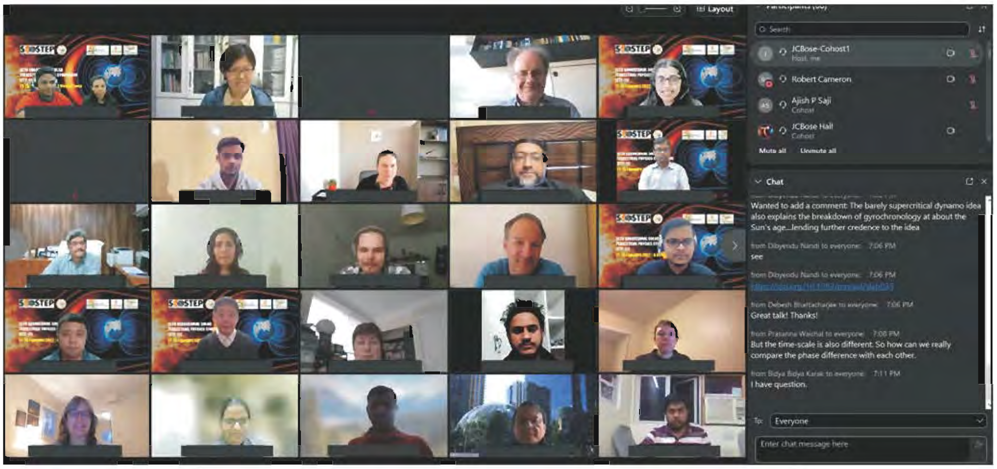
STEPSYS Workshop

IIG has also organized a two-day workshop on "Solar-Terrestrial Physics for Students and Young Scientists (STEPSYS)" on February 19-20,2022 besides the STP-15 symposium. The main objective of this workshop is to invite eminent scientists from the STP community worldwide to give tutorials/lectures to students and young scientists on topics related to Solar-Earth connections.

A total of nine popular lectures have been delivered by leading scientists in STP topics, as follows.

- Exploring Solar-Terrestrial relation through long and extensive Geomagnetic Observatory Network in India (Speaker: B.R. Arora)
- The Sun, its interior and its atmosphere (Speaker: Dibyendu Nandi)
- Solar eruptions and their impact on Geospace (Speaker: Nat Gopalswamy)
- Magnetosphere-Ionosphere Coupling (Speaker: Ramon Lopez)
- Atmosphere - Ionosphere Coupling (Speaker: Jens Oberheide)
- Solar influence on Climate Variability (Speaker: Annika Seppälä)
- Space Weather effects on Technological Systems (Speaker: Mamoru Ishii)
- Space Weather effects on Ionosphere-Thermosphere system: Science and Applications (Speaker: Duggirala Pallamraju)
- 180 years of Geomagnetism in India (Speaker: G.K. Rangarajan)

All the lectures were of typically one-hour duration aimed to provide solid foundation to Ph.D. students and early career scientists who are shaping their career in STP research. The recorded videos of all the lectures are available at STP-15 official website (https://stp15.in).



Keynote address by Dr. Robert Cameron.

The SCOSTEP and the international scientific community lauded the IIG's efforts in organizing the STP-15 Symposium and STEPSYS in a highly professional manner and making it a grand success. The SCOSTEP appreciated that ***"this symposium will be remembered as a standard-bearer of successful online conferences".***

A special issue on the scientific deliberation of STP-15 Symposium in ELSEVIER's Journal of Atmospheric and Solar-Terrestrial Physics (JASTP) is now opened for submission of research papers.

