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Nonlinear Spatiotemporal Dynamics of Equatorial Plasma Depletions

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Equatorial plasma depletions have signifcant impact on radio wave propagation in the upper atmosphere, causing rapid fuctuations in the power of radio signals used in telecommunication and GPS navigation, thus playing a crucial role in space weather impacts. Complex structuring and self-organization of equatorial plasma depletions involving bifurcation, connection, disconnection and reconnection are the signatures of nonlinear evolution of interchange instability and secondary instabilities, responsible for the generation of coherent structures and turbulence in the ionosphere. The aims of this work are three-fold: (1) to report the frst optical imaging of reconnection of equatorial plasma depletions in the South Atlantic Magnetic Anomaly, (2) to investigate the optical imaging of equatorial ionospheric intermittent turbulence, and (3) to compare nonlinear characteristics of optical imaging of equatorial plasma depletions for two diferent altitudes at same times. We show that the degree of spatiotemporal complexity of ionospheric intermittent turbulence can be quantifed by nonlinear studies of optical images, confrming the duality of amplitude-phase synchronization in multiscale interactions. By decomposing the analyses into North-South and East-West directions we show that the degree of non-Gaussianity, intermittency and multifractality is stronger in the North-South direction, confrming the anisotropic nature of the interchange instability. In particular, by using simultaneous observation of multi-spectral all-sky emissions (OI 630.0 nm and OI 777.4 nm emissions) from two diferent heights we show that the degree of non-Gaussianity and intermittency in the bottomside F-region ionosphere is stronger than the peak F-region ionosphere. Our results are confrmed by two sets of observations on different nights.

This work is dedicated to Drs. H. G. Booker, P. C. Clemmow, and D. T. Farley for their pioneer work on ionosphere and plasmas. A.C.L.C. is grateful to Drs. Farley (Cornell) and Clemmow (Cambridge) for supervision of undergraduate and doctoral studies. Dr. Booker supervised doctoral thesis of Drs. Clemmow and Farley.

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Ionospheric vertical ExB drift variations during sudden stratospheric warming events

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Ionospheric vertical **E**x**B** drift plays an important role in the plasma distribution, dynamics and instability processes in the low latitude ionosphere. Climatology of these drifts has been established around the globe using radar and satellite based measurements. Recent studies found that, during sudden stratospheric warming (SSW) events the vertical **E**x**B** drift values are remarkably different from the climatological values. In this paper, we present the variations of the daytime vertical **E**x**B** drift velocities made during SSW events (Feb 2017, Feb 2018, Jan 2019, and Sep 2019) in the Indonesian sector. For this study we have used vertical **E**x**B** drift velocities derived using shifts of the 150-km echoes observed by the Equatorial Atmospheric Radar (EAR) located at Kototabang, Indonesia. Vertical **E**x**B** drift values were highly positive in the morning hours and near zero or negative in the afternoon hours, showing a semidiurnal variation during the SSW events. A clear and large day-to-day variability in the vertical **E**x**B** drift is also observed during SSW. The onset of semidiurnal variations occurred during SSW events were close to the new and full moons, which indicates that the lunar semidiurnal tidal wave effects were highly enhanced during SSW events. Further, to see the planetary scale variability in the **E**x**B** drift we performed wavelet analysis on vertical **E**x**B** drift values observed at different local time. Interestingly both ~15day and ~6 days periods are found to be strongest during the SSW period. These observations are first of their kind from Indonesian sector as far as the SSW is concerned. Local time, day-to-day and planetary scale variabilities of vertical **E**x**B** drift during SSW events will be presented and discussed in the light of current understanding.

Study of Ionospheric Irregularities Using Rocket Born In-Situ Measurement Probes in Association With Ground Based HF Radar Observations During Different Geophysical Conditions

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Equatorial ionosphere is a region characterized by frequent occurrence plasma irregularities. The in-situ measurements of electron densities using rocket born probes can be used to study the spectral characteristics of irregularities in the electrojet region. The present work deals with the study of the irregularity spectrum for different scale size obtained from different rocket experiments conducted over geomagnetic equatorial station, Thumba (8.5^{0}N, 77^{0}E). The electron density is measured using rocket borne ENWi (Electron density and Neutral Wind analyzer) probe during Sooryagrahan mission (14th and 15th January 2010, 13:05:00 IST) and ENWi and Langmuir probes during SOUREX-1 (6th April 2018, 19:00:00 IST) mission. The electron density profile obtained during eclipse day indicates the presence of day time E region irregularity structures. It exhibits a sharp nose like structure at an altitude of 110km followed by a negative gradient in electron density. These irregularities are simultaneously observed on HF radar over Thumba with a reversal of electric field which confirms the occurrence of type II irregularities. Irregularities with amplitude more than 5 % are present at lower altitudes (92-95km) of E region which exhibit positive gradient (ΔN) in electron density. During control day, strong irregularities with maximum amplitude of 25% are present in altitude region of 93 km to 97.5 km exhibiting positive gradient in electron density. Electron density profiles derived from LP and ENWi onboard RH300 rocket during SOUREX-1 mission, exhibit similar trend and the profiles indicate the presence of night time irregularity structures at E region altitudes. The irregularities are observed to manifest predominantly in regions with negative electron density gradients (ΔN) indicating the role of gradient drift instability in their triggering. The negative ΔN in the presence of a downward polarization electric field (Ez) leads to a condition conducive for type II irregularity generation. The spectral features of the irregularities obtained from different rocket experiments are analyzed for irregularities of different spatial scales. The negative and positive spectral indices of irregularities indicate the unique behavior of ionosphere during eclipse time. The comparative study of spectral characteristics and causative mechanisms of ionospheric irregularities observed during different rocket experiments at various geophysical conditions will be presented and discussed.

Comprehensive Investigation of the Relationship Between Equatorial Plasma Bubbles and Plasma Blobs Using Optical and Radio Techniques and Multi-Satellite Data

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Plasma bubbles and plasma blobs are night-time consequences of F-region plasma instability. Irregularities behaviour of plasma in the ionosphere poses adverse effects on our technologically-inclined daily activities. In the full capacity of these phenomena, we could lose communications with satellite, aircraft to mention few. Hence, it is imperative for us to investigate these phenomena continuously. The relationships between the two phenomena have been a subject of research recently and debates still persist regarding whether both phenomena are independent or causally related. Earlier works were more or less of case studies while we present detailed occurrence characteristics of blobs and bubbles during high solar activity (HSA) and low solar activity (LSA) for the period of two years (one year for each solar activity). OI 630.0 nm emission images (about 3000 in total) from two similar all-sky imaging systems, digisonde and SWARM electron density, Ne, and electron temperature, Te, data have been used to investigate the relationship between plasma bubbles and plasma blobs. Monthly, seasonal, and nocturnal variations of bubbles and blobs are present in this work. During HSA, approximately 95% of plasma blobs observed were associated with plasma bubbles whereas every single blob observed during LSA were associated with bubbles (100%). However, not all the bubbles observed were associated with blobs. In other words, bubbles without blobs cases were observed. Correlation and regression analyses of the two phenomena revealed interesting causal relationship between bubbles and blobs. Approximated average visibility time of plasma blobs, based on its time of appearance and disappearance from the field of view, during HSA and LSA were 1.08 hr (approx. 65 mins) and 0.57 hr (approx. 34 mins), respectively. Whereas the average visibility time of plasma bubbles during HSA and LSA were 4.01 hr and 2.19 hr, respectively. Plasma blobs occurrence frequency had its maximum at around midnight hours whereas plasma bubble has its occurrence maximum frequency at around post-sunset hours. From these concise results and the ones obtained from the literature, we have been able to propose two distinct mechanisms for the development of plasma blobs: (1) plasma blobs associated with plasma bubbles; and (2) plasma blobs not associated with plasma bubbles.

Keywords: plasma bubbles; plasma blobs; occurrence patterns; all-sky imagers; multi-satellite

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The Effect of Prompt Penetration Electric Fields on Plasma Bubble Growth Rates

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Equatorial plasma bubbles can occur at any geomagnetic activity level, but occur more frequently during geomagnetic storms. In this study, we focus on prompt penetration events during major geomagnetic storms. We describe work to use numerical simulations with the coupled SAMI3/RCM first-principles model to understand ionospheric storm-time electrodynamics and plasma bubble formation. We use simulations results to estimate linear growth rates of the generalized Rayleigh-Taylor instability during major geomagnetic storms. The relative contributions of neutral and plasma dynamics are considered when examining the growth rates, with a specific focus on prompt penetration electric fields. For comparison, we utilize observation of plasma bubbles from the FPMU aboard ISS and TEC from GNSS. By comparing calculated growth rates to plasma bubble occurrence, we examine the role of storm-time electric fields in plasma bubble formation.

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On the importance of bottomside upwelling in the growth of equatorial plasma bubble- Experimental evidence

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Conventionally, post-sunset height rise of the F layer due to pre-reversal enhancement of zonal electric field has been found to have a close linkage on the equatorial plasma bubble (EPB) formation. EPB however grows at discrete locations, which have been linked to the seeding mechanism through a seed wave structures at the bottom of the F layer. Every wave structure, however, does not lead to the growth of EPB. In view of this, localized upwelling has been invoked for the growth of EPB- a mechanism which is quiet appealing. In this paper, we present observational results based on a detailed analysis of collocated radar and digisonde observations clearly showing the localized upwelling as a prerequisite for the growth of EPB. Our observations show a clear local uplift of the F layer bottom-side with a zonal dimension of about 300 km in digisonde observation with a close linkage to the growth of EPB seen by the scanning radar. The height of the satellite trace with respect to the main F layer trace in the ionogram is found to be consistent with the horizontal dimension of the local upwelling. The vertical height rise velocity in the EPB cases growing in this localized space is found to be extraordinarily higher than the rest of the cases that are linked post-sunset height rise of the F layer having a much larger zonal envelop. These results, providing support in favour of the bottomside upwelling process in the EPB formation, will be presented and discussed.

Modeling the Tonga Event with SAMI3/HIAMCM: Development of a Super-Bubble

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The Tonga volcanic eruption on 15 January 2022 generated an enormous atmospheric disturbance that impacted the thermosphere and ionosphere for several days [1]. Additionally, large scale ionospheric equatorial holes and bubbles developed within hours of the eruption [2]. We present simulation results of the Tonga event using the coupled SAMI3/HIAMCM ionosphere/thermosphere model. SAMI3 is a comprehensive ionosphere/plasmasphere model and HIAMCM is a whole atmosphere model extending to the thermosphere. The neutral wind disturbances generated by the Tonga eruption are captured by HIAMCM and used to drive SAMI3. The simulation study uses a high resolution grid with latitude/longitude scales of 50 km. We find that a large scale ionospheric hole forms shortly after the eruption to the west of Tonga. Subsequently equatorial plasma bubbles are generated and one of them rises to a height over 3500 km. We compare the simulation results to data [2].

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Forecasting equatorial *F*-region instability with a regional ionosphere model and WAM-IPE

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We use a regional simulation of plasma convective instability in the postsunset equatorial ionosphere together with a global atmosphere/ionosphere/plasmasphere GCM (WAM-IPE) to forecast irregularities associated with equatorial spread F (ESF). To begin with, the regional simulation is initialized and forced using state parameters derived from campaign data from the Jicamarca Radio Observatory and from empirical models. The irregularities produced by these simulations are found to be quantitatively similar to those observed. Then, the aforementioned state parameters are replaced with parameters from WAM-IPE, and the resulting departures between the simulated and observed irregularities are noted. In one of five cases studied, the forecast failed to predict ESF irregularities due to the late reversal of the zonal thermospheric winds. In four of five cases, significant differences between the observed and predicted prereversal enhancement (PRE) of the background vertical drifts resulted in degraded forecast accuracy. This highlights the need for improved PRE forecasting in the global-scale model.

Improved Kinetic Simulations of Photoelectron Driven Instabilities Applied to 150 Km Echoes

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Equatorial VHF radars looking near-perpendicular to the Earth's magnetic field observe strong, coherent echoes between 130 km and 170 km altitude. Figure 1 shows an example of these 150 km echoes observed by the 50 MHz Jicamarca incoherent scatter radar. While these echoes have been observed for nearly 60 years, the physical processes that cause their structuring remains a partial mystery. These echoes generally start at ~170 km after sunrise, then descend to ~130 km by noon, before rising again to ~170 km at sunset and then disappearing overnight. This pattern motivated kinetic simulations showing that photoelectron driven instabilities can produce density irregularities with characteristics that could produce 150 km radar echoes [2]. Those simulations, however, did not correctly account for the inelastic scattering processes from N_2 that create a reduced population of photoelectrons centered at 2.5eV. They also did not resolve 3m waves well or include suffient statistics to model radar outputs. This research presents improved and larger simulations with a new inelastic and velocity dependent collision algorithm. Current theory argues that the inclusion of multiple photoelectron distributions can either stabilize or destabilize the upper hybrid instability, depending on where the energy peaks exist [3]. This researcher enables scientists to better understand the source and structure of 150 km echoes.

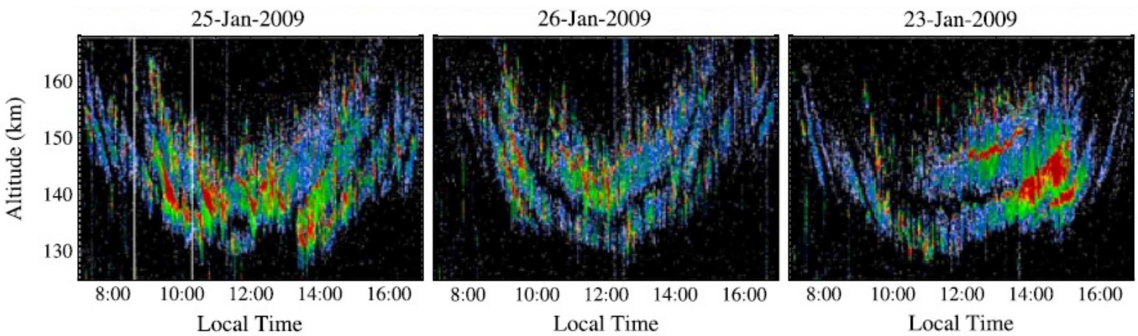

Figure 1. Measurements of 150 km echoes at Jicamarca [1]. The color scale shows the received power of the radar in dB with red being the largest power and blue the least.

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Zonal Asymmetry of the daytime 150-km echo observed by a VHF radar at Chumphon, Thailand

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Daytime Field-Aligned Irregularities (FAIs) around an altitude of 150 km, so-called 150-km FAIs, have been observed with VHF radars in the equatorial regions. We report the 150-km FAIs observed with the 39.65 MHz VHF radar at Chumphon, Thailand, which has been operating since January 2020. For the E-region and 150-km FAI echo measurements, the radar beam is allocated to 10 directions from -48^{o} to 60^{o} in azimuth around the north with a step of 12^{o}. The 150-km FAI echos were observed frequently during a period between May and August 2020. The echo intensity of the 150-km echoes shows zonal asymmetry while the echo intensity of E-region FAIs does not depend on the azimuth. The 150-km FAI echo intensity is higher on the eastward beams than the westward beams. The most intense echo is observed at 36-46^{o} east with respect to the magnetic north, on average. The altitude of the echo appearance also shows the zonal asymmetry. The echo altitude increases with viewing from the east to west by approximately 5^{o} between -45^{o} and 45^{o} in azimuth. This zonal asymmetry of the echo intensity and altitude is consistent with that of the 150-km FAI echoes observed by the EAR (Equatorial Atmosphere Radar) at Kototabang, Indonesia, located at approximately 10^{o} south in the almost same longitude as Chumphon, whereas the echo intensity of the 150-km echo over Kototabang is highest at 6^{o} east from the north (Pavan Chaitanya et al., 2018). Our observation supports the idea that the 150-km echo region has arc-like structure which bulges to the east in the zonal-vertical cross-section (Yokoyama et al., 2009). Considering the zonal asymmetry of the 150-km echo at Chumphon and Kototabang, we can speculate that the arc-like structure is tilted by approximately 6～13^{o} from the zenith on the vertical and zonal plane and extend in the meridional direction for more than 10^{o} in magnetic latitude.

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On the Forecast of Post-Sunset Equatorial Plasma Bubble

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In the present study, we investigate the possibility to forecast the day-to-day occurrence of post-sunset equatorial plasma bubbles (EPBs) in a given longitude sector. For this purpose, we have utilized simultaneous ground-based observations made using the 30 MHz Gadanki Ionospheric Radar Interferometer (GIRI), and collocated digisonde (DPS-4D) from a low-latitude station Gadanki (6.5°N mag. latitude) to study the onset and seeding conditions prior to the occurrence/non-occurrence of EPB on a day-to-day basis. The observed results have been further substantiated with space-based observations from C/NOFS. Results show that, while the horizontal wavelengths of the pre-sunset wave structures inferred from DPS-4D correlate well with the inter-bubble spacings of EPBs as observed by GIRI, implying these wave structures possibly act as seed for EPB development, mere presence of these seed structures do not guarantee the growth of EPB on a given night. Further study show that the location of EPB development at their origin varies on a day-to-day basis and it can be as large as 2600 km. A detailed analysis reveals the cause of such variability and provides a clue as to where the background ionospheric conditions led to the growth of the Rayleigh Taylor instability (RTI) generating EPB and where they failed. Results clearly show that while digisonde observations show a great potential for understanding day-to-day variation and predicting EPB development overhead (within ±1° longitude), they are inadequate to assess the growth potential of EPB at longitudes away from a longitude zone of about ±1° from overhead. A detailed analysis suggests that the day-to-day variability in EPB development is governed by large-scale wave structures (LSWS) and it is inferred that the LSWS troughs (low electron density) are the sites for the EPB development. While the source of LSWS remains to be identified, it is proposed that observations made using longitudinally distributed ground-based sensors, viz., ionosonde, preferably separated by 250–300 km, would be an important prerequisite to understand the day-to-day variation as well as prediction of EPB in a given longitude sector.

Ionospheric Structure Modeling and Diagnostics

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Modeling ionospheric structure requires an integration of phisics-based ionospheric background models and stochastic models that characterize developed ionospheric structure. Additionally, structure models must support the interpretation of in situ and remote diagnostics that follow from electro magnetic wave propagation theory (EM). Electron density captures the essential elements for this synthesis. The recent development of high-resolution physics-based models have made it possible to demonstrate essentially complete structure models and diagnostic measurements [1].

This paper will review developments that have evolved from the analysis of high-resolution EPB models. Current structure models use stochastic processes, which are characterized by two-component inverse power law spectral density functions (SDFs). Stochastic structure models also support the interpretation of in-situ and remote EM diagnostics. However, SDFs ignore the phase of the spatial Fourier components, which is responsible for the unique configuration-space structure that identifies equatorial plasma bubbles (EPBs). Configuration-space models that build on distributions of physical striations allow us to demonstrate that physical clustering of striations does not change the SDF characteristis. The EM diagnostic ramifications are being explored.

GNSS satellites provide continuous global ionospheric diagnostic capabilities. However, by design GNSS satellites minimize the occurrence of intensity scintillation, which is the primary indication of EPB structure. Extending the EM diagnostic capabilities to phase structure with no significant intensity scintillation provides a means of fully exploiting total electron content (TEC) structure diagnostics. When significant intensity scintillation does occur, occultation of GNSS satellites received by low earth orbiting satellites can be processed to localize propagation disturbances along the propagation path.

Localization of ionospheric structure within EPBs is an ongoing diagnostic challenge, which is being exploited mainly with in-situ diagnostics. However, preliminary analysis of diagnostic procedures based on iterative filtering, provide wavelet-like scale - dependent structure localization. Using the EPB simulation we find that the evolving structure can be localized on the Eastward EPB bubble edge during the initial phase of development.

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On the generation and evolution of equatorial plasma bubble irregularities in East and Southeast Asia

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Equatorial plasma bubbles (EPBs) are known to be initiated at ionospheric F region bottomside around magnetic equator. EPBs can rise to F region topside and extend along magnetic field lines to low- even middle-latitudes of 40° or higher under some conditions[1], producing ionospheric irregularities with various scale sizes down to centimeters and causing ionospheric scintillations. Previous studies showed significant differences in the EPB generation rates at closely located stations, indicating that the decorrelation distance of EPB generation is small (tens to hundreds of kilometers) in longitude[2,3]. After the initial generation of EPBs at one longitude, they can drift zonally more than 2000 km[4]. These features make it difficult to identify the possible seeding sources for EPBs and to accurately predict their occurrence, especially when the onset locations of EPBs are far outside the observation sector[5].

In this talk we will briefly review the current knowledge of EPBs and ionospheric scintillations in the East and Southeast Asia. Some results from the recently developed Ionospheric Observation Network for Irregularity and Scintillation in the East and Southeast Asia (IONISE) will be presented. Some unresolved issues related to the day-to-day variability of EPBs will be discussed. We will also briefly introduce a Low lAtitude long Range Ionospheric raDar (LARID), which is developed under the support of Chinese Meridian Project Phase II, for observing EPB irregularities over a wide longitude region.

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Imaging ionospheric irregularities by earth observation radar satellite

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The sensitivity of Synthetic Aperture Radar (SAR) satellite signal in the L-band to ionospheric plasma density [1] is used to obtain two-dimensional imaging of ionospheric density irregularities. As an application for equatorial ionosphere, we have recently reported first simultaneous observation of equatorial plasma bubble by the ALOS-2/PALSAR-2 satellite and a ground 630-nm airglow imager in northern Brazil [2]. In this case, SAR ionospheric scintillation are represented as stripe-like signature of radar image over the terrain along the local magnetic field lines near an airglow depletion region. This so-called SAR scintillation stripes are discussed to be the signature of existing small-scale plasma irregularities with the scale size of hundreds of meters associated with equatorial plasma bubbles. We present the observational setup and the interpretation of SAR signal parameters to characterize the two-dimensional ionospheric density structures, and disucss future studies.