International Science Council (ISC)

SCIENTIFIC COMMITTEE ON SOLAR-TERRESTRIAL PHYSICS

SCOSTEP

Scientific Committee on Solar-Terrestrial Physics

President:
Prof. Kazuo Shiokawa
Institute for Space-Earth Environmental Research,
Nagoya University
Nagoya, Aichi 464-8601
Japan

Vice-President:
Prof. Daniel Marsh
ACOM & HAO
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Boulder, Colorado 80307-3000
USA

Past President:
Dr. Nat Gopalswamy
Code 671 Heliophysics
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Greenbelt, MD 20881
USA

Scientific Secretary:
Ms. Patricia Doherty
Institute for Scientific Research
Boston College
885 Centre Street
Newton, MA 02459
USA

March 7, 2022

Letter of Appreciation

Professor S. Gurubaran
Indian Institute of Geomagnetism
Navi Mumbai, 410218, India

Dear Professor Gurubaran,

This letter is to express our sincere appreciation to you and to all the Local Organizing Committee (LOC) members for hosting the 15th Quadrennial Solar-Terrestrial Physics Symposium (STP-15, February 21-25, 2022) of the Scientific Committee on Solar Terrestrial Physics (SCOSTEP) with the Workshop on Solar-Terrestrial Physics for Students and Young Scientists (STEPSYS, February 19-20, 2022), via full online. Under the difficult situation of COVID-19 pandemic, the LOC did a magnificent job in accomplishing this highly-interactive symposium via the WebEx platform, handling nearly 350 presentations. The LOC made timely announcements to the STP-15/STEPSYS participants on the progress of the meeting and presentation instructions. The recorded presentations became available to the participants in a prompt way. The clear and concise guidance from the LOC members to the session conveners in advance of the meeting facilitated the conveners in planning, and executing, the sessions. Furthermore, the support from the LOC members during the sessions and in the breakout rooms were really incredible, enabling the participants to communicate with the presenters to have in-depth scientific discussions. This symposium will be remembered as a standard-bearer of successful online conferences. Again, we express our sincere appreciation to you and to the LOC members for making the symposium highly successful.

Respectfully,

Kazuo Shiokawa

Professor Kazuo Shiokawa
SCOSTEP President, on behalf of the SCOSTEP Bureau members and the PRESTO Steering Committee members

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Fax: +1 617 552 2818

COSPAR . IAGA . IAMAS . IAU . IUPAP . SCAR . URSI . WDS

Appreciation Letter from SCOSTEP for the grand success of the STP-15 Symposium.

WORLD WATER DAY CELEBRATIONS 2022

World Water Day was observed on March 22, 2022, to underline the significance of fresh water in our lives. According to the United Nations, the day not just celebrates water but also raises awareness about some lesser-known facts. The theme this year is ***"Groundwater: making the invisible visible".*** Groundwater plays a critical role in adapting to climate change. We need to work together to sustainably manage this precious resource. We must protect groundwater from pollution and use it judiciously, balancing the needs of people and the planet. On this occasion, Dr. D.I. Eldho, Professor in Water Resources Engineering, IIT Bombay delivered a lecture on the topic "Groundwater Management – The Challenges of Making Invisible Visible" at IIG HQ.

Celebrating World Water Day-Dr. D.I. Eldho, Professor in Water Resources Engineering, IIT Bombay delivered a lecture on the topic "Groundwater Management – The Challenges of Making Invisible Visible" at IIG HQ.

IIG STAFF WELFARE AND RECREATION CLUB

Indian Institute of Geomagnetism celebrates its Golden Jubilee in 2021. In this connection the institute arranged the Foundation Day lecture virtually. Mrs. Vishakha Shirke, Distinguished Senior Editor (Content & Language) was the Chief Guest and delivered a lecture on "Bridging the gaps post pandemic". Staff members and students of IIG HQ, Regional Centres and Observatories attended the lecture. To commemorate the Golden Jubilee, a Coffee Table Book, depicting the ethos and works of IIG was in aguarated by the Director. The new IIG Logo was also released during this function.

The staff members of the Institute bid farewell on superannuation to Dr. N. Basavaiah and Shri A.L. Gudade on June 30, 2021, Dr. D.S. Ramesh on October 31, 2021, Dr. Ashwini Kumar Sinha (under VRS) on December 31, 2021, Shri R.N. Mauryaon January 31, 2022.

The co-operation and support extended by staff members are deeply acknowledged.

STAFF WELFARE MEASURES

Various staff welfare measure, such as, Benevolent Fund Scheme, Canteen facility etc. is being provided to the staff members.