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When Traveling Ionospheric Disturbances Meet with Equatorial Plasma Bubbles

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There are observations of suppresion of the equatorial plasma bubbles (EPBs) due to the nighttime medium-scale traveling ionospheric disturbances (MSTIDs), and the extreme poleward extension of EPBs after arrival of the TIDs driven by the 2022 Tonga volcano eruption. To understand their underlying interactions theorectically, the Naval Research Laboratory first-principles ionosphere model SAMI3/ESF is performed to study the two coupling effects. For the interactions between MSTIDs and EPBs, the synthetic dynamo currents are imposed into the potential equation to induce polarization electric fields for generating the MSTIDs. Simulations demonstrate that the MSTIDs can inhibit the upward growth of EPBs; however, MSTIDs alone are insufficient to explain the disappearance of EPBs. We found that the meridional winds likely contribute to the disappearance of MSTIDs by reducing the background electron density and polarization electric fields within the EPBs. Then, the MSTIDs transport plasma to fill the EPB depletions up via $\mathbf{E} \times \mathbf{B}$ drifts. Both MSTIDs and meridional winds are necessary to comprehend the underlying mechanism of EPB disappearance. Additionally, we also found that the zonal and vertical $\mathbf{E} \times \mathbf{B}$ drifts within the MSTIDs affect the morphology of EPBs, leading to a reverse-C shape structure. For the extreme EPBs during volcano eruption, the TIDs play the role of accelerating growth of EPBs at the seeding phase. It also requires strong uplift of the ionospheric layer in order to accelerate upward/poleward extension of EPBs over 2500 km or to mid-latitude. This theoretical study help understand the role of TIDs in generation of EPBs.

Implications of Equatorial E-Region Electrodynamics in Ionospheric Density Restructuring

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Blanketing E layers (E_{sb}), observed in the ionograms, are manifestations of additional ionization converging over the equatorial E-region from low latitudes which have the capacity of blocking the propagation of radio waves through this region to the upper ionospheric layers. Previous studies involving magnetic field observations and simulations have verified that near zero or reversed vertical polarization electric field along with equatorward Thermospheric winds are the major factors that control the evolution of E_{sb} layer. In view of this, study of the electric field variations is important in context of understanding this and allied phenomenon. However, obtaining continuous and systematic measurements of the E region electric field on a day-to-day basis is rather difficult. The 18MHz HF radar located at Thumba(8.5°N, 77°E, 0.5° dip), Trivandrum, which is very close to the magnetic dip equator, provides an opportunity to study the plasma irregularities in the Equatorial Electrojet (EEJ) of scale size 8.3m. The Doppler shifts obtained from the radar echoes depend on the drift velocity of the plasma irregularities, from which the electric fields in the EEJ altitude can be estimated.

The year 2021 was in the rising phase of 25th solar cycle and was characterized by low solar activity with a few geomagnetically disturbed days.The present study explores different cases of blanketing E layer over Thumba during the latter half of 2021 with simultaneous observations of the magnetic field variations, ionospheric changes, plasma drift and hence the electric field under different geomagnetic conditions. The observations from Thumba shows that the formation of E_{sb} is preceded by a sudden decrease in the ionospheric plasma drift as observed by the radar. Some of these E_{sb} last a few hours. The ground based magnetometer observations also shows a sudden decrease in the change in magnetic field or a reversal, i.e., the Counter Electrojet (CEJ). These results will be presented and discussed in detail.

Early development of shorter (3m) scale irregularities in the topside region of an Equatorial Plasma Bubble

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The equatorial plasma bubbles, once developed, grow nonlinearly into topside ionosphere, and simultaneous secondary instabilities lead to the development of shorter scale irregularities. The altitudinal growth and generation of smaller scale irregularities determine the spatio-temporal occurrence and the intensity of ionospheric scintillations at wide spectrum of radio waves and have significant implications on the GNSS/Satellite Based Augmentation Systems. We present a unique equatorial plasma bubble observation from equatorial atmosphere radar that provides hitherto undisclosed evidence for the smaller (3-m) scale irregularities initially developing at higher altitudes and subsequently developing to lower altitudes in a narrow funnel-like structure. The responsible mechanisms for early development of shorter-scale irregularities in the topside and their subsequent development at lower altitudes are discussed in light of the difference between the time scales of altitudinal growth and cascading rate of secondary instabilities through high-resolution bubble model simulations.

On the Intensity Estimation of Sporadic E Layers

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The typical measure of sporadic E metal ion layer intensity is the ordinary wave critical frequency foEs which is measured routinely by ionosondes. However since sporadic E layers are metal ion layers, foEs inherently represents the sum of both the layer metal and the regular E region plasma densities which implies that foEs is in fact an overestimation of Es intensity. To account for this deficiency, a new parameter, foμEs, was proposed by Haldoupis [1] which represents only the Es layer metal plasma density, and a simple method was proposed for its calculation. In this presentation, we discuss the importance of replacing foEs by foμEs in Es studies by outlining the diurnal and seasonal variability of sporadic E over the mid-latitude station of Nicosia. The Es mean diurnal and seasonal variation estimated by means of using foμEs, differ substantially from those based on foEs, indicating that the use of foEs gives rise to biased results and misleading physical inferences.

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Estimating the daytime vertical $\vec{E} \times \vec{B}$ drift velocities in the F-region of the equatorial ionosphere using the IEEY and AMBER magnetic data in West Africa

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In this study, the diurnal vertical drift velocity $\vec{E} \times \vec{B}$ in the F region of the equatorial ionosphere was estimated from the magnetic effect of the equatorial electrojet (EEJ) in the West African longitude sector in 1993 (solar cycle 22) and 2013 (solar cycle 24). Geomagnetic data recorded during the International Equatorial Electrojet Year (IEEY) from 1993 to 1994 and the African Meridian B-field Education and Research (AMBER) program started in 2008 were used. The vertical drift velocity was deduced from the EEJ intensity (ΔH). IEEY data were used to examine seasonal variations of the daytime drift velocity. Seasonal averages at noon are V_d = 10.95 m/s and V_d = 9.46 m/s for the March and September equinoxes respectively, and V_d = 8.75 m/s and V_d = 8.27 m/s for the December and June solstices. We found that the daytime vertical drift velocity was greater at the equinoxes than at the solstices. The dependence of the daytime vertical drift velocity on solar cycle was also shown by comparing the results of September equinox in 1993 and 2013. The drift velocity of 9.5 m/s in 1993 is significantly weaker than that of 24.5 m/s in 2013. This strong difference in Vd reflects the level of solar cycle between 1993 when the mean $F_{10.7}$ = 109.86 sfu and 2013 when the mean $F_{10.7}$ = 122.55 sfu.

Equatorial F-Region Irregularities in Africa: Its Latitudinal Pattern at Different Seasons

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Abstract
In this study, the latitudinal pattern of equatorial F-region irregularities (EFI) is investigated at different seasons in Africa using a GPS-derived proxy (rate of change of TEC index (ROTI)). Generally, EFI is mostly visible between 19:00 and 0:00 LT and also indicates seasonal features. EFI are generally observed within $\sim \pm 22^o$ magnetic latitudes (ML) in the region regardless of the seasons. The occurrence probability is generally higher in equinoxes and almost comparable across the entire latitudes whereas it indicates a dip around the magnetic equator in solstices. Its latitudinal dependence is also indicated in the average seasonal value of ROTI with appearance generally within $\sim \pm(0^o$-$12^o)$ ML in solstices and extended up to $\sim 18^o$ in equinoxes, in particular in the southern region. Analysis of latitudinal TEC profile favored the observed hemispheric asymmetry in the average seasonal values of ROTI. However, the TEC gradient delineates the latitude of peak occurrence of EFI.

Further, severe cases of EFI are mainly found in equinoxes than in solstices irrespective of the latitude of occurrence and are mostly pronounced around the southern crest in the region. On the other hand, moderate cases of EFI are typically found in solstices and particularly around the magnetic equator and the poleward edge of northern equatorial ionization anomaly (EIA) region.

Vertical Propagation Speeds of Gravity Waves in the Daytime as a Precursor to the Onset of Equatorial Spread-F

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The equatorial spread-F (ESF) refers to the spread observed in the return echoes of ionograms, which are due to plasma irregularities occurring in the ionospheric heights on some nights. Under seemingly identical background conditions, ESF might occur on one night but remain absent on the other. These plasma irregularities adversely affect the trans-ionospheric radio wave propagation, and their occurrence on a given night continues to be one of the missing elements in our understanding of the equatorial ionospheric phenomena. We have carried out a detailed investigation on the day-to-day variability in ESF occurrence during post-sunset hours using digisonde data of Trivandrum, a dip-equatorial station in Indian longitudes. We found that vertical propagation activity of gravity waves, derived using the height variations of constant electron densities, exists on 85% of the ESF days, whereas it is only 50% for the days without the occurrence of ESF in the post-sunset hours. The vertical propagation speeds of these gravity waves are higher on ESF days than on non-ESF days. These high-speed gravity waves have been found to perturb the bottom side of the ionosphere more efficiently on ESF days compared to non-ESF days. Further, ESF has been found to occur on 100% of the occasions whenever the vertical speeds of these gravity waves are greater than 80 ms^{-1}. This threshold value of vertical propagation speeds of gravity waves can be used to predict the ESF occurrence around 14 LT on that day, which is much in advance of the occurrence of ESF. Some of these results will be presented.

Characteristics Gravity Wave Scale Sizes present in the Plasma Bubbles as seen in the OI 630 nm Nightglow Emissions over Low-Latitudes

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Equatorial plasma irregularities/ plasma bubbles (EPBs) are the depletions in ionospheric plasma which are generated during sunset time over the equatorial region that span scale sizes from a few centimetres to several thousands of kilometres as seen through different observation techniques. OI 630 nm nightglow emissions (redline) acts as good tracer to study such plasma depletion structures and their movement in the ionosphere. The observation of OI 630 nm nocturnal emissions had been carried out during 2013-17 from Mt. Abu (24.6^{o} N, 72.7^{o} E, 16^{o} Mag N), a low-latitude location in Indian longitudes using a High Throughput Imaging Echelle Spectrograph (HiTIES). On several nights in the year 2014, especially during March, excursions in the nocturnal emissions have been observed which were in simultaneity with the spread-F occurrences as observed using a digisonde operating from a nearby location, Ahmedabad (23.0^{o} N, 72.6^{o} E, 15^{o} Mag N). All-sky imager redline observations from Kolhapur (16.8^{o} N, 74.2^{o} E, 8.2^{o} Mag N), which is an off-equatorial location, situated in between the magnetic equator and Mt. Abu, are compared with those from Mt. Abu. The depletions in emissions observed in the nightglow emissions over Mt. Abu match in time with the plasma depletions observed in the all-sky images, which reveal that the plasma depletions observed over Kolhapur extend to the latitudes at least until the latitude of Mt. Abu. The characteristics of plasma bubbles investigated under these conditions, such as, their spatial extents, both in latitude and longitude, their propagation speeds, the scale sizes of gravity waves in the ionosphere thermosphere regions that exist during high solar activity conditions of the solar cycle 24 will be presented. The characteristics of the seed perturbation, in gravity waves, sustain in the plasma bubbles structures in terms of inter-bubble separations. Significant contrast in zonal scale sizes of gravity waves is observed between non-EPB and EPB nights. The scale sizes in the range 250-300 km are omnipresent, whereas, shorter scale sizes (50-250 km) have been found to be present only during the presence of EPBs. These results will be presented.

Inferring Zonal Drift Velocity of Ionospheric Irregularities from a Spaced GNSS Receivers Arrangement at a low-latitude location Guntur, India

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The zonal drift velocity of ionospheric irregularities plays an important role in understanding the temporal evolution and propagation characteristics of equatorial plasma bubbles. The present work focuses on the exploitation of concurrent recordings of signal strengths from a spaced configuration of Ionospheric monitoring Global Navigation Satellite System (GNSS) receivers at a low latitude location in Guntur, Andhra Pradesh, India, to estimate zonal drift velocities of ionospheric irregularities through employing a cross-correlation technique. The analysis of drift velocity (v) with strongly supporting observations of amplitude scintillation index (S_4 index) and phase scintillation index (σ_φ index) from the ionospheric monitoring GNSS receivers reveals the drift velocity ranging from 80 to 140 km/s that increases from sunset to pre-midnight and then declines towards post-midnight during an equinoctial month of October 2021. The results from this work seem to be interesting for undertaking further investigations on drifting plasma bubbles during the varied season and geomagnetic conditions.

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Towards development of a statistical model of Loss of lock and scintillations during the equatorial post-sunset ionospheric irregularities

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Abstract

Loss of Lock (LoL) in GNSS receivers are associated with ionospheric amplitude and phase scintillations and serevely limit the performance of satellite-based navigation systems. The LoL may also occur due to receiver dynamics, multipath, and interference apart from the ionospheric irregularities for a given receiver configuration and site. This study makes a robust analysis of the LoL associated with ionosperic irregularities by using multi-frequency GNSS observations during 2014–2017 from a low latitude station at Waltair (17.7^{o}N, 83.3^{o}E), India. The results of the study shows a strong seasonal, local time, and solar activity dependence of the LoL. The LoL occurrence is found to increase with the severity of scintillation and maximize for strong scintillations, it is also found that the LoL may occur at any level of S4 due to other dominating factors. A limitation of the scintillation data is highlighted wherein spurious values of 60 s σ_{φ}(i.e. σ_{φ}> 1.5) are found to constitute more than 53% of total LoL events against the widely accepted σ_{φ}< 1.5. It is found that while the weak and moderate S4 events weigh the distribution, they correspond to fewer than 15% of the total LoL. A combination of 0.5 < S4 < 0.7 and 0.4 <σ_{φ}< 0.6 is found to produce LoL for most of the seasons for all the signals. The LoL events are found to increase over latitudes away from the dip equator for most of the signals, whereas they decrease with an increasing elevation angle of IPP, possibly due to multiple refractions over excess path lengths at lower elevation angles and a latitudinal gradient in the electron density. A combination is found to be composed of S4 > 0.6 and σ_{φ}> 1.5 with lower elevation angles that produce more LoL events between 20:00 and 22:00 local times. As a final product of this analysis, we have developed new probabilistic forecast models for the occurrence of the LoL for different seasons showing a dependence upon S4, σ_{φ} and local time that would be useful for different class of GNSS users. In this context our results emphasize lower number of LoL at higher elevation angles during the post-sunset hours, favouring those precise positioning applications which have shown limitations at satellite visibility at lower elevation angles like urban civil structures and city pathways.

New digisonde analysis tools for equatorial ionospheric research

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Modern Digisondes are equipped with interferometry and Doppler capabilities which can provide vital information in understanding ionosphere not pursued much. We have developed new tools using Digisonde DPS-4D observations located at Gadanki (13.5°N, 79.2°E). This provide (1) auto-detection and characterization of F3 layer and (2) characterization of reflected and scattered echoes in terms plasma density/irregularities and (3) angle-of-arrival of reflected/scattered echoes to study wavelike structures. Auto-scaling of ionograms provides range-time variations of electron density and signal-to-noise ratio (SNR). These provide ambient and disturbed states of ionosphere with features that closely resembles plume structures observed by collocated 30 MHz Gadanki Ionospheric Radar Interferometer (GIRI). Using this capability we have studied wave features, Viz., wave periods, wavelengths and propagation direction of wave like structures, equatorial plasma bubble (EPB) and evolution of F3 layer. Results obtained using new tools will be presented and discussed in terms of their usefulness in furthering equatorial ionospheric research.

Midlatitude Plamsa Bubbles Detected over the African-Eorupean Longitude Sector

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The occurrence of the midlatitude extension of equatorial plamsa bubbles over the African-European longitudes is investigated using electron density measurements in 2014 and 2019 from Swarm satellites. The distribution of the midlatitude plasma depletions are restricted to latitudes between ±20°–45° (geographic) to prevent contamination from equatorial plasma bubbles and the ionospheric midlatitude trough. Preliminary results will show seasonal and solar cycle variations of the depletions as well as their possible link to the equatorial plasma bubbles. In addition, hermispheric symmetry in the distribution of these depletion structures are also investigated.

GOLD Mission's Observations on the Variabilities of Equatorial Plasma Bubbles Occurrence Rate

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Equatorial Plasma Bubbles (EPBs) are an interesting and important nighttime ionospheric plasma irregularity phenomenon that occur over the equatorial- and low-latitudes. The seeding, development, and persistence of EPBs depend on factors such as alignment of dusk terminator with the magnetic field lines, thermospheric winds and waves, electric fields, etc. At a given longitude sector, these factors change with season, producing longitudinal differences in the EPBs occurrence rate. These variabilities can change with the solar activity. The NASA Global-scale Observations of the Limb and Disk (GOLD) mission takes far-ultraviolet images of the Earth from geostationary orbit. Individual EPBs, measured as depleted N-S elongated regions in the OI 135.6 nm emission, can be detected multiple times after the sunset over the South America, Atlantic, and West African longitude sectors. Over these longitude sectors we compared EPBs occurrence rates from 2019 to 2021. Observations suggest that EPB occurrence increased linearly with the solar activity increase. Over the South American and Atlantic longitude sectors, EPBs occurrence rate was around 95% in December solstices. The occurrence rate over the West African longitude sector in the same month was 10%. The seasonal and longitudinal variations of EPBs occurrence rates and their solar activity dependence will be discussed in this work.

An Interhemispheric Analysis of Plasma Irregularities Over South America Using a Disturbance Ionosphere indeX

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In this work, we use the Disturbance Ionosphere indeX (DIX) to evaluate the localized ionospheric response to equatorial plasma irregularities from 2015 to 2020 over the South America region. The DIX is defined as the TEC deviation from a non-perturbed reference, with a scale ranging from 0 (quiet ionosphere) to over 5 (extremely disturbed ionosphere) levels. This index has been used as a proxy to scale the intensity of Space Weather events driven by external (e.g., magnetic storms) and internal sources (e.g., plasma bubbles) (Denardini et al., 2020, Picanço et al., 2020, 2021, 2022). Thus, we obtained the DIX for stations located at conjugate magnetic latitudes and investigated the interhemispheric asymmetries observed during plasma irregularities. Specifically, we compared DIX values observed during the irregularity passage over both hemispheres, supported by data from ionosonde and All-Sky Imager stations. Finally, we discuss how the DIX response to plasma irregularities is affected by different local phenomena over time (e.g., Equatorial Ionization Anomaly [EIA], South America Magnetic Anomaly [SAMA]).

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VHF to UHF scintillation by using beacon and NOAA signals

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The ionosphere plays an important role as a communication path between a ground-ground and satellite-ground. The irregularity of the plasma density in the ionosphere is often generated from a few tens of kilometers to a few meters. Notably, irregularities on the scale sizes of hundreds of meters to a few kilometers cause fluctuation in the radio wave transmitted from the Global Navigation Satellite System (GNSS) satellites. Previous studies presented small-scale ionospheric irregularities were generated by cascading of the large-scale irregularities. Therefore, it is essential to observe large (a few km) scale irregularities simultaneously with small (several 100s m) scale irregularities.

We started a test observation at Chofu, Tokyo (35.68 N, 139.56 E) since August 2021 by receiving the VHF (150 MHz) and UHF (400 MHz) beacon signals transmitted from Low Earth Orbit satellites by receivers based on the software-defined radio (SDR) targeting on irregularities associated with the sporadic E (Es) layer. The total electron content (TEC) and amplitude scintillation index were derived from the phase and amplitude of the signals. Unfortunately, however, we found that there were few satellites transmitting the beacon signals and the signal intensities were weak probably due to aging of satellites. To increase the observation opportunity, we have also developed a receiver for the signal of the American National Oceanic and Atmospheric Administration (NOAA) series of weather satellites. The NOAA satellites transmit frequency modulated (FM) signals at 137 MHz. Although TEC cannot be derived from the NOAA satellite signals, the amplitude scintillation index can be derived from the time series of the amplitude of the FM signals. The opportunity for scintillation observations will be roughly doubled, although TEC cannot be derived from NOAA signals.

After the test observation, we relocated the beacon receiver to Tarumizu, Kagoshima (31.49 N, 130.70 E) in Jun 2022 to receive the 150 and 400 MHz beacon signals transmitted from a sounding rocket launched at Uchinoura, Kagoshima which aims to obseve irregularities associated with the Es layer and medium-scale traveling ionospheric distubances (MSTIDs). The signals from FORMOSAT-7/COSMIC-2 (Constellation Observing System for Meteorology Ionosphere and Climate) satellites, which are placed in the low-inclination orbit, can also beobserved. Furthermore, the amplitude fluctuation caused by the plasma bubble could be observed in the southern part of the field of view. Thus, the observation and occurrence of scintillation events opportunity seem more promising.

In this presentation, we will describe our system and present observation results conducted at Chofu and Tarumizu. The results are compared with the ROTI (rate of TEC index) map which represents the existence of ionospheric irregularities. Future plans to extenced our observation to equatorial regions will also be presented.

Satellite Observations of BSS Irregularities Coordinated with Ground Measurements

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BottomSide Sinusoidal (BSS) irregularities were first reported in 1983 using observations collected by the Atmospheric Explorer satellites (AE-C and AE-E). This paper demonstrates that this type of irregularity is different from other types of processes detected at low latitudes as bottomside layers or plasma bubbles but is created during times when an unusual pattern of vertical velocities and neutral winds prevail during the evening hours. This paper presents a high spatial resolution of density and vertical velocity values measured by two low-latitude satellites such as ROCSAT and the C/NOFS satellites that have observed BSS structures. Additional measurements of BSS were coordinated with concurrent ground-based measurements using networks of GPS receivers, a digisonde, and VIPIR ionosondes in South America. The new observations revealed that BSS irregularities occur when the vertical drift's pre-reversal enhancement is unusually intense or during events when long-lasting and strong meridional wind prevails at low latitudes. Under these circumstances, the bottomside F region is lifted above the height of strong ion-neutral coupling creating an altitude range of reduced ion temperatures (Ti) due to adiabatic cooling as the plasma rises to more significant apex heights. The existence of negative Ti and Te gradients, collocated with a positive density gradient at the bottomside, is required for initiating the ion temperature gradient convective (ITGC) instability.

Vast expanses of kilometer-scale waves discovered in the earth's ionosphere by probes on the C/NOFS satellite -- A new source of scintillations

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The Vector Electric Field Investigation (VEFI) on the C/NOFS satellite has revealed vast expanses of quasi-coherent, kilometer scale electric field and plasma density oscillations sometimes existing for several thousands of kilometers along the satellite track. The electric field components are shown to be locked in phase with plasma density oscillations and generally appear without evidence of larger-scale spread-F depletions sometimes referred to as "bubbles". Vector electric field data show the waves propagate in the zonal direction. The waves cannot be detected by ground-based radars due to their kilometer scale wavelengths. The waves are most prevalent near the C/NOFS perigee of 400 km but have been observed as high as 800 km altitude. The VEFI team has determined that they are a source of strong radiowave scintillations using the C/NOFS GPS receiver. The origins of these large expanses of intense km-scale waves are not known. They do not appear to be associated with plasma gradients and appear driven by a threshold instability. The data resemble bottomside (< 300 km altitude), sinusoidal density irregularities observed in the Atmosphere Explorer satellite data below the F-peak reported by Valladares et al. [1983]. These waves appear to represent a fundamental, natural phenomenon likely present in all planetary upper atmospheres.

Observation on Large-Scale Wave Structure in Southeast Asia

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Ionospheric irregularities that occurred after sunset are referred to as the Equatorial Plasma Bubble (EPB) and its seeding mechanism is unclear due to a lack of observation in EPB seeding observation. The EPB is believed to have developed during the post-sunset period when large-scale wave structure (LSWS) upwelled at the bottom of the F layer. The upward atmospheric gravity wave (AGW) causes an increase in the Rayleigh-Taylor instability's development rate, may result in LSWS [1, 2, 3]. The LSWS is observed using the Gnu Radio Beacon Receiver (GRBR) with signals from the C/NOFS satellite. The data between 2012 and 2014 were used to analyse the seasonal variance of LSWS in Southeast Asia. The results revealed that the equinoctial season's LSWS amplitude is generally higher than the solstitial season's amplitude. The occurrence of EPB is more frequent during the equinoctial seasons than the solstitial seasons. LSWS might be the seed to initiate RT instability and lead to the development of EPB from the upwelling when LSWS grows to sufficient strength [3, 4, 5]. However, EPB does not always follow the existence of LSWS. These findings will be discussed in terms of seeding.

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First Observation of Daytime Range Spread F at Middle Latitude in the Afternoon

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Daytime spread F (DSF) is not as common as nighttime spread F (NSF) due to the presence of a highly conducting E-layer during the daytime which hinders the development of F-layer ionospheric irregularities. However, some remnants or fossils of NSF-like plasma irregularities can overcome adverse conditions in the daytime to grow and survive near the sunrise terminator. In this study, an extremely unusual DSF event on December 23, 2016 was observed for the first time by the mid-latitide ionosonde installed at Zhangye (ZHY, 39.4°N, 100.13°E, dip latitude 29.65°N) station. The DSF event, which lasted about 45 minutes, occurred unexpectedly in the afternoon, and there was no spread F observed at ZHY station on the previous night. This implies that DSF might be freshly generated at afternoon hours, rather than the remnant of the ionospheric irregularities on previous night. In addition, the morphology of DSF on ionograms was characterized by a mixture of frequency spread F (FSF) and range spread F (RSF). Previous observational studies on DSF suggested that DSF is mostly associated with FSF. The RSF even mixed spread F is seldom reported at daytime. Interestingly, some extra traces of the ionospheric F2 layer also manifested on ionograms during the period before and after this DSF event. Moreover, daytime RSF and range spread Es in the midlatitude region were simultaneously observed during the afternoon hours. The result suggests that the passage of ionospheric wave-like structures caused by TIDs maybe play a significant role in influencing daytime spread F, spread Es and multibranch traces attached on the main traces of F layer. Furthermore, the seeding of TIDs might be attributed to the active stratosphere gravity waves over the Qinghai-Tibetan Plateau.

Airglow Observation and Investigation of Equatorial Plasma Bubble Tilt Variations, and its Possible Relation to Zonal Drift Velocity over Gadanki

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The tilt, and zonal drift velocities of post-sunset equatorial ionospheric irregularities have been studied using an OI 630 nm all-sky airglow imager (ASI) installed at Gadanki ($13.5^0\mathrm{N}, 79.2^0\mathrm{E}$) in 2017. In the whole year of observations only on 5 occasions, plasma bubbles have been observed. The low occurrence of plasma bubbles can be attributed to the low solar activity in 2017. All the depletions observed are showing eastward drift with mean zonal drift velocities varying between 64 m/s – 143 m/s. For all the observed events, the zonal drift velocities increase post-sunset which is considered as the generation time of equatorial plasma depletions till ~22:30 LT, and decrease abruptly after that. The plasma bubbles have an inclination to the geomagnetic N-S, and the tilt angles are calculated using the keogram analysis of the obtained pixel averaged image intensity variations. Through the observation period, we have found the tilt of the plasma bubbles varies between $21^o\mathrm{W}$ to $14^o\mathrm{E}$ to the geomagnetic N-S. We report an event on 27th March 2017 showing a wide plasma bubble having perfect alignment to the geomagnetic field line throughout the night, and slowly drifting eastwards with a mean zonal drift velocity of 64 m/s. The cause of the plasma bubble tilt and its temporal variations are explained using the latitudinal, and altitudinal variation in zonal drift velocity by taking into consideration the electrodynamical impacts of neutral wind, and associated polarization electric field variations.

As an extended study, the simultaneous observations of tilts, and zonal drift velocities are analyzed for all the observed plasma bubbles to show a direct influence of zonal drift velocity on tilt, and we conclude that faster drifting plasma bubbles show larger tilt and vice versa. This characteristic study of plasma bubbles contributes to a better understanding of the dynamics of equatorial plasma bubbles.

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Variabilities of Equatorial Plasma Bubble: Causes and predictability

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Equatorial plasma bubble (EPB) displays variabilities whose temporal scale varies from day-to-day to 11-year solar cycle and spatial scale varies from a few meters (field-aligned irregularities, or FAIs, responsible for radar backscatter) to more than 500 km (Large scale wave structure or LSWS). Of prime importance is the day-to-day variability of EPB. We present a series of investigations, aimed at resolving the large-scale morphological features of EPB and its day-to-day variability. The large-scale spatial variability of EPB associated with LSWS, which refers to spatial sinusoidal variation in the F layer height in the post-sunset hours, has been studied in detail. It is recently observed that the LSWS is preceded by oppositely phased large-scale spatial variability of low latitude Es layer. LSWS not only plays a role in the Spatio-temporal morphology of EPB but also in its day-to-day variability. However, recent observations reveal that among the most vital cause of day-to-day variability of EPB is the planetary scale variation of terrestrial factors like quiet time geomagnetic activity and solar irradiance. Recent studies based on year-round continuous observation of F-region FAIs using Equatorial Atmosphere Radar (EAR) have also revealed the planetary scale variability of EPB to be oppositely phased with respect to the variability of quiet period geomagnetic activity, indicating that over planetary scale, geomagnetic activity stabilizes the nighttime low latitude ionosphere. Thermospheric density over low latitude, derived from drag analysis of SWARM satellite constellation, reveals planetary-scale periods similar to EPB. Calculation of the ion-neutral collision frequency from thermospheric density and subsequent assessment of collisional Rayleigh-Taylor (RT) instability growth rate indicates a variation of up to one order of magnitude over planetary scale. These and other vital results will be presented and discussed in the light of existing knowledge on the generation of EPB.

Signatures of Space Weather events in low latitudes ionosphere and on the Earth's magnetic field

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Within the framework of international projects IHY (International Heliophysical Year /2007-2009) and ISWI (International Space Weather Initiative /2010-2012), many studies have been made on the impact of solar events on Low latitude ionosphere and Earth’s magnetic field.

We will present some results obtained during the last decade concerning :
The different longitudinal response of the EIA to CMEs and fast solar winds flowing from coronal holes,
The signature of plasma instabilities (EPB) on the ROTI index and the role of PPEF (Prompt Penetration of Magnetospheric electric field) or DDEF (Disturbed Dynamo Electric field) mechanisms in increasing or inhibiting the ROTI index,
The different signatures on the Earth's magnetic field of CMEs and fast solar winds flowing from coronal holes.

Regulation of Ionospheric Plasma Velocities by Thermospheric Winds

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Earth's equatorial ionosphere exhibits substantial and unpredictable day-to-day variations in density and morphology. This presents challenges in preparing for adverse impacts on geopositioning systems and radio communications even 24 hours in advance. The variability is now theoretically understood as a manifestation of thermospheric weather, where winds in the upper atmosphere respond strongly to a spectrum of atmospheric waves that propagate into space from the lower and middle atmosphere. First-principles simulations predict related, large changes in the ionosphere, primarily through modification of wind-driven electromotive forces: the wind-driven dynamo. Here we show the first direct evidence of the action of a wind dynamo in space, using the coordinated, space-based observations of winds and plasma motion made by the National Aeronautics and Space Administration Ionospheric Connection Explorer. A clear relationship is found between vertical plasma velocities measured at the magnetic equator near 600 km and the thermospheric winds much farther below. Significant correlations are found between the plasma and wind velocities during several successive precession cycles of the Ionospheric Connection Explorer's orbit. A simplified relationship between the winds, conductivities, and drifts is presented that is useful for considering the physics of the daytime ionosphere.

Small-scale variability of ionospheric electrodynamics process inferred from LEO satellite magnetic observations

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Ionospheric electrodynamical processes like equatorial electrojet (EEJ) exhibit spatial variation over various spatial scales. The large-scale variations are caused by the tidal and planetary wave forcing, variation of main ambient magnetic field strength, and the difference between geographic and geomagnetic equator. In the last two decades, magnetic field observation from low earth orbiting (LEO) satellites have been extensively used to study the spatial variation of electrodynamics processes over thousands of kilometers. However, the measurements on the small-scale variations of electrodynamics processes is sparse. In this study, we explore the variation of electrodynamical processes over the small scales using the magnetic observations from SWARM satellite constellation. A high-resolution magnetic field model and high-resolution quasi-dipole coordinate mapping is used to derive the residual magnetic field signal associated with the ionospheric currents. Our results show that, on several days, small-scale wave-like variations are present in the satellite magnetic residuals. We believe these signals are related to interaction of gravity waves with the E region ionosphere dynamo. In this work, we will be presenting the global distribution of these wave-like signals, their scale sizes and their seasonal variability. We will also be discussing the presence of these features during extreme terrestrial events. These results may provide important insights into the climatology of gravity waves in the lower thermosphere and role of mesoscale process in ionospheric electrodynamics.

Hemispheric and Longitudinal variation of the low latitude ionospheric dynamics

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The hemispheric and longitudinal variations of NmF2 and TEC during quiet and disturbed periods is discussed. The African, Indian and East Asian sectors are covered. A conjugate hemisphere study of the monthly quiet time mean ionosonde derived NmF2 was undertaken for the year 2015 along 100°E longitude sector where the dip equator is north of the geographic equator by about 9°. It was noted that the reversal of the season from summer to winter and vice-versa do not lead to a complete reversal of the NmF2 behaviour at the two pairs of conjugate stations. The morning time inter-hemispheric plasma transport to the winter hemisphere is clearly noticeable in June solstice for the southern low latitude stations but not in December solstice for the northern low latitude stations. In contrast, the real height, hmF2 derived from ionogram using POLAN by profile inversion show a more significant enhancement in the southern low latitude during December than in the northern low latitude during June. HWM wind simulations indicate that the northward wind is much stronger over the stations during December than during June. The seasonal/hemispheric asymmetry in the response of ionospheric parameters of NmF2/TEC were noticed through the geomagnetically disturbed periods of 22-23 June and 20-21 December, 2015. On 23 June, large differences were noticed between the NmF2 and TEC over the southern low latitude station Cocos Islands, located near the EIA crest. This altitudinal asymmetry may be attributed to large topside enhancements in the southern low to midlatitude on 23 June shown by the SWARM satellite observations. In contrast, during 20-21 December no topside enhancements were noticed in the northern low latitudes, although the southern low latitude stations showed TEC/NmF2 depletions. Interestingly, a difference between NmF2 and TEC response to the long duration storm of 14-16 July, 2012 was also noticeable. This may suggest a seasonal preference for inter-hemispheric transport due to the shifted position of the dip equator as the geographic-geomagnetic offset puts the subsolar point or the driver of the neutral wind system at different positions relative to the EIA crest regions in the two solstices. A climatological study of the hemispheric-longitudinal NmF2 asymmetry using two pairs of low latitude conjugate stations along 100°E and 120°E revealed the effect of the magnetic declination. The case studies of the response of the TEC to the SSW events of 2019 and 2013 in the 10°E (Africa-Europe) and 100°E (East Asia) sectors further suggest that the magnetic field geometry plays a crucial role in the longitudinal difference of the ionospheric response. The geometry of the geo-magnetic field lines,which affect the neutral wind system via the ion-drag seems to be a major contributor to the hemispheric and longitudinal asymmetries observed in the low latitude ionospheric behavior.

On the longitudinal variability of complexities associated with equatorial electrojet

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Equatorial electrojet indices obtained from ground based magnetometers at 6 representative stations across the magnetic equatorial belt for the year 2009 (mean annual sunspot number Rz = 3.1) were treated to nonlinear time series analysis technique to ascertain the longitudinal dependence of the chaos/complexities associated with the phenomena. The selected stations were along the magnetic equator in the South American (Huancayo, dip latitude -1.80°), African (Ilorin, dip latitude -1.82°; Addis Ababa, dip latitude – 0.18°), and Philippine (Langkawi, dip latitude -2.32°; Davao, dip latitude -1.02°; Yap, dip latitude -1.49°) sectors. The non-linear quantifiers engaged in this work include: Recurrence rate, determinism, diagonal line length, entropy, laminarity, Tsallis entropy, Lyapunov exponent and correlation dimension. Ordinarily the EEJ was found to undergo variability from one longitudinal representative station to another, with the strongest EEJ of about 192.5 nT at the South American axis at Huancayo. The degree of complexity in the EEJ was found to vary qualitatively from one sector to another. Probable physical mechanisms responsible for longitudinal variability of EEJ strength and its complexities were highlighted.

STATISTICAL Results of Traveling Ionospheric Disturbances in Equatorial and Low Latitudes During Geomagnetic Storms

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This work presents statistical results of travelling ionospheric disturbances (TIDs) during geomagnetic storms over the equatorial and low latitudes in the African and American sectors during 2010-2018. The TIDs are identified in total electron content data derived from Global Navigation Satellite systems observations. Statistical results show that large and medium scale TIDs occur mostly during main and recovery phases of geomagnetic storms, respectively. We have found that most of the observed cases have a correlation with enhanced equatorial electrojet, highlighting that ionospheric electrodynamics in equatorial latitudes may play a role in launching these TIDs.

The Ionospheric Response for Two Geomagnetic Storms and their Relation to the Latitudes and Longitudes.

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Abstract: The variation in the ionosphere due to geomagnetic storms prompt severe scintillation that disturb or enlarge changes in ionization. TEC (Total Electron content) value was employed in studying the ionospheric response to solar flare and CME (Cornal Mass Ejection). Different studies investigated the ionospheric response in both HSS (High-Speed Solar Stream) and HILCDAA (High Long Duration Continuous Auroral Electro-jet AE) activity cases during 2008-2009. Our work is motivated by the fact that the ionosphere is responding to Earth's magnetic disturbance and electric field penetration to modulate the electrodynamics phenomena in the ionosphere which shows a significant signature at the equator. We monitor the ionospheric response for magnetic storm using GPS stations, swarm satellite and some magnetic and solar parameters, and its relation to latitude and longitude. The Δt_{iono} average value found to be 1~2 days for regular storms facing the earth side at the equator and we found a linear relation between the longitude and the Δt_{iono} for longitude between [-100 0] as well.

New Perceptions of Various Scale Heights as Revealed by Recent Radio Occultation Technique on COSMIC-2 Microsatellites

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Abstract

The radio occultation (RO) performed on a constellation of six micro-satellites named Constellation System of Meteorology, Ionosphere, and Climate (COSMIC, launched in 2006 and decommissioned in May 2020) had revealed several interesting features of the lower atmosphere, ionosphere, and space weather. A follow-up mission named COSMIC-2, which was launched on 25 June 2019 consisting of a cluster of six satellites identical to the COSMIC-1 RO technique, should provide better features as it is delivering almost 5000 occultations (Figure 1), which is thrice the number of occultations provided by the COSMIC-1. In this research, we present one-month (January 2022) global features of various scale heights, including vertical scale height at 500 km (VSH-500), vertical scale height at the upper ionosphere, and the Chapman scale height (Hm) during 1300-1500 local time (LT). Dominant longitudinal structures are observed along the geomagnetic equator in all scale heights during the daytime, a first-time observational finding reported using the COSMIC-2 RO technique. To our surprise, the Chapman scale heights and vertical scale heights at the upper ionosphere have shown greater intensities. This interesting observational finding, therefore, indicates that the presence of longitudinal structures is omnipresent in all ionosphere parameters, but it is the ability of an observational technique whether it is capable of capturing those features or not. Indeed, we have only considered one month's data, but if we take into account long-term data or several years of data put together, we are sure that further details of the ionosphere could be observed which is going to reveal further interesting features of the ionosphere. We, therefore, conclude here that RO-based research will dominate the Earth's atmosphere and ionosphere studies.

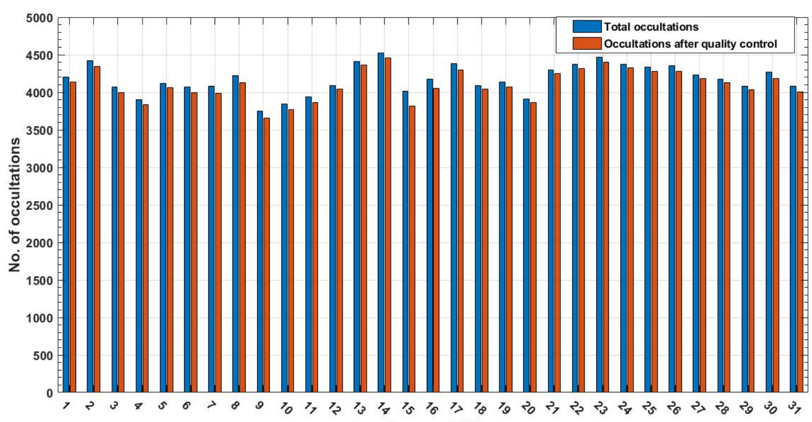

Figure 1. Total number of COSMIC-2 occultations in January 2022, which are almost thrice larger than the occultations obtained by the COSMIC-1 radio occultation (RO) technique

Investigation on Longitudinal and Decadal Variations of the Equatorial Electrojet using a Physical Model

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Longitudinal and decadal variations of equatorial electrojet (EEJ) characteristics (amplitude, width, peak altitude) are investigated using a physics-based model. The study brings out (i) Changes in EEJ half-width with longitude and its dependence on the rate of change of dip-angle with latitude, (ii) 10-20% changes in EEJ strength over the Peruvian and Brazilian sectors from 1960 to 2020 due to significant variation in the local geomagnetic field, (iii) Wave-4 structure in the EEJ current density and integrated EEJ current. In addition, it is shown that the peak EEJ current density over different longitudes depends on the inverse of geomagnetic field strength. The results provide relationships of EEJ parameters (such as half-width, peak current density, and integrated current) with the ionospheric electric field, electron density, and geomagnetic field. These relationships are verified using EEJ observations carried out earlier using rocket and ground-based magnetometers. These findings can be used in observational and modeling studies to understand the low-latitude ionospheric electrodynamics in greater detail.

Explicit characteristics of longitudinal wavenumber structure observed using COSMIC-2 RO

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High rate radio occultation (RO) in COSMIC2 (FORMOSAT7) enables us to investigate the continuous variability of the ionosphere at a Spatio-temporal resolution which was unthinkable a few years ago. We present unique characteristics of ionospheric wavenumber structures observed using COSMIC2 RO data, not reported before. Altitude-longitude maps of normalized electron density of local time ionosphere in the Equatorial Ionization Anomaly (EIA) region, indicate wavenumber structures with vertically tilted phase fronts. The longitudinal extent of a tilted wavenumber 4 (WN4) phase front approximates its zonal wavelength in the local-time ionosphere, i.e., ~90^0 in longitudes. WN4 filtered component indicates a greater tilt (when visible), with a larger longitudinal extent of a wavenumber structure in the vertical plane. High latitudinal resolution investigation of wavenumber structure presents a significant difference in the characteristics of wavenumber structures at different geomagnetic latitudes within the EIA region. During the daytime WN4 structure in the EIA crest region is found to be out-of-phase with respect to that in the EIA trough region. However, during the nighttime, the two were observed to be in phase with each other. These characteristics also vary with altitude. Above 400 km WN4 structure in EIA crest and trough region is seen to be in phase with each other at all local time. CREST. These results highlight that, while the direct role of non-migrating tides, which provides the vertical tilt to the wavenumber structure, may be the dominant mechanism, however, electrodynamical transport of plasma in the EIA region driven by eastward zonal electric field during the daytime also plays a significant role in the formation of wavenumber structure. During the nighttime, in the absence of the fountain effect, wavenumber structures are driven by the direct forcing of non-migrating tides within the EIA region. These and upcoming results will be presented and discussed in light of existing knowledge of the formation of wavenumber structures and the impact of non-migrating tides on the longitudinal ionospheric structure.