Amid the adverse times of the pandemic, this year the 7th International Day of Yoga was celebrated virtually at Indian Institute of Geomagnetism on 21st June, 2021. Emphasising on well-being beyond the immediate impact on physical health at a time when society is still recovering from the impact of the COVID-19 pandemic, the International Yoga Day 2021 was observed on the theme 'Yoga for well-being'. A total of 200 staff and their family members have participated in the event.

The Vigilance Awareness Week was observed from October 26-November 01, 2021. The observance week commenced with the pledge on October 26, 2021 at 11.00 a.m. All the staff members present at the Institute attended the pledge by maintaining social distance due to COVID6 17 while Staff members working from home took the pledge and submitted the report HRD Section. The theme this year was **"Independent India @75: Self Reliance with Integrity".**

The observance of Vigilance Awareness week commenced with the pledge on October 26, 2021 by the staff members.

On the occasion of International Women's Day, the Institute organized two lectures on March 8, 2022. The forenoon talk was by Ms. Indu Khanna on the topic "How my life can be better than this! What else is possible?" This was attended by all IIG staff. The afternoon lecture was delivered by Ms. Aparna Randive, Transformation & Leadership Development expert, Mumbai, who spoke about "Women, the true architects of society". This was attended by all female staff and students of IIG.

Guest lectures (Left) Ms. Indu Khanna (Right) Ms. Aparna Randive arranged on the occasion of International Women's Day,

CORPORATE SOCIAL RESPONSIBILITIES

CITIZEN CHARTER

Information / suggestion on the functioning of the Institute can be obtained / given by the public. The following nodal officers have been nominated for this purpose:

Central Public Information Officer (CPIO):

Prof.A.K. Singh, (Professor E)
Indian Institute of Geomagnetism
Plot No. 5, Sector-18
New Panvel (W), Navi Mumbai-410218
Maharashtra
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Fax: 022-27480762
E-mail:ajaykishore.s@iigm.res.in

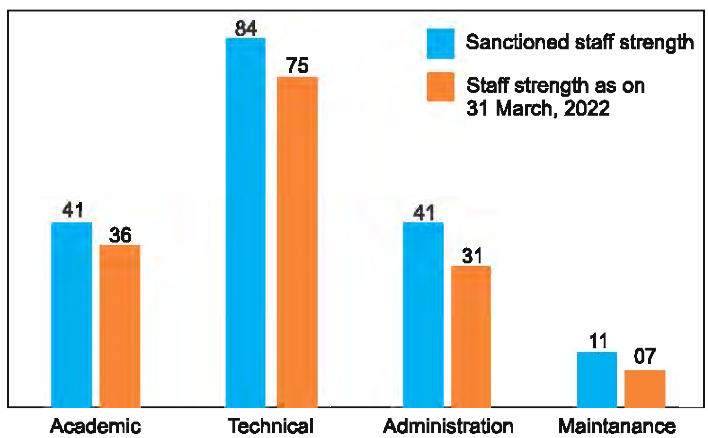
Appellate Authority:

Prof. S. Gurubaran, (Professor G)
Indian Institute of Geomagnetism
Plot No. 5, Sector-18
New Panvel (W), Navi Mumbai-410218
Maharashtra
Tel.:022-27484227
Fax: 022-27480762
E-mail:gurubaran.s@iigm.res.in

RESERVATION POLICY

The Institute has been implementing the reservation policy of the Govt. of India from time to time.

STAFF PROFILE



ACTION TAKEN NOTE ON AUDITORS REPORT

No serious adverse comments have been received. However, replies to some of the observations made are appended with the Audit Report of the Institute for the year 2020–2021.

MOBILIZATION OF RESOURCES

The Institute has been constantly making endeavors to mobilize resources by extending its scientific and technical expertise to organizations like ISRO, DRDO, AAIetc and by selling magnetic data to outside organizations. During the year 2020–2021, the Institute received funds for carrying out the objectives of various sponsored projects. The gains from sponsored projects in terms of academic activity are immense.

In Service of the Nation.....