Equatorial Electrojet, Counter-Electrojet, and Other Ionospheric Currents and Related DC Electric Fields Observed on the C/NOFS Satellite

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NASA's Vector Electric Field Investigation (VEFI) onboard the C/NOFS spacecraft includes a sensitive fluxgate magnetometer to measure DC magnetic fields as well as a 3-axis double probe detector to measure DC Electric Fields and **E** x **B** drifts. The combined data sets contribute to our understanding of equatorial electrodynamics with detailed observations of low latitude ionospheric currents and their association with ionospheric DC electric fields. In particular, we show measurements that reveal electrojet and counter-electrojet currents that vary with longitude and local time. Afternoon counter-electrojet observations are shown to be co-incident with reversals of the F-region DC electric fields indicative of tidal forcing. Other low latitude currents and their concurrent DC electric fields reveal a rich array of electrodynamic processes, particularly when global averages are displayed as a function of local time, longitude, and season. With its unique low inclination (13 degree) orbit and long life (7.5 years) of continuous measurements, the C/NOFS data present a fresh view of important electrodynamic processes in the earth's low latitude ionosphere.

Connections Between Stratospheric Gravity Waves and TID Activity at Middle Latitudes

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Understanding the sources of traveling ionospheric disturbances (TIDs) remains an active area of research for the last decades. This study investigates the role of hotspots in stratospheric gravity waves (GWs) in the generation of TIDs at middle latitudes. We utilize observations of GWs at 35 km altitude by the Atmospheric InfraRed Sounder (AIRS) on NASA's Aqua satellite to characterize stratospheric gravity wave activity. The evolution of GWs with altitudes extending from the stratosphere to mesosphere-lower-thermosphere (MLT) region is examined using temperature observations from the Sounding of the Atmosphere using Broadband Emission Radiometry instrument. Ground-based total electron content observations from GNSS receivers are used to characterize TID activity in the ionosphere. Simulations by the High Altitude Mechanistic general Circulation Model (HIAMCM) that is nudged to the Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA-2) reanalysis in the troposphere and stratosphere are used to study multi-step vertical coupling between the stratosphere and the thermosphere. We investigate two case studies, the Arctic winter of 2016/2017 when a sudden stratospheric warming developed in January-February 2017, and the winter of 2019/2020 that was characterized by mostly strong polar vortex conditions. The hotspot in stratospheric GWs peaks at 55-75°N at the edge of polar vortex and in a limited range of longitudes. Our results indicate that GW activity evolves with altitude and expands to 35-40°N in the MLT region. Amplifications of TIDs during times of high stratospheric GW activity are seen from ~25-30°N to 60°N in a specific range of longitudes. HIAMCM simulations indicate a very good agreement with observations in the timing of GW activity and latitudinal coverage. We conclude that TIDs are generally amplified during high stratospheric GW activity and weakened during the periods of low stratospheric GW activity (during and after SSW).

6-day oscillation in the thermosphere and ionosphere during the 2019 SSW event

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A sudden stratospheric warming (SSW) event occurred in September 2019 in the Antarctic region. During the SSW event, the quasi 6-day wave (Q6DW) was enhanced in the middle atmosphere, and strong 6-day oscillations are observed in the equatorial electrojet (EEJ) and electron density. The 6-day variation in the EEJ has a westward moving structure with the zonal wavenumber 1, indicating the influence of the Q6DW. In this study, we investigate the excitation mechanism of the 6-day variations in the EEJ and electron density by conducting numerical simulations. In this study an atmosphere-ionosphere coupled model (GAIA) is used. The main results are as follows. The Q6DW propagates to the mesosphere and lower thermosphere, and has large amplitude in the lower thermosphere, where the E-region dynamo process is active. However, the 6-day variations in the ionosphere are generated not by the Q6DW, but by the tides. The amplitude of the semidiurnal tides are modulated with a period of 6 days, due to the nonlinear interaction between the Q6DW and migrating semidiurnal tide. The detailed mechanisms for the 6-day modulation of the tides and its effect on the 6-day variation in the ionosphere is shown.

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Bright Band-Like Structures of the Mesospheric Airglow in the Equatorial Region Elucidated by Imaging Observations from ISS

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Bright band-like structures of the mesospheric airglow have been observed from space in the equatorial region. Nadir-viewing observation of the mesospheric airglow from the international space station enabled to capture these band-like structures. The observation was carried out by Visible and near Infrared Spectral Imager (VISI) instrument of the International Space Station-Ionosphere, Mesosphere, upper Atmosphere and Plasmasphere mapping (ISS-IMAP) mission from the Exposed Facility of Japanese Experiment Module of the ISS between August 2012 and August 2015. The airglow emission from the molecular oxygen around 95km altitude in 762nm wavelength was observed with 10km of the horizontal resolution. The FOV width of VISI's 762nm observations was 600 km in the direction perpendicular to the ISS trajectory, and longer than 10,000km along the trajectory, that are idealistic to capture these mesospheric structures. The band-like airglow structures tend to stretch in the zonal direction. Their horizontal scale size is several hundreds of kilometers in latitude. Because it is larger than the field-of-view of the ground-based all-sky imagers, these bright bands are difficult to be identified from the ground-based observations. Comparison between the GAIA model and VISI's observation revealed that the atomic oxygen is transported by the meridional wind and accumulated in the pre-midnight equatorial region. This accumulation causes this intense emission of the airglow. Therefore, the bright bands can be a proxy of convergence of the meridional wind around 95km altitude on the equator. In the presentation, the morphological and occurrence features of the structures will be reported, and the physical mechanism of the generation will be discussed.

Evaluation of Atmospheric 3-Day Waves as a Scource of Day-to-Day Variation of the Ionospheric Longitudinal Structure

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We report the day-to-day variation of the longitudinal structure in height of the F_2 layer (h_mF_2) in the equatorial ionosphere using multi-satellite observations of electron density profiles by the Constellation Observing System for Meteorology, Ionosphere and Climate-2 (COSMIC-2). These observations reveal a ~3-day modulation of the h_mF_2 wavenumber-4 structure viewed in a fixed local time frame during January 30-February 14, 2021. Simultaneously, ~3-day planetary wave activity is discerned from the zonal wind observations at ~100 km altitude by the Ionospheric Connection Explorer (ICON) Michelson Interferometer for Global High-Resolutiion Thermospheric Imaging (MIGHTI). This wave signature is not observed at ~180-250 km, suggesting the dissipation of the wave below the F-region. We propose that the 3-day variation identified in h_mF_2 is likely caused by the planetary wave-tide interaction through the E-region dynamo.

Electromagnetic conjugacy of ionospheric disturbances after the 2022 Hunga Tonga-Hunga Ha'apai volcanic eruption observed by GNSS-TEC and SuperDARN Hokkaido pair of radars

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To elucidate the characteristics of electromagnetic conjugacy of traveling ionospheric disturbances (TIDs) observed just after the 15 January 2022 Hunga Tonga-Hunga Ha'apai volcanic eruption, we analyze global navigation satellite system (GNSS)-total electron content (TEC) data and ionospheric plasma velocity data obtained from the Super Dual Auroral Radar Network (SuperDARN) Hokkaido pair of radars. Further, we use thermal infrared (TIR) grid data with high spatial resolution observed by the Himawari 8 satellite to identify lower atmospheric disturbances associated with surface air pressure waves propagating as a Lamb mode. After 07:30 UT on 15 January 2022, two distinct traveling ionospheric disturbances propagating in the westward direction appeared over Japan with the same structure as those at magnetically conjugate points in the Southern Hemisphere. Corresponding to these TIDs with their large amplitude of $0.5–1.1 \times 10^{16}$ el/m^2 observed in the Southern Hemisphere, the plasma flow direction in the F region of the ionosphere changed from southward to northward. At this time, the magnetically conjugate points in the Southern Hemisphere were located in the sunlit region at a height of 105 km. The amplitude and period of the plasma flow variation are ~100–110 m/s and ~36–38 min, respectively. From the plasma flow perturbation, a zonal electric field is estimated as ~2.8–3.1 mV/m. Further, there is a phase difference of ~10–12 min between the TEC and plasma flow perturbations. The observational result is reproduced by a simple numerical calculation given the electric field perturbation. These results suggest that the external electric field perturbation generates the TIDs observed in both Southern and Northern Hemispheres. The origin of the external electric field is an E region dynamo driven by the neutral wind oscillation associated with atmospheric acoustic waves and gravity waves. Finally, the electric field propagates to the F region and magnetically conjugate ionosphere along magnetic field lines with the local Alfven speed, which is much faster than that of Lamb mode waves propagating in the troposphere. From these observational facts, it can be concluded that the E region dynamo electric field produced in the sunlit Southern Hemisphere is a main cause of the two distinct traveling ionospheric disturbances appearing over Japan before the initial arrival of the air pressure waves.

Atmospheric and Ionospheric Signatures Associated with the 15 January 2022 Hunga-Tonga Volcanic Eruption: A Multi-layer Observation

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The release of large amount of energy into the atmosphere during volcanic eruption generates various atmospheric waves. When such waves propagate upward and reach ionospheric altitudes, they introduce electron density perturbations. The Hunga-Tonga volcanic eruption occurred on 15th January 2022 generated different modes of atmospheric and ionospheric waves. Using the Geostationary Operational Environment Satellite-17 (GOES-17), Aqua and Global Positioning System (GPS) satellite observations, an atmospheric and ionospheric multi-layer study of the Tonga volcano induced signatures over the New Zealand region is performed. The visible channel data of GOES-17 and Atmospheric Infrared Sounder (AIRS) data from NASA Aqua satellite confirm the presence of a highly convective zone and occurrence of concentric gravity waves at lower atmospheric altitudes. The Total Electron Content (TEC) derived from 175 GPS stations covering the entire New Zealand region brings out two dominant modes of Travelling Ionospheric Disturbances (TIDs) having periodicity between 30-50 minutes. These two modes are observed to propagate towards the south-west direction over the New Zealand region with velocities of 542 m/s and 354 m/s respectively.

Unusual ionospheric disturbances and irregularities following the eruption of Hunga Tonga-Hunga Ha'apai on 15 January 2022

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Following the strong eruption of the submarine volcano Hunga Tonga-Hunga Ha'apai, Tonga on 15 January 2022, ionospheric disturbances were observed all over the world. There were prominent ionospheric disturrbances coinciding with the atmospheric ramb wave as well as those having geomagnetic conjugate characteristics. Saito (2022) [1] reported that there were stong ionospheric irregularities observed over Japan during the passage of traveling ionospheric disturbances (TIDs) but the distribution of the ionospheric irregularities were very different from the TID structure. This paper investigate the cause of the strong ionospheric irregularities over Japan.
Ionospheric total electron contents (TECs) derived from 200 selected GNSS receivers of the GEONET (GNSS Earth Observation Network) were used. The strong ionospheric irregularities started to be observed from 10 UT when the TIDs mapped from the southern hemisphere were observed. The irregularities continued to be observed when the TIDs coincided with the ramb wave arrival were observed. While the TIDs had wavefront aligned from NNE to SSW for the first TIDs and NE to SW for the second TIDs, the irregularities were distributed in areas elongated in the NW direction originating from the Equatorial Ionization Anomaly (EIA) crest. TThe irregularities were foun to be collocated with enhancement of TECs rather than the TIDs. The characteristics were very similar to those observed associated with a strong geomagnetic storm over Japan in 2004 [2]. Maruyama et al. (2013) explained that it was associated with the development of the EIA and enhanced westward thermosphric wind. Although it was indeed in the recovery phase of a minor geomagnetic storm commenced on 14 January 2022, it was much weaker than the geomagnetic strom which caused the similar ionospheric irregularities in 2004. However, unusual thermospheric wind changes were observed by the ICON mission [3]. The eruption may have changed the thermospheric wind conditions and caused a similar ionospheric conditions as those in a strong geomagnetic storm so that the TEC enhanced regions and ionospheric irregularities embedded in them were developed.

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Intense Equatorial Electrojet and Counter Electrojet Caused by the 15 January 2022 Tonga Volcanic Eruption: Space- and Ground-based Observations

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We present space and ground-based multi-instrument observations demonstrating the impact of the 2022 Tonga volcanic eruption on dayside equatorial electrodynamics. A strong counter electrojet (CEJ) was observed by Swarm and ground-based magnetometers on 15 January after the Tonga eruption and during the recovery phase of a moderate geomagnetic storm. Swarm also observed an enhanced equatorial electrojet (EEJ) preceding the CEJ in the previous orbit. The observed EEJ and CEJ exhibited complex spatiotemporal variations. We combine them with the Ionospheric Connection Explorer (ICON) neutral wind measurements to disentangle the potential mechanisms. Our analysis indicates that the geomagnetic storm had minimal impact; instead, a large-scale atmospheric disturbance propagating eastward from the Tonga eruption site was the most likely driver for the observed intensification and directional reversal of the equatorial electrojet. The CEJ was associated with strong eastward zonal winds in the E-region ionosphere, as a direct response to the lower atmosphere forcing.

Volcanic Modification of the E-Region Dynamo: Observations of the Recent Tonga Eruption

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The Hunga Tonga-Hunga Ha'apai (hereafter called 'Tonga') volcano erupted at ~4:15UT on 15 January 2022, driving atmospheric pressure waves around the globe [1]. These waves then propagated into space, producing traveling ionospheric disturbances (TIDs) which persisted for several days after the eruption [2]. While direct modification of the ionosphere has been associated with the passage of atmospheric waves originating in the lithosphere and lower atmosphere, the potentially larger electrodynamic effects on the plasma have only recently been considered. Here we explore both the immediate (<1hr post-eruption), and longer-term (several hours post-eruption) dynamo effects of the volcano using observations from NASA's Ionospheric Connection Explorer and the European Space Agency's Swarm satellites [3]. We report extreme zonal and vertical ExB ion drifts (6.9σ and 8.8σ according to quiet-time statistics, respectively) 1000s of kilometers away from Tonga within an hour of the eruption, well before the arrival of any atmospheric wave. The measured drifts were magnetically connected to the ionospheric E-region just 400km from Tonga, suggesting that the wavefront expanding from Tonga created strong electric potentials which were then transmitted along Earth's magnetic field via Alfvén waves. Hours later, after the atmospheric pressure wave entered the dayside, Swarm A observed an eastward and then westward equatorial electrojet (EEJ) on two consecutive orbits, each with magnitudes exceeding the 99.9th percentile of typically observed values. ICON simultaneously observed extreme neutral winds (>99.9th percentile at some altitudes) at approximately the same distance from Tonga. The covariation of EEJ and winds is consistent with recent theoretical and observational results, indicating that the westward EEJ is driven by strong westward winds in the Pedersen region (~120–150 km). These observations are the first direct detection in space of the immediate electrodynamic effects of a volcanic eruption, and will prove essential for constraining ionospheric models of impulsive lower atmospheric events.

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Exploring the low-latitude valley region: Latest results from a multi-disciplinary approach

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The ionosphere valley region extends from the peak altitude of the daytime E-region electron density profile to the bottomside F-region, typically covering the 110 to 200 km altitudes. This complex region couples the neutral and ionized components of the atmosphere, the effective boundary between terrestrial and space weather domains. The plasma in this region consists of magnetized electrons and ions that transition from collisionally dominated at the bottom to magnetically dominated at the top. The low-latitude valley region (LLVR) is among the least understood regions of the atmospheric/ionospheric system due to its complex interplay of dynamics and photochemistry.

The LLVR has been mainly explored with ground-based radars and occasional rockets. These studies have revealed the existence of considerable density structuring, quasi-periodicity in radar backscatter, spectral features in two broad categories with their occurrence probability having different solar flux dependence and strong radar frequency dependence for which the sources and configurations remain a long standing mystery. Despite this lack of understanding, researchers often use the Doppler shifts of daytime LLVR echoes to monitor equatorial F-region zonal electric fields, a key parameter necessary for understanding the entire low latitude electrodynamics.

Observing this region remotely has always been a challenge due, among other factors, to the lower ionization than the surrounding E and F regions. It also lies above the range of balloons and below the orbit of satellites. It is now timely to put a special effort into investigating this region since an increasing number of global observations from ground and space, as well as sophisticated modeling of the whole atmosphere are making rapid progress to characterize the near space environment.

In order to further our understanding of lower atmospheric forcing of the LLVR and, in turn, low latitude space weather, we have put together a multi-disciplinary group of experts to contribute to the 4D (altitude, longitude, latitude, time) exploration of the region. In this work we present the latest results of our efforts within an International Team at the International Space Science Institute (ISSI). They involve observations, modeling as well as theoretical advances. For example, we currently understand more than 70% of the observed features of the so-called daytime 150-km echoes. The remaining features are being explored and are expected to result from the interplay of the plasma physics, photochemistry, and lower atmospheric dynamics.

Midlatitude sporadic E layer structing related to neutral atmospheric instability

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We report on observations of quasiperiodic (QP) echoes from postsunset E region field-aligned plasma density irregularities observed in the Great Lakes region by a coherent scatter radar imager located in Ithaca, New York. The E-region scattering volume lies at upper middle latitudes, near the subauroral region and beneath the ionospheric trough. Another radar imager near Clemson, South Carolina, had been deployed to observe field-aligned coherent scatter from the F-region on magnetic field lines which map to the E-region volume. The same F-region volume can also be observed by the Millstone Hill incoherent scatter radar. The objective of the study is to discriminate between causal mechanisms rooted in ionospheric dynamics and in neutral atmospheric dynamics. Numerical simulations of neutral instabilities related to Ekman-type flows are able to reproduce many of the salient features in E-region radar imagery of structured sporadic-E layers.

Variations of the peak positions in the longitudinal profile of noon -time equatorial electrojet

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In this study, the seasonal variations of the EEJ longitudinal profiles were examined based on the full CHAMP satellite magnetic measurements from 2001 to 2010. A total of 7537 satellite noon-time passes across the magnetic dip-equator were analyzed. On the average, the EEJ exhibits the wave-four longitudinal pattern with four maxima located, respectively, around 170° W, 80° W, 10° W and 100° E longitudes. However, a detailed analysis of the monthly averages yielded the classification of the longitudinal profiles in two types. Profiles with three main maxima located, respectively, around 150° W, 0° and 120° E, were observed in December solstice (D) of the Lloyd seasons. In addition, a secondary maximum observed near 90° W in November, December and January, reinforces from March to October to establish the wave-four patterns of the EEJ longitudinal variation. These wave-four patterns were divided into two groups: a group of transition which includes equinox months March, April and October and May in the June solstice; and another group of well-established wave-four pattern which covers June, July, August of the June solstice and the month of September in September equinox. For the first time, the motions in the course of seasons of various maxima of the EEJ noon-time longitudinal profiles have been clearly highlighted.

Ground-Based Observations of Continual 24-Hour Equatorial Thermospheric Winds

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Abstract

The thermospheric neutral wind circulation drives the global scale dynamo processes leading to various upper atmospheric phenomena associated with the couplings by modulating neutral and plasma dynamics. This coupling process in the ionosphere/thermosphere system is key to the potential forecasting of scintillation activity that impacts our communication and navigation system. The observation of neutral winds in the upper atmospheric region can be carried out through a variety of ground- and space-based interferometric techniques. But a widely used Fabry-Perot interferometer (FPI) measurements are only possible during nighttime conditions when there is no solar background obscuring thermospheric emission. Despite these constraints, the Second-generation, Optimized, Fabry-Perot Doppler Imager (SOFDI) is designed for both daytime and nighttime measurements of thermospheric winds from OI 630 nm emission and is currently operating at the Huancayo, Peru, near the geomagnetic equator. The SOFDI system represents unique aspects of FPI design never before tried in ground-based FPI observatories.

Here, we present continual 24-hour observations of thermospheric neutral winds made with the ground-based SOFDI operating in Peruvian geomagnetic equatorial latitude over the summer (northern) of 2014 through 2019. We analyze the long-term SOFDI equatorial wind climatological data and compare it with several other modeled outputs including, but not limited to, Horizontal Wind Model 2014 (HWM-14), Whole Atmosphere Model (WAM), and Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics (CTIPe) model with and without implementing Prompt Penetration Electric Field (PPEF). We examine the relative performances of these models in the context of direct-measured equatorial thermospheric winds using the SOFDI instrument. The day and nighttime modeled winds show excellent agreement with the SOFDI wind data at the equatorial latitude, except for the daytime zonal winds. First and foremost, we propose either lower atmospheric forcing or local circulation might be a possible driver of this discrepancy. Importantly, we investigate and discuss the sources, drivers, and mechanisms of the equatorial thermospheric neutral wind variability based on measured and modeled results.

Simultaneous Occurrence of Three Non-Interacting Characteristically Different Ionospheric Plasma Structures Over the Geomagnetic Low-Mid Latitude Transition Region

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An unusual event of three characteristically different plasma structures on a geomagnetically quiet night (Ap = 4) of 08 July 2018 has been investigated in this paper using an all-sky imager installed at Hanle, Leh Ladakh (32.7°N, 78.9°E; Mlat. ~24.1°N), India. These structures include a freshly generated electrified MSTID (EMSTID), ambiguous plasma depletions, and a northward propagating non-electrified MSTID. One of the most fascinating aspects of this event was the lack of mutual interaction between the three structures, even though they existed simultaneously and propagated in different directions. They individually underwent evolution, distortion, and dissipation separately. One of the structures was an EMSTID, which got generated within the imager's field-of-view (FOV) and evolved with time. As time progressed, different strip-like structures travelled southwestward, merged with each other to form the EMSTID and disappeared later. The second structure was plasma depletions which appeared in the southeastern part of the FOV. They eventually merged into a single band. The merged band evolved with time, extended further northward, and dissipated later. Along with these, a very rare non-electrified MSTID structure with east-west aligned fronts was observed which propagated northward. Its fronts underwent distortion, became curved and dissipated. In this study, we have explored the role of electrodynamics and neutral dynamics behind the observed unique features of the three plasma structures. The highlights of these results will be discussed in the meeting.