Indian Institute of Geomagnetism (IIG) is a premier research institute of national and international importance, energetically engaged in basic and applied research in Geomagnetism and allied areas of Geophysics, Atmospheric & Space Physics and Plasma Physics. The study of Geomagnetism encompasses the entire Heliosphere starting from the centre of the Earth extending to all the planets and the Sun itself. The vision of IIG is to promote, guide, and conduct research in all branches of Geomagnetism and enable India become a global knowledge centre. IIG currently operates 12 geomagnetic observatories and three regional centres at Tirunelveli, Prayagraj and Shillong. The Institute regularly participates in the Indian Expeditions to the Arctic and Antarctic.

The mandate of the Institute is also to maintain and modernize the magnetic observatories under its magnetometer network, establish new observatories and publish high quality data as Indian Magnetic Data volumes. These magnetic records are useful for understanding the electrical current systems flowing in the near space environment, which has a bearing on monitoring and assessing the fitness of satellite navigation systems. The World Data Center (WDC)-Geomagnetism, Mumbai, is a member of the International Council for Science-World Data System. IIG regularly calibrates the magnetic compasses of Indian Navy, Indian Coast Guard, Naval Air Stations.

Some major and significant accomplishments on the research front include a novel Ensemble Kalman Filter (EnKF) method to make reliable forecasts of geomagnetic activity (Dst index) for real-time applications. It is found that the EnKF method offers the best accurate forecast of Dst with a root mean square error (RMSE) and regression coefficient (R) of 4.3 nT and 0.99, respectively.

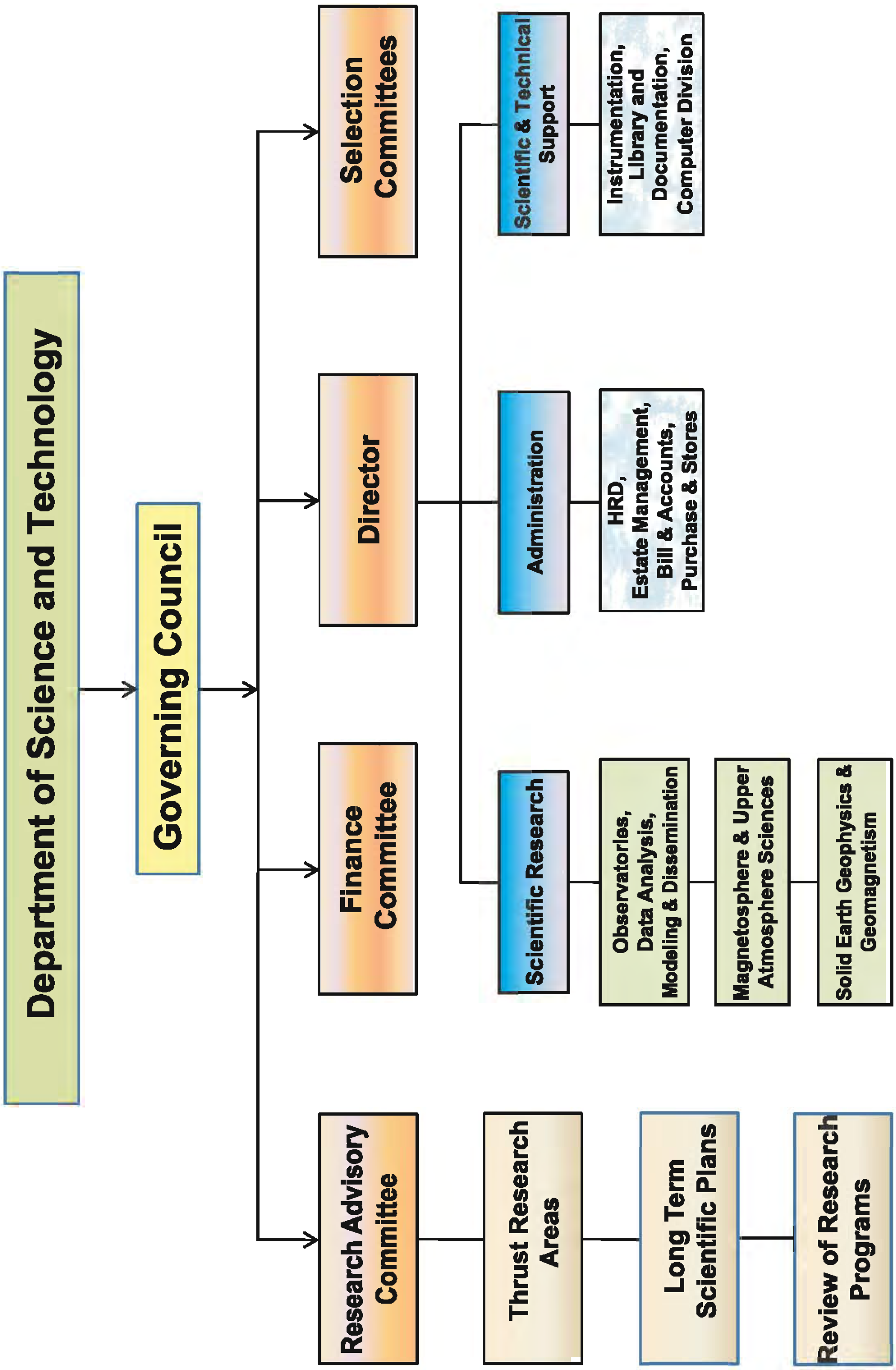
The Cambay rift basin (CRB) in western India is a hydrocarbon-producing basin, which has been extensively explored geophysically for hydrocarbon reserves. Magnetotelluric studies reveal weak zones within the Proterozoic lithosphere that act as pathways for the migration of volatile enriched materials (CO_2, H_2O) and magmatic material to the crustal depths, possibly altering the Proterozoic lithosphere on the eastern side of the CRB.