Variation in OI 630.0 nm Dayglow Emission at Different latitudes due to Equatorial Electrodynamics and Meridional Winds Over Low Latitudes

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In the Earth's upper atmosphere over low-latitudes, equatorial electrodynamic processes play an important role in the dynamics as they take away the plasma from the equatorial latitudes and deposit over low-latitudes. Its effect on the plasma distribution can be modulated in the presence of thermospheric meridional winds as poleward wind brings down the ionospheric layer to lower altitudes. The upper atmospheric dynamics in the daytime can be investigated by the measurements of dayglow emissions. In this work, two MISE (multi-wavelength imaging spectrograph using echelle grating) operating from Hyderabad (17° N, 78° E, 9° MLAT) and Ahmedabad (23° N, 73° E, 15° MLAT) in Indian longitude, have been used to obtain the dayglow emissions from a large spatial extent 5° - 18° MLAT as MISE has a large field-of-view (140°). The study has been carried out for the data of January – February 2020 when the variation in the solar flux was negligible (68 – 72 sfu). Hence, the response of the OI 630.0 nm dayglow emissions at different latitudes has been analysed to assess the relative effects of the equatorial electrodynamics and meridional winds. It is found that the variations in OI 630.0 nm dayglow emissions due to the equatorial electrodynamics remain almost similar in this latitudinal belt, whereas, the meridional winds contribute to enhancement in OI 630.0 nm dayglow emission closer to the equator and a decrement at latitudes further away from the equator. Simulations have been carried out to understand the sensitivity of the altitude for the OI 630.0 nm dayglow emissions. The details of this study will be presented.

On the Influence of Major Sudden Stratospheric Warming on Mesospheric Cooling by Nitric Oxide, Ozone Abundance, and Their Interrelation

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Sudden stratospheric warmings (SSWs) are polar phenomena accompanied by the interaction between planetary-scale waves and stratospheric mean flow. The dramatic increase in the polar stratospheric temperature in the winters during major SSWs is associated with the zonal wind reversal. Although SSWs are polar stratospheric phenomena, their effects can also be observed in the lower atmosphere and in the mesosphere and thermosphere as well. The impacts of sudden stratospheric warming events on mesospheric ozone and nitric oxide layers have been investigated between 70° N and 80° N using SABER (The Sounding of the Atmosphere using Broadband Emission Radiometry) and the WACCM-X (extended version of WACCM) datasets. Three major sudden stratospheric warmings (2006, 2009, and 2013), are selected for this study based on their similar characteristics (major SSWs in the northern hemisphere with elevated stratopause). The early reversal of mesospheric zonal winds observed in this study indicates that an SSW starts in the mesosphere and gradually propagates into the stratosphere.

This study suggests that the variations in the concentration and altitude of the secondary ozone maximum layer, observed by the SABER, could be associated with the stratopause height and temperature variability during these anomalous winters. Nitric oxide (NO) density and emission are highly sensitive to the temperature variation in the mesosphere and lower thermosphere (MLT) and emission by the NO represents a natural thermostat. Nitric oxide volume emission rate (NO-VER) at 5.3 µm has been used here to study the IR cooling during SSWs and can be used as a proxy for the NO in the mesosphere. It has been observed that NO-VER decreases during SSW onset and is followed by an enhancement after the SSWs. The centroid height of the mesospheric NO layer is also found to be descending during the recovery of SSW. The insignificant correlation between NO-VER and ozone density suggests that mesospheric ozone is not influenced by the variation in the NO. The atmospheric neutral density observations by SABER also suggest strong perturbations in the MLT region during the SSW events.

A meteor Radar Network Study on the Polar-to-Tropical Mesospheric Coupling During the 2018 Sudden Stratosphere Warming

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The 2018 Sudden stratosphere warmings (SSW) in the northern hemisphere (NH) gained significant importance as it took place after a 4-year gap following the 2013/2014 major SSW during the westerly phase of the quasi-biennial oscillation, and is the 34th major SSW in the NH counted since 1959. In the present study, for the first time, we report the observational evidence of polar to tropical mesospheric teleconnections during the 2018 major SSW using advanced meteor radar network observations along with ERA5 data. A peak SSW on February 14, 2018, characterized by a ~ 45 K rise in polar stratosphere temperature and a zonal wind reversal of ~ (–25) m/s at 60°N and 10 hPa, is observed. In the tropical lower mesosphere, a maximum zonal wind reversal (–24 m/s) compared with that identified in the extra-tropical regions was observed. Moreover, a time delay in the wind reversal between the tropical/polar stations and the mid-latitudes was detected. The wind reversal in the mesosphere is due to the propagation of dominant intra-seasonal oscillations (ISOs) of 30–60-days and the presence and superposition of 8-day period planetary waves (PWs). The ISOs phase propagation is observed from the high- to low-latitudes (60°N to 20°N) in contrast to 8-day PWs phase propagation, indicating the change in the meridional propagation of winds during SSW. However, the superposition of dominant ISOs and weak 8-day PWs could be responsible for the delay of the wind reversal in the tropical mesosphere. Therefore, this study has strong implications for understanding the reversed (polar to tropical) mesospheric meridional circulation during SSW.

Investigation on the Middle atmosphere Tidal variability during September 2019 Southern Hemisphere minor Sudden Stratospheric Warming

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Tidal variability in the middle atmosphere during September 2019 Southern hemisphere minor sudden stratospheric warming (SSW) is investigated utilizing ground-based meteor radar wind observations from the equatorial, extratropical, middle, and high latitude stations and reanalysis dataset. The poleward warming moves from the mesosphere to the stratosphere before the onset of SSW. The diurnal and semidiurnal tides at individual observational sites do not exhibit any significant response to the warming event, but a notable response in some specific zonal wavenumber components, i. e., DW1 (migrating diurnal tide), DE3 (nonmigrating eastward wavenumber 3 diurnal tide), and SW2 (migrating semidiurnal tide) is found in the global reanalysis dataset. The DW1 enhances during the post-warming days in the mesosphere and lower thermosphere (MLT) possibly due to increased water vapor at all the meteor radar observing locations. The DE3 amplitude at mid and high latitude shows a contrasting behavior with respect to the low latitude in the MLT i.e., a decrease in the amplitude at mid and high latitudes concurrent with an increase at low latitudes during the post-warming phase. SSW-related convective activity variability may explain the observed DE3 variability. In general, the SW2 amplitude diminishes during the post-warming interval in the MLT, possibly due to the weakening and subsequent reversal of the zonal wind and reduction in ozone concentration. The present study entails the disparate responses between the local tidal dynamics at individual observational locations and the global tidal variability in connection with the SSW.

Reverse Ray Tracing of Mesospheric Gravity Waves Observed Over the Indian Equatorial Region

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Gravity wave observations by all-sky airglow imaging of OH emission from Tirunelveli (8.7°N, 77.8°E) during the year 2007 were considered for this work. The characteristics of the observed wave events were presented in an earlier work by *Narayanan et al.* (2013). A total of 260 wave events were observed during this period. The whole dataset from the previous work is used here to examine the extent of lower atmospheric forcing. The background wind information was obtained from the co-located medium frequency (MF) radar using which the intrinsic wave parameters are estimated. The horizontal wavelengths for the observed wave events were in the range of 10-50 km, the periods ranged from 3 to 40 min and the phase speeds were in the range 20-150 m/s. The present work is an effort to study the propagation of those observed gravity waves through the middle atmosphere and also to assess their source regions using a reverse ray tracing technique. The Horizontal Wind Model-14 (HWM-14) for background wind and NRLMSIS-00 model for temperature were also used in the present analysis. The reverse ray tracing analysis was carried out for two scenarios: i) With HWM winds and ii) No wind condition. The initial results showed that majority of the ray paths stopped in the mesosphere at levels where the imposed condition of the square of the vertical wavenumber less than 0 (m^2<0) is met. Further results and a discussion on the nature of identified waves and their corresponding sources are presented in this study.

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Ionospheric disturbances triggered by tropical cyclones over India during 2014-2021

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Abstract

Tropical cyclones can generate wide spectrum of gravity waves which can transfer the energy and momentum to higher altitudes under favourbale wind conditions and can perturb the ionosphere-thermosphere system. Particularly, it is important to decipher the propagation of the low-amplitude perturbations within Indian tropical zone, where the equatorial ionization anomaly dominates the day-to-day variability. The present study mainly focus on 11 events of severe to very severe tropical cyclones over Indian region which induced perturbations in the GPS based total electron content (TEC). The main results include varying structures of gravity waves like concentric gravity waves (CGWs) and linear stariations, which are observed first at the stratospheric altitudes. The brightness temperature from AIRS and synchronized, simultaneous perturbations in ionospheric VTEC are found to peak intermittently during the cyclone periods. The results from severe cyclonic storm Hudhud occurred during 7-14 October 2014 are presented as a case study. During Hudhud cyclone, the AIRS observations show stratospheric perturbations in form of CGWs at varying mean radial distance between ~730-2500 km with horizontal wavelengths between 307-541 km and also episodic perturbations in TEC are observed on 10, 11 and 12 October. The band-pass filtered daytime TEC variations are employed uniquely to a wavelet analysis compositely derived from the west and east side of the eye of the cyclone. It shows enhancement in power associated with periods of ~30-40 minutes when the eye of the cyclone moves closer to either side of stations. The radial phase speeds of the ionospheric TEC perturbations for a spectrum of different temporal bands are found to vary between 70 and 230 m/s at different intervals during 10-12 October. Similar kind of is performed for other 10 cyclonic stroms and statistical results on the wave parametrs in AIRS and TEC are obtained. The observations evidently indicate towards coupling between the GWs/CGWs and its wave-like imprints in the VTEC, however, not all the cyclones always produce similar or systematic pertuations in all the directions. So more invesitgations using the variability of the lower atmospheric winds, vertical profile of electron density and dense GPS receivers are needful to understand a pattern that could arise in ionosphere during a severe tropical cyclone.

Spectral Analysis of the Phase Velocity Distribution of AGWs and MSTIDs in Airglow Images at Darwin, Australia, and Sata, Japan

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Atmospheric gravity waves (AGWs) and medium-scale traveling ionospheric disturbances (MSTIDs) in the upper atmosphere affect the atmospheric circulation and the radio-wave transmission including satellite positioning. These waves can be observed in nocturnal airglow images. Thus, spectral analysis of airglow images provides propagation direction and intensity of these waves. In this study, we calculated the horizontal phase velocity distribution of AGWs in the mesosphere-lower-thermosphere (MLT) at 90-100 km altitude, and MSTIDs in the F-region ionosphere at 200-300 km altitude by applying the 3-dimensional spectral analysis method of Matsuda et al. [JGR, 2014] to the airglow images obtained at Darwin (12.4°S, 131.0°E) in Australia from 2001 to 2019 and Sata (31.0°N, 130.7°E) in Japan from 2000 to 2020.

The spectra of AGWs in the MLT region show clear characteristics that the poleward power spectral density (PSD) is stronger in summer and weaker in winter at both stations. Tropospheric convection was located at north of Darwin in summer and above Darwin in winter, suggesting that the tropospheric convection is a possible source of AGWs in the MLT region.

The spectra of F-region MSTIDs show that the westward PSD is stronger in summer at both stations. The stronger PSD in summer in Darwin is different from previous and present observations of stronger PSD in summer over Japan, if we consider symmetry of MSTIDs between northern and southern hemispheres. A weak positive correlation was observed between PSDs of MLT region AGWs and higher F-region MSTIDs at Darwin, suggesting partial connection between the AGWs and MSTIDs separated by over 100 km in altitude.

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Ionospheric response against Tonga volcanic eruption observed over South America

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A huge volcanic eruption occurred at the Volcano Hunga Tonga-Hunga Ha'apai, South Pacific-Ocean (20.6 S, 175.4W), on 15 January 2022 at 04:15 UT, provoked a variety of atmospheric waves: Earthquakes, atmospheric pressure waves (Lamb mode), acoustic and internal gravity waves. These waves propagated from the troposphere to ionosphere in global scale, those provided us a rare opportunity to understand the dynamical processes in the atmosphere as a whole system. From the south American sector, we observed at least 9 different travelling ionospheric disturbances (TIDS) those related to Tsunami and Lamb waves. They are stating from the SW of the Chile sector propagating toward the equator, interacting with the equatorial ionosphere. We present a general feature of the observed TIDs and to study possible influence of the Tsunami and Lamb waves in the equatorial ionosphere.

The vertical structure of quasi-6 day wave in neutral wind and temperature and the corresponding oscillation in column O/N2

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The quasi-6-day wave (Q6DW) is driven by planetary wave (PW) with period around 6 days. The creation of Q6DW are related to background atmosphere and amplifications of the atmospheric instability. The signature of Q6DW has been observed in neutral atmosphere and ionosphere, which demonstrates the mesosphere-ionosphere-thermosphere coupling. This study focuses on a period in April 2020, with significant Q6DW in neutral winds and tempera ture (TN) observed by Ionospheric Connection Explorer (ICON). We report the continuous vertical structure of Q6DW from 90 to 180 km in zonal wind the for first time. The upward propagating feature is identified in zonal wind and TN, but not in meridional wind. The latitudinal preference of the wind the temperature is consistent with the 6-day normal mode in classic tidal theory. During the same period, column O/N2 from Global-scale Observations of the Limb and Disk (GOLD) shows quasi-6-day oscillation(Q6DO) at mid-high latitudes, suggesting the response of the neutral composition to the Q6DW in a broad latitudinal range.

Dynamical mechanisms for zonal mean wind responses in the thermosphere to doubled CO2 concentration.

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The thermosphere is cooling with increasing CO2 concentration, while the troposphere is warming. Although the thermal cooling due to increased CO2 concentration is understood well, the dynamical response in the thermosphere remains unclear. Recently, Liu et al. (2020) explored doubled CO2 concentration effects on the thermospheric circulation using model simulations with the whole atmosphere model GAIA (Ground-to-topside Atmosphere Ionosphere model for Aeronomy, Jin et al., 2011). The simulation results revealed a strengthening of the zonal mean meridional wind by 5-15 ms-1, along with a strengthening of the zonal mean zonal wind in the lower thermosphere below ~150 km altitude at solstice. The purpose of this study is to explore the detailed underlying mechanisms for the strengthening of the zonal mean winds in terms of momentum balance.

Our analysis shows that ion drag, molecular viscosity, and meridional pressure gradient force vary 3-20 times more than the other forces due to the doubled CO2 concentration. The three forces strongly attenuate each other; consequently, the increase in zonal mean zonal ion drag dominantly strengthens the southward wind (~15 ms-1 at maximum) in the northern (summer) hemisphere and latitudes north of 35°S. This strengthened ion drag was attributed to increased ion density/relative velocity between ions and neutral particles in the northern/southern hemisphere. Southward of 35°S, the zonal pressure gradient force and the meridional advection of zonal wind strengthen the southward wind by 4-12 ms-1 in total. On the other hand, the zonal wind is mainly altered by increased meridional pressure gradient force (~15 ms-1 at maximum) caused by a latitudinally asymmetric response of the thermosphere density to increasing CO2. Our presentation will show those results and the underlying trigger for the wind responses to increasing CO2 concentration.

Effect of Equatorial Electric Fields seen in the Latitudinal Movement of the OI 630 nm Nocturnal Emissions over Indian Longitude

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OI 630 nm nightglow emissions (redline) act as tracers of the ionosphere-thermosphere regions. These emissions have been observed over a low latitudinal region Mt. Abu (24.6^o N, 72.7^o E, 16^o Mag N), a location situated typically under the northern crest of the equatorial ionization anomaly (EIA). High Throughput Imaging Echelle Spectrograph (HiTIES), an optical slit spectrograph, is used to observe this nocturnal redline emissions. The slit of HiTIES is oriented in the north-south direction, therefore, it is capable to observe the latitudinal variation in this thermospheric emissions. During the observation period in a high solar active epoch (2014), the northern-side of Mt. Abu showed larger emissions as compared to the southern-side after the sunset time. The northward movement of the emissions has been observed for around of an hour after the sunset in response to pre-reversal enhancement (PRE). After that, a reversal in OI 630 nm emissions towards the equator has been noticed. The equatorial electrodynamics, like EIA, PRE have been studied to understand both the northward and equatorward movement of the OI 630 nm emissions. The speeds of the reverse movement have been calculated to be in the range of 10-55 ms^{-1} but without any relation to the strength of EIA or PRE. In this background, this motion is inferred to be due to the nighttime westward electric field. These results will be discussed.

Zonal Winds in the Lower Ionosphere and Their Effects on EEJ Return Currents: An Observational Study Using ICON/MIGHTI And Swarm

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The Equatorial Electrojet (EEJ) return currents are westward currents flowing at either side of the dip equator. The present study focuses on understanding the effect of local zonal winds at E to lower-F region altitudes on the intensity of these currents. The zonal wind measurements taken by the MIGHTI instrument onboard the ICON satellite and the latitudinal profile of EEJ currents given by the Swarm satellites are utilized for this study. The vertical gradient in zonal wind velocity at the altitudes where Pedersen conductivity dominates plays a major role in increasing or decreasing the return current intensity. Using the MIGHTI winds along with the equatorial electric field estimated by the Swarm observations in the Richmond (1973) EEJ model produces return currents considerably weaker than those observed by Swarm. The model shows that only the gradient in wind velocity is important in determining the return current magnitude. The dependence of the return current on the vertical gradient in the zonal wind for different solar cycle conditions will also be presented.

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Geomagnetically induced current (GIC) at low latitudes: Major characteristics and prediction for extreme events

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Geomagnetically induced current (GIC) is one of the major concerns originating in solar eruptions. Many high-latitude countries have taken measures to prevent the hazard of GIC. For example, in the United States of America, vulnerability assessment of power transformers has been suggested to perform on the basis of the large magnetic storm of March 1989. At low latitudes, like Japan, the power grid has been though to be safe against GIC because of a great distance from the auroral oval. However, recent studies have overturned conventional wisdom. The GIC with amplitude of 129 A was recorded at a Japanese power plant during the October 2003 magnetic storm [1]. Fortunately, no damage was reported in association with the large-amplitude of GIC. We have conducted observations of GIC flowing at 5 substations of the Japanese 500 kV power grid since 2017 [2]. The GIC are shown to increase during the SCs and storm main phases. Contributions from the solar flare effects (SFEs) and bay disturbances are minor [2]. GIC flowing at the substations are found to be reasonably represented by a linear combination of the geoelectric field on the ground [3]. The geoelectric field can be obtained by a convolution of the variations of the geomagnetic field. Thus, we can predict GIC on the basis of the variations of the geomagnetic field. These models were applied for the variations of the geomagnetic field recorded at Colaba (India) during the extremely large magnetic storm of September 1859 (Carrington event). If the Carrington event occurs again, the geoelectric field would reach ~2.5 V/km at Kakioka Magnetic Observatory, Japan [3], resulting in several hundreds of A of GIC at the same power facility [1][3]. This estimation suggests that the low-latitude countries have to care about, at least, the Carrington-class event. We overview the recently achieved scientific advances on GIC as well as administrative activities led by the Ministry of Internal Affairs and Communications of Japan.

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Anomalous Electric Field Perturbations during Post-Sunset Hours over Indian Dip Equator

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During a minor geomagnetic storm in December, 2014, anomalous electric field polarities of the F region electric field are observed over the Indian sector. We analyzed the night-time vertical drifts over the Indian dip equatorial station, Tirunelveli (8.7° N, 77.7° E, dip angle 1.7°) during the period of 21-24 December 2014 to find the evening and pre/post-midnight space weather induced electric field perturbations over the dip equator. We observe strong eastward and westward perturbations in the zonal electric field on 24 December. During this event, PRE gets enhanced due to an enhanced prompt penetration electric field arising out of the southward transition of the Z-component of interplanetary magnetic field (IMF Bz). However, during the periods 19-20 LT, the vertical drift reaches and stays near zero while the amplitude of the southward IMF Bz increases. This variation in equatorial vertical drift is anomalous as with the increase in the southward IMF Bz magnitude, the vertical drift does not increase while enhancement of the eastward prompt penetration electric field is expected. Therefore, it is clear that instead of eastward penetration electric field, westward electric field penetrated into equatorial ionosphere at this time. Moreover, as IMF Bz becomes less southward after 2000 LT, the vertical drift starts to increase and reaches the level of PRE at 2100 LT. This is also anomalous as the enhancement of the zonal electric field in this case is apparently associated with the decrease of the prompt penetration electric field magnitude associated with the weakening of the southward IMF Bz. The effects of these anomalous equatorial electric field variations were also observed in the vertical total electron content (VTEC) over Ahmedabad (23° N, 72.6° E, dip angle 35.2°) and OI 630.0 nm airglow intensity over Mt. Abu (24.6o N, 72.7o E, dip angle 38.0o). These stations are closed to the crest region of the equatorial ionization anomaly. In this presentation, the cause (s) of these anomalous equatorial electric field perturbations and their impact on the low latitude F region plasma distributions will be discussed.

Ionospheric Total Electron Content (TEC) Gradient Characterization in Magnetic Low Latitude Region

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Global navigation satellite system (GNSS) has been widely used in various systems as an infrastructure. Air navigation is one of such applications. Because current air navigation systems are based on the single frequency GNSS, they are susceptible to the ionospheric effects. To mitigate various threats including the propagation delay effect by the ionosphere, augmentation systems are required to use GNSS for air navigation. GBAS (Ground-based augmentation system) is one of the augmentation systems for aviation use based on the differential GNSS technique. It is known that the equatorial plasma bubbles (EPBs) often occurs in the low magnetic latitude region and accompany sharp changes of the total electron content (TEC) equivalent to the ionospheric delay which we call the ionospheric delay gradient. Because the ionospheric delay gradient may cause differential correction errors, such ionospheric delay gradient must be detected and excluded. To design a safe and operationally usable systems, ionospheric delay gradients must be characterized based on observations. International Civil Aviation Organization (ICAO) has conducted data collection and analysis to establish an ionospheric delay gradient model (ionospheric threat model) for GBAS in the Asia-Pacific (APAC) region [1]. It treats all the equatorial and low latitude regions together. However, due to spatial variations in background TEC most eminently represented by the equatorial ionization anomaly (EIA), the ionospheric delay gradient would also change significantly when plasma bubbles develop into the EIA region. Therefore, the ICAO APAC model is a conservative model and local optimization of the model could reasonably reduce the conservativeness. Therefore, more observations in different locations within the equatorial and low magnetic latitude regions are necessary.