The north-eastern region (NER) of India has several complex regional geological structures, out of which the Dauki fault (DF) is a prominent one. The E–W trending reverse DF, which is inferred to go through the southern margin of Shillong Plateau (SP), has played a major role in the regional deformation of the adjoining areas and was believed to be active during the Late Quaternary time. Scientists at IIG, for the first time, reported soft-sediment deformation structures (SSDS) from five trenches in and around the DF zone, SP, from the Indian side. A provisional recurrence interval of ~ 2250 years for M 5.5 to 6.5 events is inferred for the Dauki region.

Rare simultaneous imaging observations of sprites associated with an intense Mesoscale Convective System (MCS) and Gravity Waves (GWs) are reported that indicate their possible interrelationship. The study suggests that MCS/thunderstorms associated GWs can significantly coupling besides the electrical coupling. This is the first such report from the Indian subcontinent that features sprites and GWs imaging observations, and the associated D-, E- and F-region coupling.perturb the atmosphere–ionosphere system supporting the D-, E- and F-region.

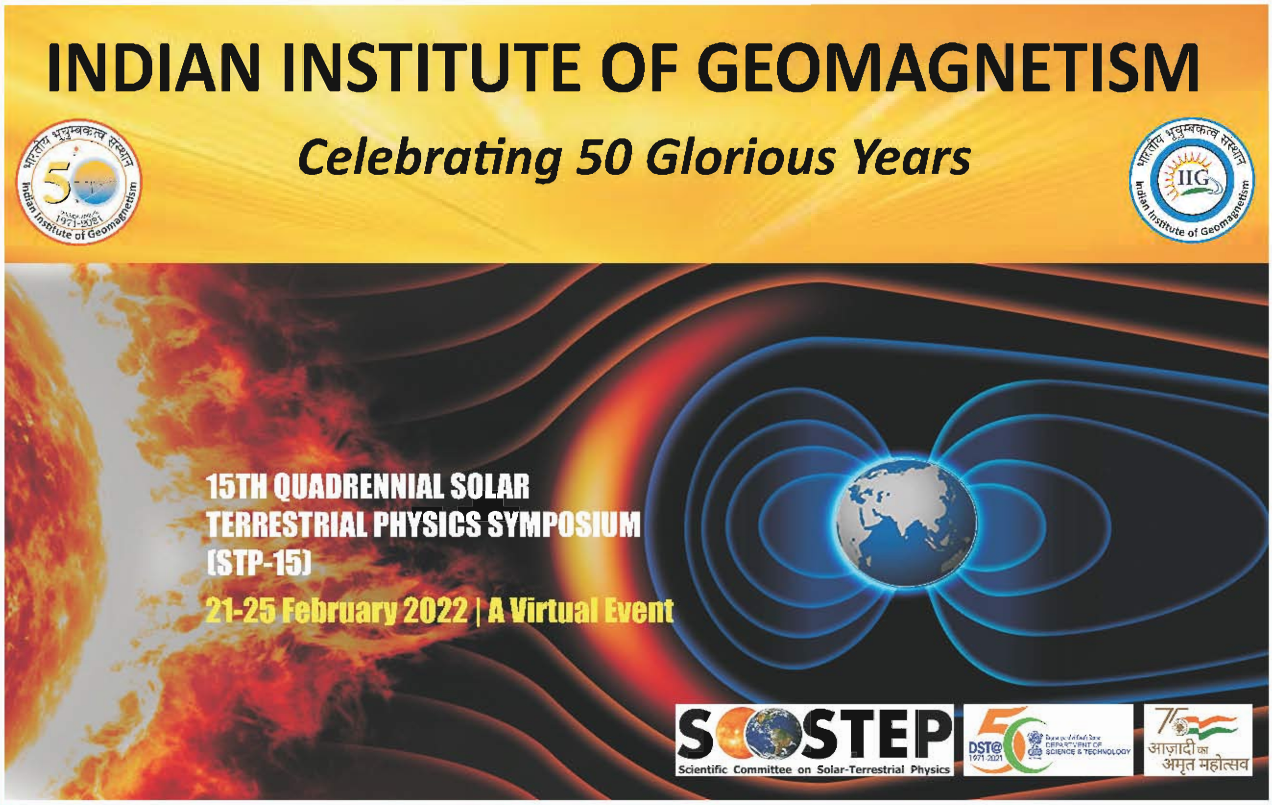
The year 2021-2022 is a momentous year for IIG which is celebrating its Golden Jubilee coinciding with the Semi-sesquicentennial of Indian Independence (Azadi Ka Amrit Mahotsav). During this ceremonial year, IIG hosted the SCOSTEP's 15th Quadrennial Solar-Terrestrial Physics (STP-15) Symposium in India during February 21-25, 2022 in a fully online mode. Under the Science Outreach program, the Institute promotes several scientific exhibitions for students and its faculty and participate in several state and national level scientific expositions every year.