Because GBAS is a local augmentation system for use around an airport, the TEC gradients of scale sizes of about 10 km is important. Therefore, observations of closely distributed GNSS receivers are necessary. We have started observations at Hanoi (21.0N, 105.8E, 16.9Mag.Lat.), Vietnam and at Bandung (-6.9N, 107.5E, -16.4Mag.Lat.), Indonesia.In this paper, we would like to introduce the observation systems of Vietnam and of Indonesia and will show some preliminary results.

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The dayside ionospheric-thermospheric changes during minor geomagnetic storm activity of 3 - 4 February 2022

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The sunspot AR2936 erupted halo CME on 30 January 2022, which struck the Earth's magnetic field on 01 February 2022. The G1-class storms were observed on 3 and 4 February 2022 when the Earth's passed through the wake region of CME. The minor storm observed on 4 February continued on 5 February 2022 as the Earth entered into a high-speed solar wind stream. The present study is aimed to investigate the dayside ionospheric-thermospheric response to this minor geomagnetic storm activity by using the Global Positioning System (GPS) – total electron content (TEC) and Global-scale Observations of the Limb and Disk (GOLD) mission measured O/N2 over the American sector. Our results suggest that the competing effects between storms and season controlled the thermospheric neutral composition changes which reflected well into the electron density variations. In addition to these, the storm time electrodynamical changes over the American low latitudes also played a major role in inducing observed TEC variations. The observational results are compared with the TIE-GCM model output. The present study is one of its kind which demonstrate that G1-class storm can also produce significant electron density variations at low latitudes and also the efficiency of model in deriving large scale ionospheric-thermospheric changes at low latitudes during minor storm activity.

Evolution and Decay of an EMSTID During Two Consecutive Substorms: A Case Study

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Nighttime electrified medium scale traveling ionospheric disturbances (EMSTIDs), ionospheric irregularities generated in the mid-latitude F-region, have been extensively studied using techniques such as airglow, ionosonde, radar, GPS-TEC, etc. EMSTIDs usually originate during geomagnetic quiet periods. On a moderately geomagnetic active night (Ap=24) of 26 October 2019, the airglow imager over Hanle (32.7°N, 78.9°E; Mlat. ~24.1°N), Leh Ladakh, India recorded the evolution and decay of an EMSTID within a short time span of one and half hours (in between 14:08:37-15:48:38 UT). Along with the evolution and decay of the observed EMSTID, the overall intensity of the airglow images decreased during 13:31:07-14:33:37 UT whereas, it increased during 14:39:52-15:17:22 UT. In addition, steep rise and fall of the virtual base height (h’F) of the ionospheric F layer were also recorded by a nearby digisonde at New Delhi (28.70°N, 77.10°E; Mlat. ~20.2°N) during 13.75-14.5 UT and 14.5-15.5 UT respectively on that night. The most important aspect of the event was the occurrence of the two consecutive substorms during the same period. In this study, we have explored the role of the prompt penetration electric field (PPEF) on the evolution and decay of the EMSTID over the transition region of geomagnetic low-mid latitudes. This study provides crucial information about the role of PPEF on the mid-latitude ionospheric irregularities and helps to understand the complex coupling between auroral and low-mid latitude regions. Detailed results from the study will be discussed in the meeting.

2020 September Geomagnetic Storm's effect on the Nighttime Equatorial Ionization Anomaly (EIA) and Equatorial Plasma Bubbles (EPBs) as Observed by the GOLD Mission

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The present study investigates the effects of the 2020 September geomagnetic storm on the nighttime ionosphere over the South American, Atlantic, and West African longitude sectors, using 135.6 nm emission nighttime images taken by NASA's GOLD (Global-scale Observations of the Limb and Disk) imager. From the images, northern and southern crest latitudes of the Equatorial Ionization Anomaly (EIA) are obtained for all nights of September 2020. We have calculated the shifts in the EIA crest latitudes on the geomagnetically disturbed nights compared to the average latitude obtained from the undisturbed nights. On 27th September the poleward shifts in the EIA crests were maximum and the EIA crests were brightest. Further, we have obtained the locations of the Equatorial Plasma Bubbles (EPBs) on all the days of this month. More EPBs are observed during the geomagnetic active days. The maximum number of EPBs was observed on 27th September. On this evening the solar wind conditions were favorable for the penetration of interplanetary electric fields to the equatorial ionosphere over the longitude sector where GOLD takes the measurements. The penetrated electric field strengthened the prereversal enhancement of the zonal electric field and thereby enhanced the plasma fountain which is confirmed by the electric field data and ionosonde measurements. This study reports the first simultaneous investigation of EIA morphology and EPB occurrences during a geomagnetic storm period.

Effect of Geomagnetic Storm Associated HILDCAA Events on Radiative Cooling by Nitric Oxide Infrared Emissions in the Mid-High Latitude MLT Region

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Thermospheric infrared radiative cooling by Nitric Oxide (NO) plays an important role in maintaining the energy budget of the earth's upper atmosphere during space weather events. This study presents the results of radiative cooling by NO during geomagnetic storm associated HILDCAA (High Intensity Long Duration Continuous Auroral Activities) events and tries to compare it with the radiative cooling pattern during individual isolated geomagnetic storm. The lower thermospheric cooling pattern of NO radiative emissions observed during geomagnetic storms associated with HILDCAAs are found to be significantly different from that observed during an isolated moderate geomagnetic storm. We have considered two moderate ($SYM\text{-}H_{min}$ -80 nT; April 2005 (event-1), and -65 nT; December 2006 (event-2)) and an intense (Dst_{min} -150 nT; May-Jun 2000 (event-3)) geomagnetic storms for this study. A HILDCAA event is present in the recovery phase of all these storms. We have utilized the TIMED/SABER (Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics/Sounding of the Atmosphere using Broadband Emission Radiometry), Envisat/MIPAS (The Michelson Interferometer for Passive Atmospheric Sounding), and SNOE (Student Nitric Oxide explorer) observations for this study.

The strength of radiative cooling by NO is mainly attributed to the variation in temperature, atomic oxygen density, and NO abundance during space weather events. Although, the energy coupling between solar wind and magnetosphere is stronger during the main phase of moderate geomagnetic storms (event-1 and event-2), both the heating and Nitric Oxide raditive cooling have been found to be maximum during the associated HILDCAA event in the recovery phase of these storms. Comprehensive thermospheric-ionospheric numerical models, such as TIE-GCM and WACCM-X estimate a good correlation between NO density, its collisional excitation rate through O, and the subsequent emission rate, with the SABER observations of radiative emission. Atmospheric chemistry-based thermospheric NO radiative emission model which uses background densities from models such as NRLMSISE, IRI-2016, and SNOE measurements has been used to calculate the NO cooling emission rates during event-3 (Intense storm). This model shows the higher amount of NO cooling emissions during the main phase of the storm as expected, which also agrees with the TIE-GCM modelled NO cooling emissions.

Large Scale Traveling Ionospheric Disturbances in the Topside Ionosphere

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Understanding the formation, progression, and global impact of Large Scale Traveling Atmospheric/Ionospheric Disturbances (LSTADs/LSTIDs) is a long-standing challenge in global space weather research. This has been a particularly perplexing problem due to the strongly coupled nature of the high-latitude ionosphere-thermosphere (I-T) system, where they are believed to originate from. At high latitudes, the magnetosphere dumps a large amount of energy (both directly and indirectly) into the I-T system through Joule heating, auroral particle heating, and ion drag. LSTADs are a commonly observed thermospheric response to magnetospheric energy entering the I-T system. It is believed that LSTADs drive a similar wave response in the ionosphere, known as LSTIDs. Recent studies suggest that LSTADs/LSTIDs may also play an important role in transporting high-latitude variability to lower latitudes.

This study examines the impact of LSTIDs propagating from higher latitudes on the topside equatorial ionosphere. The altitude variation of LSTIDs is investigated using a combination of observational and modeling methods. The geomagnetic storms that occurred on the 25-26 March 2014 are used as a case study, as several Low Earth Orbit (LEO) satellites with orbits at different altitudes in the topside ionosphere were operational. The variations seen in the observations are then explored using model runs, which further allow a more detailed analysis of altitude variations once their variations are validated against the observational data.

Generation Mechanisms of Plasma Density Irregularity in the Equatorial Ionosphere During a Geomagnetic Storm on 21–22 December 2014

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The equatorial ionosphere endured plasma density irregularities during a geomagnetic storm on 21–22 December 2014. To understand the underlying mechanism, we analyzed the rate of the total electron content change (ROTI) data obtained from a global navigation satellite system, along with solar wind, interplanetary magnetic field (IMF), geomagnetic indices, Jicamarca incoherent scatter radar, and magnetometer data. The results indicate that the ROTI enhancement related to plasma density irregularities (plasma bubbles) occurred three times in the equatorial and low latitude regions of the American sector during the geomagnetic storm. The first, second, and third enhancements which have a longitudinal extent of ~20° appeared in the post-sunset, pre-midnight, and post-midnight sectors, respectively. The second enhancement occurred during the recovery phase of the storm-time substorm even though the IMF remained southward. During this period, the direction of the dayside equatorial electrojet (EEJ) changed from eastward to westward, while the nightside upward plasma velocity at Jicamarca increased to 28.8 m/s. The response of the EEJ and upward ion drift implies that the westward and eastward electric fields were intensified on the dayside and nightside, respectively. Therefore, these results suggest that an over-shielding electric field penetrates the dayside/nightside equator simultaneously in association with a substorm recovery phase, and that the electric field generates plasma bubbles by the Rayleigh-Taylor instability mechanism. Plasma bubbles induced by the penetration of an over-shielding electric field due to substorm activity have not previously been reported.

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Thermosphere-Ionosphere Response to Weak Geomagnetic Storms The Case of the Starlink Satellite Loss in February 2022

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Geomagnetic storms are large-scale perturbations of the magnetosphere-ionosphere-thermosphere coupled system triggered by extreme solar events. Their physical consequences range from enhanced particle precipitation in the polar upper atmosphere and field-aligned currents to disturbances in thermosphere and generation of ground induced electrical currents. From the technological point of view, geomagnetic storms may cause severe damage to satellites and power grids, threatened astronauts in the ISS, and disrupt radiowaves propagation. On 3 February 2022, SpaceX sent 49 Starlink satellites in orbit at about 210 km altitude and during the following days, 40 of them were lost. Two weak geomagnetic storms occurred the same day and the following, yielding an increase in the thermospheric density and thus a larger air drag. This was said to cause a premature re-entry in the atmosphere. We detail the succession of events that supposedly led to this loss. We compare the results of a few thermospheric models with data from low-altitude satellites such as Swarm, Grace-FO and ICON. We discuss the response of the thermosphere-ionosphere coupled system and the possible consequences on low-altitude satellites. In particular, we point out the risks SpaceX run in optimising its launches with a very low injection altitude, allowing very little margin in case of thermospheric density increase.

The Space Weather Impacts on the Ionosphere over the African Mid-latitude Region

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The ionosphere suffers major perturbations during severe space weather events such as Coronal Mass Ejection (CME), solar flares, High speed streams and Corotating Interaction Region (CIR). During severe space weather conditions, the ionosphere can experience depletions or enhancements in Total Electron Content (TEC). The South African National Space Agency (SANSA) near-real time TEC maps [1] were used to show the ionospheric variability during the geomagnetic storm of 3 – 7 November 2021 over the Southern Africa. The digisonde, Global Positioning System (GPS), and the quiet-time AFriTEC model were compared during the five-day period. A negative ionospheric response was observed during the main and recovery phase of the geomagnetic storm (4 – 5 November 2021). The Physical process that leads to the decrease in TEC over the mid-latitude region will be presented. The GPS TEC maps showed a very good agreement with ionosonde measurements and AfriTEC model.

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First detection of daytime E-region disturbance winds

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The middle to low-latitude ionosphere is affected by geomagnetic storms, promptly at their onset and then over the following hours and days, by different processes that occur in the magnetosphere-ionosphere-thermosphere system. As momentum from the solar wind is transferred to the atmosphere through coupling at high latitudes, the ionospheric wind dynamo is affected in ways that can promote high plasma densities at points equatorward. To be significantly effective in modifying daytime electrodynamics, the winds of the disturbance must reach as low as the daytime Hall and Pedersen conductivity peaks around 110 and 130 km altitude respectively. Further, the maximum effects of the disturbance dynamo will only be generated if the momentum forcing leads to a prevailing westward surge in mean winds around these altitudes, which can come naturally from Coriolis forces on bulk transport from high to low latitude. During the ICON mission, we identify dozens of geomagnetic events that drove atmospheric waves to the equator in the F-region, travelling north or south along magnetic meridians from the poles. Of all of these storms, exactly one of these in August of 2021 was accompanied by a significant change in E-region zonal mean winds. Thus, it has to be considered that almost none of the disturbances of the daytime ionosphere in 2020-2021 could be attributed to an enhanced disturbance dynamo. However, large storms that may drive reversal of the global thermopsheric Hadley cells may lay in wait, as the August 2021 event was not "large". However it was unique and further investigation of its characteristics is therefore due.

Day-to-day Changes in Equatorial Electrodynamics and Response to Transient Solar Processes

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The E region dynamo electric field is the primary driver of the electrodynamics of the terrestrial ionosphere region. The difficulty in continuously measuring the electric field variations makes the complete understanding of ionosphere-thermosphere system challenging. In the equatorial ionosphere, the plasma irregularities associated with the equatorial electrojet (EEJ) drift in response to dynamo electric field. The 18MHz HF radar at Thumba (8.5°N, 77°E, 0.5° dip), Trivandrum gives an opportunity to probe the plasma irregularities of 8.3m scale size over the dip equatorial region. The drift velocities estimated from the Doppler shifted backscattered echoes are proportional to the dynamo electric field. The period under study, 2021-2022 which comes under the rising phase of solar cycle 25, has been an ideal period to understand the seasonal variability in the E region electrodynamics and also to study the response of ionosphere-thermosphere system to minor external perturbations in the form of Corotating Interaction Regions (CIRs). Even though there were only very few instances of significant magnetospheric activities akin to storm, there were occasions when the solar wind number density, temperature and magnetic field changed suddenly. Some of these changes being recurrent. This study indicates that these changes in the solar wind, though small, affect the auroral current system significantly, which in turn is observed to produce variability in the Equatorial ionospheric currents/electrodynamics. It is observed that the plasma drifts and dynamo electric field respond to the changes in the magnetospheric processes via High-Low latitude coupling. This study finds that the magnitude of the maximum equatorial electric field/drift on a given day is governed by the extent of maximum equatorward movement of the auroral oval for the day. These results will be presented and discussed in detail.

Correlation Between foEs and Zonal Winds Over Mid-Latitude Stations Using Horizontal Wind Model (HWM14) During Solar Cycle 23-24.

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This study is the extension of our previous work. The critical frequency of the ionospheric sporadic E-layer (foEs) and neutral winds on Earth have been extensively studied, and the disturbed zonal component of wind has been identified as a major phenomenon underlying the propagation of Es layers (particularly in temperate regions). The correlation between median foEs values and zonal winds obtained from the climatological Horizontal Wind Model (HWM14) is investigated. The preliminary investigation focused solely on one value of geomagnetic disturbances. This extension includes spatio-temporal coverage as well as the effect of increased Ap(Kp) index on disturbed zonal winds, which is correlated with mid latitudinal sporadic E layer. The correlation coefficients (cc) increased by at least 10% at mid-latitudinal stations, with cc values dominating in the northern hemisphere. It is expected that ‘cc’ will increase with the increase in the Ap index. As a result, foEs are more prominent during disturbed conditions.

Ionospheric Response to an Intense Geomagnetic Storm (26 August 2018) over Low latitudes and Southern Hemisphere

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Abstract: Solar Cycle 24 was going through a deep minima during 2018, however, a few geomagnetic storms occurred in this year and the shock related to it arrived at Earth's magnetosphere, which resulted an intense storm of 26 August 2018. This storm is significant not only because of the extremely high magnetic activity, but also due to its great impact on the geo-magnetosphere. The ionospheric response to this storm has been investigated using14 GPS receivers at the low latitudes and Polar Regions in the Asian and Antarctica sectors. Analysis of GPS-TEC data during the geomagnetic storm found positive and negative storm effect over low and high latitudes.

The enhancement in VTEC data before the commencement of the geomagnetic storm is observed over all the locations at low and mid-latitude region which is attributed to the pre-storm solar induced events like: solar flare, CMEs, proton events. Observed storm effects whether it is positive or negative during the period of geomagnetic storm could be caused by prompt penetration of electric field, disturbance dynamo electric field, neutral wind composition changes, and storm-induced wind lifting effects which are discussed in this paper. Disturbance in ionospheric TEC during the geomagnetic storm is a major issue in navigation/aviation/communication application using GPS and other satellite communication system at low and high latitudes and advance knowledge of such disturbances is useful to improve them.

Keywords: Geomagnetic storm, Total Electron Contents, GPS, Low latitude, Polar Regions.

Climatology of Global, Hemispheric and Regional electron content variations during the Solar Cycles 23 and 24

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Abstract

We present the results of study on the variations of ionospheric total electron content (TEC) by using global, hemispheric, and regional electron contents computed from the global ionospheric maps (GIMs) for the period from 1999 to 2020. For a low and moderate solar activity, the global and regional electron contents vary linearly with solar 10.7 cm radio flux and EUV flux. While a saturation effect in the electron content verses EUV and F10.7 is found during the high solar activity periods at all regions, the maximum effect is observed at low-latitudes followed by high and mid-latitudes region. The extent of saturation effect is more pronounced for F10.7 as compared to EUV. A wavelet transform is applied to global and hemispheric electron contents to examine the relative strength of different variations. The semi-annual variations dominate in the northern hemisphere, whereas annual variations dominate in the southern counterpart. The amplitude of annual variations in southern hemisphere is found to be higher than northern counterpart at all latitudes. This asymmetry in the amplitude of annual variation is maximum at low-latitudes, followed by mid and high-latitudes, respectively. The semi-annual variations are in-phase in both hemisphere and follow the solar cycle. The northern hemisphere depicts relatively large amplitude of semi-annual variations and exhibit the maximum effect at high-latitudes.

AFRICAN EQUATORIAL IONOSPHERIC STORM-TIME IRREGULARITIES IN EQUINOXES DURING SOLAR CYCLE 24 PEAK

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Ionospheric irregularity is a major source of challenge for trans-ionospheric radiowave propagation. Geomagnetic storms, are known to modify these irregularities. Using the rate of change of TEC index (ROTI) obtained from total electron content (TEC) data inferred from ten (10) stations in the Global Navigation Satellite System (GNSS) service database, the effects of the February and September 2014 storm events (minimum SYM-H index of ~ -100 nT around 2300 UT or ~0130 LT during both events) on the African equatorial ionosphere was investigated. These stations are spread within the Equatorial Ionospheric Anomaly (EIA) region and aligned along the east African sector. There were substantial irregularities during the quiet-time in September unlike in February, but storm-time irregularities deviated from quiet-time observations in both events. The duration of the occurrence of irregularities was 2 hours longer during the night of the main phase than the night of the quiet periods during the February event, while they were almost the same (about 5 hours) during the September event. The irregularities occurred between 1700 UT and 2100 UT, which with higher severity an hour after its apperance and before its disappearance. The recovery phase recorded higher severity of irregularities and longer duration than than the main phase, beginning around 1700 UT and persisting at some stations until 2200 UT. Similar pattern was observed for the September event, but with decreased degree of enhancement. Generally, the highest severity occurred around the EIA crests, but with hemispheric assymetry. There was no inhibition in the African sector during these two events. More case studies will be needed to contribute to the characterization of the African ionospheric irregularities.

Neutral Gravity Wave Dynamics Over Mid-Latitudes

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The mid-latitude upper atmosphere undergoes dramatic changes during geomagnetically disturbed times and witnesses several space weather phenomena e.g., storm enhanced density (SED), stable auroral red arcs (SAR arcs), sub-auroral polarization streams (SAPS), etc. The mid-latitude region lies inside the plasmaspheric boundary and thus, some of these phenomena are a direct consequence of magnetosphere-ionosphere coupling. During geomagnetic storms, the joule heating at high latitudes produces waves in the upper atmosphere which propagates equatorward. These wave perturbations in the form of TADs/TIDs during geomagnetic disturbances affect the upper atmospheric composition by disturbing the plasma and neutral densities. The variations in ion-neutral composition are well captured by airglow emissions. Airglow emissions also enable the investigation of gravity waves present in the medium. $O(^1D)$ 630.0 nm dayglow emissions are the brightest emissions in the daytime upper atmosphere which are produced by the photo-dissociation, photoelectron impact, and dissociative recombination production mechanisms. These daytime $O(^1D)$ emissions show majorly solar flux dependence, but are very sensitive to any changes in the upper atmospheric dynamics also. Therefore, daytime airglow ground-based measurements have been used in this study to investigate these dynamics of plasma and neutrals in the upper atmosphere over mid-latitudes. We present the results from the $O(^1D)$ dayglow emission measurements obtained from Boston (42.36°N, 71.06°W), a mid-latitude station, using a high-spectral imager called the High-resolution imaging echelle spectrograph (HIRISE). The large field of view of the instrument (~140°) has the spatial coverage of around 800 Km in meridional direction and thus permits diagnosis of the neutral gravity wave features, both periodicities and meridional scale sizes. Analysis of OI (630.0 nm) emission line has been performed at various times of existing dataset to quantify the effect of geomagnetic storms on temporal and spatial dayglow variations. The gravity wave periods during 2006 were found to be in the range of 0.5 to 3 hours, with > 1.5 hr for geomagnetic quiet times and < 1.5 hour during geomagnetic disturbances. The meridional scale sizes were > 200 km for quiet and < 200 km for geomagnetic disturbances. Results for different seasons and solar flux conditions will be presented in the backdrop of background geomagnetic conditions.

Study of Equinoctial Asymmetry in Total Electron Content (TEC) for the Two Extremes of Solar Cycle 24

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Due to the Earth's tilted axis of about 23.44°, the events of equinoxes happen two times a year throughout the globe. During these times, the Earth's equator passes through the geometric center of the Sun, resulting in an approximately equal amount of daylight and darkness at all latitudes. Though solar zenith angle and solar activity conditions are almost the same in both spring and autumn equinoxes, yet the ionosphere behaves differently in the two equinoxes. This ionospheric behavior is named as the Equinoctial Asymmetry (different ionospheric parameters in the two equinoxes). Over the past decades, studies regarding ionospheric variation have been modeled, toward seasonal and semiannual variations, along with summer-to-winter and solstice-to-equinox differences using the critical frequency of the F2 layer (foF2), peak electron density (NmF2), and total electron content (TEC) data. In a recent study by Madeeha (under review), EA in F2-layer critical frequency (f_oF2) has been studied for low and mid latitude stations ranges from 20° N – 55° N. In this study, EA behavior during solar minimum (solar cycle 22-23 (1996) and 23-24 (2008)) conditions has been analyzed. Decrease in EA strength with latitude during daytime while during night time, superposition of annual and semi-annual variations at low latitude have been observed at low latitudes whereas annual variations have been noted at mid-latitude. Since ionosonde data is not enough to specify the reason behind EA, TEC provides an opportunity to study the phenomenon in the entire frame. In order to find out the liable mechanisms responsible for Equinoctial asymmetry (EA), EA in Total Electron Content (TEC) during two extremes of solar cycle 24 for low and mid latitude stations ranges from 25° N - 60° N geog. Lat will be analyzed. In preliminary results, values of TEC in March-April are observed to be usually larger than the values in September-October equinoxes in Northern hemisphere. Also, during low solar activity, EA is mainly a low-latitude phenomenon.

Particle Precipitation Effects on the Global Secondary Ozone Distribution

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The secondary ozone layer is a global peak in ozone abundance in the upper mesosphere-lower thermosphere (UMLT) around 90-95 km. Energetic particle precipitation (EPP) from geomagnetic processes is known to influence the primary (stratospheric) and tertiary (mesospheric) ozone layers, but its effect on UMLT ozone has not been well studied. Here we present both climatological and a case study of the effect of EPP on high-, mid- and low-latitude nighttime ozone in the UMLT. Ozone volume mixing rates as well as dynamical and temperature variables were taken from the Microwave Limb Sounder (MLS) on the Aura Earth Observing System satellite and the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on the Thermosphere Ionosphere Mesosphere Energetics Dynamics (TIMED) satellite. In addition, the Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension and specified dynamics (SD-WACCM-X) was used to characterize the residual circulation. These variables were examined during times of high- and low-Ap, as well as during the Solar Proton Event of November 2004, in order to attribute changes in the ozone at low- and mid- lattiudes to EPP induced modifications of either the chemistry or dynamics of the UMLT.

Study of Equatorial Geomagnetic Field Activities and its Relationship with Ionospheric disturbances at Low-Latitude

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Monitoring geomagnetic and ionospheric disturbances has become vital in space weather communities because these disturbances can severely affect the crucial technologies in daily human life, particularly satellite communication and navigation [1]. Global and local geomagnetic activities can also cause ionospheric regularities in low latitude regions; thus, the correlation between the scintillation effects and the geomagnetic activities was investigated in [2]. The characteristics of geomagnetic fields measured in the equatorial Phuket station during high and low solar activity years were studied, and equatorial local K-indices were computed to examine geomagnetic activity [3]. The interplay between geomagnetic fields and ionosphere, particularly at low latitudes in the Asian sector, still needs to be explored more to understand the drivers of the ionospheric disturbances.

Therefore, this work statistically analyzed the equatorial geomagnetic activities during the 24th solar cycle using the observations from the magnetometer installed at Phuket, Thailand (AACGM 1.07°N, 171.15°E). In this work, the descriptive statistics of the geomagnetic fields and local K-index such as monthly and yearly media and the frequency and time of the irregular event occurrence were examined to study the dynamics of the equatorial geomagnetic field. Moreover, we investigated the correlation between the ionospheric disturbances, including scintillation, total electron content (TEC), its standard deviation observed in low-latitude regions of Thailand, and the equatorial geomagnetic activity during low solar activity and high solar activity years. The preliminary results found that there was also a weak correlation between the amplitude scintillation and the geomagnetic activities during 2019 (low solar activity year).

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Assessment of Long-Term Impact of Solar Activity on the Ionosphere Over an African Equatorial GNSS Station

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This paper examines the long-term solar activity impact on the ionosphere over an African equatorial global navigation satellite system (GNSS) station based on a large database of solar and ionospheric datasets. The ionospheric total electron content (TEC) periodic variations, climatology and its relation to solar activity are investigated through wavelet analyses. It is observed that the magnitude and intensity of TEC fluctuations measured by GNSS receivers vary substantially with solar radiation intensity. To probe the processes accountable for the TEC periodicities in the region, the wavelet analysis is undertaken by considering solar indices (solar radio flux and sunspot number) and observed TEC values. The results show a clear strong periodicity of 16 days and 27 days in the ionospheric TEC, sunspots and F10.7 solar flux power spectra. The 16 days periodicity is associated with the lunar tidal effect, while the 27 days periodicity is associated with the sun's 27 days rotation period. The ultraviolet ray intensity and solar ionization were lower during the solar maximum period (2013 to 2014) of solar cycle 24 compared to the solar maximum period (2001 to 2002) of solar cycle 23, which is the key factor for driving the decreasing trend in TEC between 1999 and 2017. The ionospheric and solar climatology analysis indicates that ionospheric TEC behaviour could be a good indicator of long-term solar activity trend. A large mass of Africa lies within the equatorial and low latitudes making the ionosphere over the region being highly susceptible to low latitude electrodynamics. Results from this study would support the concerted efforts towards developing a reliable regional ionospheric forecasting model.

The observations of localize ionospheric scintillation structure by FORMOSAT-7/COSMIC-2 beacon and GNSS network

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The localized scintillation structure where the radio signals are affected by irregularities is recognized. Irregularities in the ionosphere will affect a radio transmission traveling through it. The open-source coherent beacon receiver[1] may receive beacon signals from beacon satellite systems such as the FORMOSAT-3/COSMIC Tri-band Beacon Transmitter (150, 400, 1066.7 MHz) or the FORMOSAT-7/COSMIC-2 Tri-band Beacon Transmitter (150, 400, 1066.7 MHz) (400, 965, and 2200 MHz) and 160 gnss stations network. In Taiwan, the three beacon stations of were located around 360 kilometers apart in a north-south direction. We can recognize the localize scintillation position where the radio signals are affected by abnormalities by projecting the course of the satellite's orbit. Because the maximum potential height in the F2 layer is 350 km, the height was previously believed to be 350 km. We apply a project method to approximate the realistic height and length from the 3 stations by a scintillation case near midnight in order to improve on this assumption. As a result, the height of scintillation would be confirmed using the project approach, whether in the F layer or the E layer.

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Validation of NeQuick 2 model over Brazil using GNSS-derived Total Electron Content

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Considering the unique geometry of the geomagnetic fields near the magnetic equator and low-latitude regions, the satellite communication systems such as GNSS (Global Navigation Satellite System) and other related radio systems in the Brazilian sector are strongly affected by the effects of the solar and geomagnetic activities. The first-order delay caused by the ionosphere is proportional to the Total Electron Content (TEC) along the signal path between the satellite and the receiver. As a result, precise modeling of the ionospheric TEC is very important and remains a challenge for positioning and navigation systems such as GNSS. Hence, this study investigates the performance of the NeQuick 2 model for the prediction of TEC variation during high and moderate solar activities. GPS data from a station located at the magnetic equator has been ingested in the NeQuick model for ionospheric correction over this region. The results of the diurnal and seasonal variations have been presented considering both equinoxes and solstices. The diurnal variation in both observation and model presents the day-to-night variation with higher values of VTEC during the day and lower values at night. Seasonal variation showed a peak in equinox and a minimum in the solstice. The comparison between the GPS-TEC and NeQuick 2 model revealed a great improvement in the model after data ingestion.

The LLITED Mission: Part of the Growing Grass-Roots Ionosphere/Thermosphere Constellation

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The LLITED mission will provide both ionosphere and thermosphere measurements with the goal of better understanding the coupling between the Equatorial Ionization Anomaly (EIA) and the Equatorial Temperature and Wind Anomaly (ETWA). While the EIA and ETWA are form and are maintained throughout the day, they also persist for a time post-sunset. LLITED will observe the phenomenon at this later time in order to better understand its coupling and dissipation. LLITED will, for the first time from a CubeSat, provide coincident high-resolution measurements of the dusk side ionosphere/thermosphere (IT) at lower altitudes that will characterize and improve our understanding of the ETWA, provide insight into the coupling physics between the ETWA and EIA, and increase our knowledge of the dusk side dynamics that may influence space weather.

The LLITED mission consists of two 1.5U CubeSats in a high-inclination circular orbit hosting three payloads each: an ionization gauge (IG), planar ion probe (PIP), and GPS radio occultation sensor (GPSRO). In addition to provide a focused study on the EIA/ETWA, LLITED will be one of over a dozen more IT CubeSat mission that will fly in the next few years resulting in a unique grass-roots IT constellation that will enable exploration of different parts of the IT system. This presentation will discuss the LLITED mission, the growing IT constellation of CubeSats, and how to better utilize and visualize the data from the constellation.

Key Observations and Discoveries from the Vector Electric Field Investigation on the C/NOFS Satellite

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Launched in 2008 and operating for 7.5 years, the Air Force Communication /Navigation Outage Forecasting System (C/NOFS) satellite included the Vector Electric Field Investigation (VEFI) designed and built at NASA's Goddard Space Flight Center [1]. VEFI successfully met its objectives: 1) investigate the role of ambient electric fields in initiating nighttime density depletions and turbulence; 2) determine the quasi-DC electric fields associated with abrupt density depletions, and 3) quantify the spectrum of the irregularities associated with density depletions, providing many key observations and discoveries including:

-- Global (low latitude) vector DC electric fields at 16 s/sec revealing variations with local time, longitude, and season between extremely low and moderate solar activity
-- Reversed zonal **E** x **B** drifts below the F-region ledge at sunset and simultaneous observations of large scale Kelvin-Helmholtz instabilities as seeds of spread-F
-- Large expanses of quasi-coherent kilometer-scale vector wave observations (electric field and density) below 450 km and their discovery as a source of scintillations using the C/NOFS GPS
-- Reversed zonal DC electric fields and simultaneous observations of afternoon counter electrojet
-- Enhanced zonal DC electric fields at sunrise and full vector plasma flow continuity at the terminator
-- Vector electric field and density irregularities extending to meter-scales within equatorial plasma depletions
-- Intense electric field structure within the equatorial ionosphere at night in the absence of density depletions
-- First observations of the westward equatorial electrojet in post-midnight ionosphere and possible association with downward meridional drifts
-- Spaceborne Dst observations and implications for ring current asymmetries

-- Vector electric and magnetic field Poynting flux within depletions and TIDs

-- Measurements of ionospheric reflectance and Alfvenic waves associated with TIDs

-- Observations of Alfven resonators

-- ULF magnetic field structure within the nightime equatorial ionosphere

-- Discovery of Schumman resonances in space and implications of ELF radiowave propagation

-- Vector observations of 50-60 Hz powerline radiation without harmonics

-- Ion cyclotron resonance absorption lines associated with ELF hiss and the identification of ambient ions

-- Parallel electric fields associated with lower hybrid waves driven by thunderstorm lightning-related sferics

-- Discovery of Z-mode radiation in the equatorial ionosphere including its associated with density depletions

-- Optical lightning detector waveforms and electric field sferics observed up to altitudes of 800 km

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Perpendicular-to-B Incoherent Scatter Spectral Measurements with AMISR-14 at Jicamarca

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Incoherent scatter radar observations with beams pointing perpendicular to the geomagnetic field were recently conducted with the AMISR-14 radar at the Jicamarca Radio Observatory. The AMISR-14 system operates at 445 MHz and can deliver pulses at a nominal peak power of 224 kW. Applying a standard long pulse configuration, F-region spectral measurements were obtained. The spectrum shows a relatively narrow shape with a spectral width in the order of a few kHz. More interesting, spectral peaks at frequencies close to the lower hybrid oscillation were also detected. We have modeled the measured spectra applying the Coulomb collision incoherent scatter spectral approach developed by Milla & Kudeki [2011]. The modeled spectrum shows similar features as the ones obtained with the measurements. In this presentation, we will describe the different experiments conducted to obtain the perpendicular-to-B observations, as well as the efforts to model the spectral measurements. The results show that spectral fitting might be possible to extract physical ionospheric parameters from the measurements.

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New Jicamarca Unattended Low Investigations of the Atmosphere (JULIA) using the new mid-power solid-state transmitters

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The Jicamarca Unattended Low Investigations of the Atmosphere (JULIA) mode has been used at the Jicamarca Radio Observatory - JRO for more than 30 years to study the upper atmosphere by monitoring the coherent equatorial echoes like the Equatorial ElectroJet (EEJ)[1], Equatorial Spread-F (ESF)[2], and the 150 km echoes [3] as proxy to characterize the ionosphere (i.e. horizontal and vertical drifts from 150 km echoes [4]). As part of the improvement that JRO facility, two new 96 kW solid-state transmitters were installed and added to the JULIA unattended mode. During previous tests, the use of 100 kW (mid-power) tube-transmitters allowed to obtained measurements of Incoherent scatter drifts that could reach up to 400 km, but they require continuous monitoring.
The new addition of the two 96 kW transmitter will allow to measure the IS horizontal and vertical drifts continuously in range and time which will contribute to the investigations of the upper-atmosphere directly, and it will also lead us to statistically investigate the years of measurements of drifts obtained from the 150 km echoes, as well as other phenomenon that we will detect from the continuous measurements.

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A Study of Temporal and Spatial Variations of Plasmaspheric Total Electron Content during Geomagnetic Storms by Using the Worldwide GPS Total Electron Content Data

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Total electron content (TEC) is an integration of the electron density along a ray path from satellite to receiver, which can be measured by dual-frequency Global Positioning System (GPS). However, the measured TEC contains inter-frequency biases inherent with satellites and receivers, which cannot be ignored in original TEC. Previous study has developed a method to separate ionospheric TEC from the inter-frequency biases by using the least square fitting procedure.[1] In this method, plasmaspheric TEC (PTEC) is not considered. However, it is known that the PTEC can be 10-50% of the ionospheric TEC. Considering the satellite zenith angle dependence on slant factor which converts the slant TEC to vertical TEC, PTEC could be included in the estimated inter-frequency bias. Therefore, we have analyzed the inter-frequency bias data obtained from approximately 9,000 receivers over the world. A storm on September 2017 has been investigated to compare with Arase satellite observation data.[2] The result is, the variation of PTEC deviation obtained from this study and PTEC obtained from Arase satellite observation data commonly shows that PTEC decreases after the onset of magnetic storm and recovers gradually. PTEC with high spatial and temporal resolutions during geomagnetic storms on March 2013, November 2017 and August 2018 is also investigated. It is shown that the bias at middle and low latitudes decreases during main phase of the three magnetic storms and bias decrease tends to be large at the longitudinal sector which is located in the nightside when the main phase starts. This result indicates occurrence of erosion process in the plasmasphere during the main phase of magnetic storms.[3] Therefore, this study indicates the validity of GPS data on measuring PTEC variations.

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Recent scientific discoveries using the Low-latitude Ionospheric Sensor Network (LISN)

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The LISN network has been operating for over ten years and has provided prominent discoveries of TEC depletions, scintillations, and TIDs. Here, recent observations of TEC, depletions, and scintillations are presented corresponding to 2016. On February 12 and 13, TEC maps reported a non-typical evolution of the otherwise continuous crests of the equatorial ionization anomaly (EIA). The western part of the southern crest faded, and a north-south aligned segment developed near the center of the South American continent, joining the north and south crests of the EIA, forming an anomaly that resembled a closed loop on the eastern side of the continent. Concurrently with the anomaly events, several GPS stations reported increases in the L-band scintillation index from 0.4 to values greater than one. Although the magnetic activity was moderate ($k_p=3^0$), we believe that the anomaly redistribution and the scintillation enhancements are not related to a prompt penetration electric field or disturbance dynamo effect but to enhancing the semidiurnal lunar tide propitiated by the onset of a minor Sudden Stratospheric Warming (SSW) event. It is indicated that depending on the lunar tide phase cycle, the neutral wind's meridional component can augment sub-km scale irregularities and enhance L-band scintillations through the wind gradient instability ($U\cdot\nabla n$).

Performance Analysis of a Strong Constraint 4D-var and 4DEn-var on Imaging the Mid-latitude Regional Ionosphere

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The direct and precise measurement of the ionospheric state is generally not feasible on a large scale. More so, measurements are imperfect and spotty in space (three-dimensional, 3-D) and time. To have a consistent picture of the state, the ionospheric community recently reverted to data assimilation (DA) techniques that can optimally combine a plethora of different types of ionospheric observations with a-priori information (via models, either physics-based models or empirical models) while taking into account the theoretical underpinnings. This paper compares the fidelity of two DA flavours, incremental four dimensional-Variational (Inc-4D-var) and 4D Ensemble-Var (4DEn-Var), in reconstructing the mid-latitudes ionosphere on the St. Patrick's day (17-18th March-2015) solar storm; over the Japanese archipelago and neighbouring areas. The Inc-4D-var approach has been in application for some time, but the non-trivial requirement to compute the Tangent Linear Model and Models Ad-joints makes its implementation cumbersome. The recent introduction of 4DEn-Var has alleviated this problem, thus reducing the computation burden. The electron densities are assumed to take on a log-normal distribution to adequately represent the errors involved and assert the mandatory positivity ionospheric density constraint. For further circumvention of the computation expense, background electrons are drawn from empirical models (Nequick and International reference ionosphere) and forward propagated for short periods (15 minutes) following a Gauss Markov filter.

3-D Imaging of Nighttime E-F Coupling Over Japan by Using Ground-based GNSS-TEC and Ionosondes

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Irregularities in the ionospheric E and F regions are frequently coupled in the nighttime mid-latitude ionosphere, observationally and theoretically. In this paper, a novel three-dimensional (3-D) computerized ionospheric tomography (CIT) technique has been developed to reconstruct the E- and F-region irregularity structures during the E-F coupling process. The CIT relies on total electron content (TEC) from a dense ground-based Global Navigation Satellite System (GNSS) receiver network over the Japan area. To vertically constrain the E- and F-region solutions, we introduced two families of subsets of time-dependent empirical orthogonal functions (EOFs) from a Chapman model function tuned to manually scaled ionosonde observations. We analyzed three event days of nighttime medium-scale traveling ionospheric disturbances (MSTIDs) with different maximum amplitudes. The coexistence, similar Northwest-Southeast (NW-SE) aligned wavefronts, and common propagation parameters of sporadic E (Es) and MSTIDs were observed, supporting the evidence of strong coupling between E and F regions. For the first time, this new technique effectively tracks the height variation of Es and MSTIDs over time. The altitude of F2 peak layer was observed to vary in the range of ~5–50 km, which is anticorrelated with the F-region perturbations. These 3-D reconstruction results suggest that the electrodynamic forces dominate the morphology and dynamics of Es and MSTIDs during the nighttime coupling process.

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CCD-based Daytime Airglow Photometer (CDAP) – A Portable Photometer for Obtaining Daytime OI 630.0 nm Airglow Emissions From the Ground

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A new technique to obtain daytime optical airglow emissions from the ground is described. It is optimized for measuring OI 630.0 nm dayglow emissions that emanate from the thermosphere. In this technique, a low resolution Fabry Perot to etalon is used to function as a high spectral resolution filter to bring in spectral resolution of the order of hundredths of a nanometer at around 630.0nm region. The light from the day sky is first prefiltered using a narrow spectral bandwidth interference filter. The fringe system formed of the Fraunhofer absorption lines on the CCD detector are used to carryout spectral calibration of the system, and thereby the location of the 630.0nm emission line is identified experimentally, which compares well with the optical simulations. As changes in radial distances in the images of the Fabry Perot interference fringes result in a wavelength change, counts from the neighboring radial region is considered to serve as the contribution of the solar scattered background, and this information is used to appropriately account for the background information. In this manner diurnal variations in the OI 630.0nm dayglow emissions have been obtained. These have been compared with the Multiwavelength Imaging Echelle Spectrograph (MISE) [Pallamraju et al., 2013] that is in operation simultaneously from Ahmedabad (23° N, 73° E, 15° MLAT) in Indian longitudes. The emissions from these two instruments show a very clear correspondence with each other. This CCD-based Daytime Airglow Photometer (CDAP) has no moving parts and has been automated for continuous and unattended operations. It is portable and rugged and suitable for both ground and space borne applications.

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Airglow Observations by All-Sky Imagers from the Antarctic Research Vessel "Shirase”

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Global observations of the ionosphere are necessary to understand the temporal and spatial variations of ionospheric phenomena. Satellites are widely used for observations of the ionosphere[1], but there are some disadvantages such as not being able to make continuous observations for low earth orbit satellites and limited observation area for geostationary satellites. Satellite-based observations also have low temporal and spatial resolutions. Ground-based observations of the ionosphere have used all-sky imagers for wide-area observations[2]. The number of ground-based stations is increasing, but they are limited to the land. Thus, the ionosphere over the oceans has not been sufficiently observed. It is necessary to fill these observational gaps with imaging observations of the ionosphere over the ocean from vessels. Vessel-borne all-sky magers which have a function to cancel out the vessel's vibration were developed and installed on the Antarctic research vessel "Shirase" to conduct ionospheric observations. The small imagers (ZWO: ASI 183mm Pro, about 410 g) were mounted on a three-axis attitude stabilized gimbal, and observations were conducted during three round-trip voyages between Japan and Syowa Station in three years. 630.0-nm emissions and 760.0-nm (only in the third year; 670.0-nm in the second year; single-wavelength observation in the first year) emissions were observed with an exposure time of about 20 s (about 10 s only in the second year). 630.0-nm emissions corresponds to atomic oxygen airglow and 670.0-nm and 760.0-nm emissions to the OH airglow band. The images were calibrated and converted into geographical images by assuming emission altitudes (250 km for 630.0-nm emissions, and 100 km for 670.0-nm and 760.0-nm emissions) to identify observed phenomena. Although aurora was successfully observed at high latitudes, this presentation will discuss the results of Equatorial Ionization Anomaly (EIA) observations at low latitudes. We also compare these results with data of total electron content (TEC) observed by the GNSS receiver, which was installed in our system from JARE62.