Summing up, remarkable progress has been made towards the scientific objective of understanding the geophysical processes, including the Sun-Earth interactions. However, the future focus will be on Ionospheric Seismology dealing with the dynamical coupling of the Earth's lithosphere-atmosphere-ionosphere-magnetosphere system, Space weather and Climate variability, using data from Indian Space Missions to study the Earth and planetary atmospheres, and development of several in-house geophysical instruments, to be used for field surveys.


Department of Science and Technology
Governing Council
Research Advisory Committee
Finance Committee
Director
Selection Committees
Thrust Research Areas
Long Term Scientific Plans
Review of Research Programs
Scientific Research
Observatories, Data Analysis, Modeling & Dissemination
Magnetosphere & Upper Atmosphere Sciences
Solid Earth Geophysics & Geomagnetism
Administration
HRD, Estate Management, Bill & Accounts, Purchase & Stores
Scientific & Technical Support
Instrumentation, Library and Documentation, Computer Division

IIG and the SAMEER, Mumbai signed aMoU for the joint development of advanced digital Ionosonde system.

Field survey of the AMT stations located nearby Rajapur geothermal zone, western Maharashtra, India.



The SCOSTEP's 15th Quadrennial Solar-Terrestrial Physics (STP-15) Symposium hosted by IIG in India.

A joyous moment for the Staff and students of IIG celebrating the Golden Jubilee of the institute.