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Monitoring of Equatorial Plasma Bubbles Using Aeronautical Navigation System

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The formation mechanism of Equatorial Plasma Bubbles (EPBs) has rapidly become better understood through recent numerical simulations. However, it is still difficult to precisely predict the appearance of EPBs on a shorter time scale; thus, it has highly been demanded to develop a method for continuously monitoring the appearance of EPBs in a wide area. It has long been known that field-aligned irregularities within EPBs can cause long-range propagation of radio waves in the VHF frequencies such as those used for TV broadcasting through the so-called forward scattering process [1]. However, no attempt has been made to use such anomalous propagations of VHF radio waves for wide-area, realtime-based monitoring of EPBs. In this study, we investigated the feasibility of wide-area monitoring of EPBs using VHF radio waves used for aeronautical navigation systems such as VHF Omni-directional radio Range (VOR) through actual observations in Japan, Taiwan and Thailand.

There are 370 VOR stations in the Eastern and Southeastern Asian region that can be potentially used as Tx stations for the observations of anomalous propagation. First we have exmined the forward scattering conditions of VHF waves using the magnetic field model and confirmed it possible to observe the EPB-related anomalous propagation if we set up Rx stations in Okinawa (Japan), Taiwan, and Thailand. On the other hand, when receivers are located in the mainland of Japan, the scattering points are not distributed in the low-latitude/equatorial regions where EPBs are expected to reach during the solar minimum.

Test observations were conducted in Okinawa since 2021. Howver, no signals have been received that were clearly caused by anomalous propagation due to EPBs. This is simply because EPBs have not developed to high latitudes during the observation period due to low solar activity. We plan to conduct pilot observations in Taiwan and Thailand in autumn of 2022 to demonstrate the feasibility of this monitoring technique.

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Concept Study for Pan-African Magnetometer Chain

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Several research fields are of value at and near the magnetic equator. Among them the study of the equatorial ionosphere, geomagnetic storms, the Sq-variations and the Equatorial Electrojet (EEJ). The relationship between the global Sq current system and the EEJ, defined as a concentrated eastward electric current superposed on the normal Sq currents[1], is still an ongoing debate. It is best examined using an equatorial station located within the narrow band of the EEJ ±3 degrees and a station several degrees away, but at the same longitude[2]. Sq-amplitudes, mainly in the H-component, are typically 2-3 times larger within ±3 degrees from the magnetic equator than at stations at the same longitude but 6-9 degrees further away latitudinally[2].

There are, however, currently no operating station directly at the magnetic equator in Africa: The existing magnetometer sites at or near the magnetic equator in sub-Saharan Africa, managed by several groups, are currently either inactive and/or low-latitude stations. The installation of dual-magnetometer sites along and near the magnetic equator in Ethiopia is proposed. We will use the data for studying the variability of the EEJ on various time scales (day-to-day, seasonal, ...) in the African sector as well as for modelling of the vertical E x B drift. The latter was studied by Habarulema *et al*[3], and was limited to the South American sector due to the lack of observatories in sub-Saharan Africa.

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Global Bottomside Thickness (B0) and Shape (B1) Parameters from FORMOSAT-7/ COSMIC-2 GNSS Radio Occultations and Comparison with International Reference Ionosphere Model

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The bottomside thickness (B0) and shape (B1) are the two important parameters in the bottomside electron density profile (EDP) specification of the International Reference Ionosphere (IRI) model that is accepted to be the most widely used global empirical ionospheric model. The present work investigates B0 and B1 extracted through the least-square fitting of a huge database of radio occultation (RO) profiles from FORMOSAT-7/COSMIC-2 (F7/C2) during 2021 and 2021, with an initial quality check with the coincident Digisonde soundings. A comparative analysis of the local time diurnal, seasonal, and latitudinal behaviour of B0 and B1 parameters is performed with the estimations from the IRI-2016 submodels: Bil-2000, Gul-1987, and ABT-2009 referring to the bottomside profile characteristics during the low solar activity period of 25th solar cycle. The results reveal daytime underestimation and nighttime overestimation features of IRI submodels. The typical pre-sunrise enhancement in B0 is clearly discernible in the F7/C2 observations which could not be reproduced in any of the IRI submodels. The sharp changeover in B0 magnitude from summer to winter solstice hemisphere and spring to fall equinox hemisphere in Gul-1987 indicates its inability to accurately represent the B0 variation at the equatorial and low latitude sector. With the supported data from F7/C2 and Digisonde, it has been observed that ABT-2009 performs relatively better than Gul-1987 sub-model. However, there are still scopes for possible improvement in terms of B0 and B1 representation.

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Study of the ionospheric spatial correlation

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In this study, we make a study for the Ionospheric spatial correlation scale. Firstly, the ionospheric horizontal spatial correlation study was conducted to collect global TECmap data from TEC Production that provided by the Jet Propulsion Laboratory (JPL). We use the monthly-averaged TEC over the world to calculate the deviation of the TEC and then the spatial correlation coefficient matrix of the deviation is also derived. According to the definition of correlation distance in statistics, the spatial characteristic scale is retrieved in the Zonal and meridian directions, and their variation of solar activity levels, geomagnetic field configuration conditions and seasonal conditions are investigated in details. Then, we using COSMIC occultation data, ion concentration profile data interpolation to establish electronic density three-dimensional grid data, the error covariance matrix of each level, and the error of the ion concentration in the vertical direction help poor matrix, analysis and study its time and space distribution at different heights, and its distribution in the vertical direction, The correlation scale model in the vertical direction of the ionosphere is constructed.

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A Study on the Relationship between the Real-Time Kinematic Positioning Performances and Ionospheric Delay Gradients near the Suvarnabhumi International Airport, Thailand

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Real-time Kinematic Positioning (RTK) is a relative positioning technique that offers centimeter-level accuracy based on the code pseudorange and carrier phase measurements of GNSS signals by computing the position of a rover relative to the precisely known position of the base station. However, the occurrences of equatorial plasma bubbles (EPB) during the post-sunset period may degrade the accuracy of RTK positioning due to the ionospheric delay gradients difference or delay gradients [1] between the rover and base stations. There have been some prior studies on regional ionospheric delay gradients [1-2] in Thailand as well as the RTK positioning errors during the ionospheric disturbed condition at low latitude [3].

In this research, we aim to investigate RTK positioning errors during disturbed hours as well as the relationship between RTK positioning errors and ionospheric delay gradients near the Suvarnabhumi International airport, Bangkok, Thailand. The days with ionospheric disturbance, possibly EPBs in 2021 are based on the Rate of TEC change index (ROTI) and Along the Arc TEC Rate (AATR). The base station is on the King Mongkut's Institute of Technology (KMITL) campus (13.7277° Latitude, 100.7726° Longitude) while the rover station is 12 km away in the East-West direction. We investigate RTK positioning errors using RTKLIB and ionospheric delay gradients using single frequency carrier-based and code-aided method with the experimental configuration using L1 GPS frequency with a 15-degree elevation angle cut off. From the results on five days in March and October of 2021, the 95% horizontal errors are about 50 cm in comparison with about 4 cm during quiet hours. Alternatively, the vertical errors are about 60 cm in comparison with about 8 cm during quiet hours. The positioning errors and ionospheric delay gradients both increase during the ionospheric disturbed hours. The correlation coefficient between the RTK errors and the ionospheric delay gradients at disturbed hours is about 0.6. On the other hand, the correlations between the RTK errors and AATR values are about 0.5.

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Ionospheric Plasma Anomaly Using GPS TEC Measurements Over Nepal

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Ionospheric concentration can be measured as the total electron content (TEC) i.e. the total number of electrons present per square meter along a path between a radio transmitter from a satellite and a receiver. The TEC data for this study are acquired from the UNAVCO GPS network, which is widely distributed across Nepal. The ionospheric TEC fluctuation is primarily influenced by the terrestrial, geomagnetic, and solar activities. This talk covers such ionospheric variabilities using the GPS TEC measurements over Nepal. In order to investigate the ionospheric responses with geomagnetic activities, the TEC are cross-correlated with various geomagnetic indices such as interplanetary magnetic field (Bz), disturbance storm time index (Dst), and auroral electrojet index (AE) during the superstorms events obtained from the ACE satellite observations. Similarly, to examine the eclipse-triggered consequences on TEC in response to the annular solar eclipse, the TEC variability are investigated at different solar eclipse events. Moreover, the presentation will also attempt to find the ionospheric anomalies using the TEC data before and after the great Gorkha Earthquake in Nepal (28.23°N, 84.73°E) with magnitude 7.8 on April 25, 2015.

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A New Approach to Obtain the Daytime Gravity Wave Characteristics in Three-Dimensions

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Gravity waves are considered to be omnipresent in the Earth's upper atmosphere and play a significant role in the neutral dynamics. The investigations of gravity wave dynamics are generally carried out by monitoring the fluctuations in different atmospheric parameters. In this work, we have obtained the three-dimensional propagation characteristics of thermospheric gravity waves in the daytime using collocated optical and radio measurements from Ahmedabad (23^0 N, 73^0 E, 15^0 MLAT), India. The measurements of OI 630.0 nm dayglow emission rates over zenith have been used to derive time periods of gravity waves. Wave number spectral analysis of variation in emission rates over a large field-of-view have been used to derive their scale sizes and propagation characteristics in the horizontal direction. These measured horizontal parameters of gravity waves along with the empirical model-derived neutral winds and atmospheric parameters have been used as inputs to the gravity wave dispersion relation to estimate the vertical scale sizes of these gravity waves. These estimates match well with the independently measured vertical scale sizes from the collocated digisonde that was operating simultaneously. This combined optical and radio measurements provide a new approach to describe the 3-D gravity wave characteristics in the daytime and open up future possibilities to derive neutral winds as the propagation of gravity waves and neutral winds are inter-related. The details of this work will be presented.

Ionospheric Monitoring Using a Low-Cost GNSS Receiver

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Global Navigation Satellite System (GNSS) receivers are widely used for ionospheric monitoring. Nowadays, low-cost commercial GNSS modules can provide raw GNSS data for several positioning engineering applications. The goal of this study is to assess the potential of a low-cost GNSS receiver in ionospheric monitoring with an accuracy close to that of high-grade receiver with clear advantages in cost, size and power consumption. A comparative study between a LeicaGR30 high-grade geodetic receiver, and a low-cost, GNSS Receiver dual-frequency based on a sino gnssK803 OEM product is undertaken to explore the potential of the low-cost devices for sensing the ionosphere. The housing and operation firmware of the low-cost receiver were developed by Cloudwater Ltd. A measurement campaign for several days was carried out in order to investigate the signal strength and total electron content (TEC) estimation. A GNSS signal splitter was connected with the two receivers under test and all data were recorded with a single Leica AR20 choke ring antenna at Klirou which is about 25 Km SW from Nicosia.

New Meteor Observation System using Forward Scatter FM Broadcast

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An inexpensive, low-power, portable, passive and automated meteor detection system is developed and demonstrated which can be highly useful for understanding the meteor phenomena and estimation of atmospheric parameters. This system consists of an open source-based software-defined radio receiver using USRP (universal serial radio peripheral) front end and YAGI antenna. FM signals are recorded on four days in August-September 2020 on 103.2MHz, 104MHz, and 107.5 MHz channels with a varying sample rate of 8 KHz and 200 KHz. The in-phase and quadrature signals are processed to obtain the amplitude and phase of the received signals for identification of the meteor echoes. A new algorithm is developed to automatically detect the echoes using a normalized amplitude threshold and a minimum temporal separation between two echoes. A ratio test is defined based on amplitude response of the overdense meteor echoes. Echoes with a plateau-like amplitude response are found to qualify the test and remaining echoes are rejected. The system is capable of detecting almost all types of meteor echoes reported earlier by other high-power radars. Different phase patterns due to fragmentation and background wind are also observed. Histogram of the meteor counts shows a peak for shorter durations indicating larger populations of the smaller size of meteoroids. The log-log plot of the meteor duration versus count is found to exhibit a characteristic transition of the slope. An empirical estimate of the height of the echoes is obtained. The echoes show micro-meteoroid populations which may depend upon the transmitting-receiving setup and the geometry.

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Two-dimensional UHF coherent backscatter radar observations of equatorial F-region irregularities at the Jicamarca Radio Observatory

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In this talk we will present and discuss new two-dimensional coherent backscatter UHF radar observations of F-region irregularities made at the Jicamarca Radio Observatory (JRO) in Peru. The observations to be presented were made by a 14-panel version of the Advanced Modular Incoherent Scatter Radar [1] system that has has been referred to as AMISR-14 [2]. After being deployed at the JRO in 2014, AMISR-14 stopped working due to technical problems. We recently repaired the system and started to make semi-routine observations of nighttime F-region echoes. The observations take advantage of the electronic steering capability of the system to produce observations of the spatial distribution of irregulary-causing UHF echoes in the magnetic equatorial plane. During the presentation, we will describe the mode used for F-region observations and will present examples of F-region echoes associated with equatorial spread F (ESF) events. These examples will illustrate the development, evolution and decay of ESF sub-meter irregularities in the vicinity of the JRO. We will also discuss the implication of the observations for a better understanding and specification of ESF events.

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High-altitude drift experiments over Jicamarca: low-latitude driver effects over the topside equatorial ionosphere

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The effects of ionospheric drivers over the topside equatorial ionosphere have been largely overlooked due to the lack of simulatenous equatorial plasma drifts and low-latitude neutral winds and electric field observations. One of the main drivers is the ionospheric dynamo which setup wind-driven electric fields and provide an overall explanation of the altitudinal morphology of the equatorial plasma drifts. The altitudinal dependence of the vertical plasma drifts exhibit a close relationship to the time dependence of the zonal plasma drifts following the curl-free electric field conditions (Shidler and Rodriguez 2019). The typical altitudinal profiles decrease linearly with height in the morning and decrease in the afternoon with small seasonal and solar flux dependence. Near dusk, they decrease strongly with height in the F-region than in the topside during high solar periods and during equinox (Shidler et al. 2019). They also exhibit a transition altitude (generally above 900 km) where drift velocities seems to be altitude-independent which also depends on season and solar flux conditions (Fejer et al. 2014). We use vertical plasma drifts observations from the Jicamarca Incoherent Scatter Radar along with mesospheric winds from the multistatic sytems in South America (Chau et al. 2021), and upper atmospheric winds estimates from the ICON-MIGHTI to study the low-latitude ionospheric driving effects over the equatorial topside ionosphere up to 1000 km apex height over Jicamarca. Early results suggests that the altitudinal structure of the daytime vertical plasma drifts are driven mainly by the ionospheric wind dynamo up to altitudes of ~800 km where low latitude driving effects become considerable.

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Electrojet Zeeman Imaging Explorer: measurements of low-latitude ionospheric currents and winds

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The Electrojet Zeeman Imaging Explorer (EZIE) is an upcoming NASA mission which will be a constellation of three small spacecraft to study the auroral and equatorial electrojets. Each spacecraft carries microwave receivers designed to measure radiances containing the magnetic signatures of the electrojet currents based on the Zeeman splitting of molecular oxygen thermal emissions. These novel measurements will enable the derivation of the electrojet magnetic field at around 80 km, an altitude regime which has never been systematically explored previously. In this presentation, we will focus on the low-latitude science which is planned for the EZIE mission. We will discuss measurements of both the equatorial electrojet magnetic signature and low-latitude thermospheric winds and temperatures. We will present results from a comprehensive and realistic Observing Systems Simulation Experiment (OSSE), which has been developed to simulate EZIE measurements and includes winds and currents from the WACCM-X model.

Optical Instrumentation to Study Ionospheric Processes From Equatorial to Subauroral Latitudes

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Boston University has deployed a network of all-sky imagers to study ionospheric processes from equatorial to subauroral processes, with emphasis on magnetically conjugate measurements [1]. These processes include equatorial spread F (ESF), medium scale travelling ionospheric disturbances (MSTIDs), equatorial ionization anomaly (EIA), and Stable auroral red (SAR) arcs. Additional optical instruments will be installed to enhance the science yield provided by the ASIs. In Europe, an ASI will be deployed in Southern Italy to allow the investigation of poleward excursions of the northern crest of the EIA and equatorward extent of MSTIDs in that longitude sector. A chain of Fabry-Perot Interferometers from equatorial to low latitudes, will be deployed in the near future in Western South America. This chain includes already operating instruments in Peru and Argentina and will allow us to investigate the influence of the southern crest of the EIA in the behavior of neutral winds and temperature. We also use FUV data from GOLD satellite and ionosonde data from equatorial and low latitude locations. Results showing some of these processes occurring at different latitudes will be presented.

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Initial Results of Low-Cost Small All-Sky Imagers for Multi-Point Measurements of Airglow and Aurora

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We are developing low-cost small all-sky imagers for measurements of aurora and airglow at high to low latitudes. The imagers consist of a CCD camera (WATEC WAT-910HX) or a CMOS camera (ZWO ASI294MM Pro) with a fish-eye lens Fujinon FE1185C057HA-1 and band-bass filters with bandwidths of ~10 nm. The WATEC camera observe plasma bubble images using a 630-nm filter (Hosokawa et al., 2020) and auroras in various wavelengths (Ogawa et al., 2020). From test observations at Shigaraki, Japan (34.8N, 136.1E), in August 2021 and January 2022, we obtain images of mesospheric gravity wave images using 557.7-nm and OH-band filters, and images of medium-scale traveling ionospheric disturbances using a 630.0-nm filter. Both cameras cost US$1000-2000, which is 20-40 times cheaper than the previous airglow/auroral cameras used for Optical Mesosphere Thermosphere Imagers (OMTIS, Shiokawa et al., 1999). We will use these cameras for two-point campaign observations of aurora and airglow at Athabasca, Canada in August – September 2022. We plan to distribute these low-cost small all-sky imagers in Europe, Asia, and Africa to make multi-point measurements of airglow images at middle and low latitudes.

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Development of a Neutral Mass Spectrometer for the In-situ Observation of the Upper Atmosphere

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An atmospheric composition is an important parameter for the dynamics of the upper atmosphere through collision frequencies. In order to make in-situ measurements of atmospheric compositions and density variations, we are developing a neutral mass spectrometer with high resolution that can be mounted on sounding rockets and low earth orbit satellites.

The spectrometer is based on the time of flight mass spectrometer with three-time reflections which has been developed by ISAS for the water investigation on the lunar polar surface with a rover. In the adaptation for mounting on rockets and satellites, we are mainly working on two designing tasks. One is to downsize the mass analyzing part based on optical and spatial requirements. The other is to newly design an ante-chamber. An ante-chamber is spherical and set before the entrance to decelerate the particles from the relative speed of rockets or satellites to their thermal speed.

We are planning to make a trial of the spectrometer in the sounding rocket experiment targeting a sporadic E layer scheduled for 2024. S-310 sounding rocket is going to be used and will reach the altitude around 130 km. We expect that the spectrometer will make precise measurements of atmospheric composition and density variations of N2, O2 and O from 90 km to 130 km. This will contribute to the analysis of collision frequencies which are related to ion velocities and electrical conductivities.

Software-defined radio-based receiving system for HF Doppler observation system

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High-frequency Doppler (HFD) sounding is a practical ionospheric observation technique that has been used for more than 60 years. The University of Electro-Communications (UEC) has principally promoted HFD sounding in Japan. Recently, software-defined radio (SDR) has widely spread, and then we can construct the receiver of HFD sounding system without knowledge of analog circuit equipment. SDR also enables us to reduce the size and cost of the system. To take advantage of these features, we have developed a new digital HFD receiver system using SDR.
A new digital receiving system has utilized a commercially available SDR device (Ettus Research USRP N210) with an LFRX daughterboard; a circuit board developed for USRP to receive signals between 0 to 30 MHz. The dynamic range of the new system is over 130 dB, which is more than 40 dB wider than the conventional system used for the HFD observations indebted by UEC. The signal-to-noise ratio has also been improved by 20 dB.
The new digital system can receive radio waves at four different frequencies (3925 kHz, 5006 kHz, 6055 kHz, and 8006 kHz). The new digital receivers have been installed at nine stations as of June 2022 and are already in operation, demonstrating the feasibility of SDR in actual ionospheric observations.

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VIPIR ionospheric observations in Japan

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National Institute of Information and Communications Technology (NICT) has observed ionosphere by ionosondes more than 70 years in Japan. At present, four ionosondes at Wakkanai (Sarobetsu), Kokubunji, Yamagawa, Okinawa (Ogimi) are automatically operated and controlled from Tokyo. Major ionospheric parameters such as foF2 and foEs are scaled from the ionograms automatically on a real-time basis and scaled manually for the final values. The scaled parameters are provided through our web site [1]. In 2017, we replaced the previous ionosondes with Vertical Incidence Pulsed Ionospheric Radar 2 (VIPIR2) in 2017. One of the advantages of VIPIR2 is a receiving antenna array, which makes it possible to separate O-mode from X-mode by utilizing in-phase and quadrature data. The O/X mode separated ionograms are used for automatic scaling with artificial intelligence (AI) technique. The scaling accuracy and the successful rate have been largely improved. In addition, we changed the observation interval from 15 minutes to 5 minutes. This made possible to capture much finer variations whose time scale is less than 15 minutes. We have also tried to detect arrival directions of ionospheric echo by using the 8ch receiving data as an interferometry. In this presentation, we will overview the status of ionospheric observation in NICT.

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Data Assimilation in the Ionosphere-Thermosphere System

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The solar forcing from above, atmospheric forcing (wave activities) from below, and various internal multiscale dynamics including the equatorial dynamo process influence the ionosphere-thermosphere (IT) system. The so-called *self-consistent* numerical models of the IT system depend on boundary conditions and rely on many assumptions and simplifications. Data assimilation (DA) is arguably essential for space weather forecasting due to the imprecise and incomplete modelling and sparsity of observations of the IT system. In this talk, we present some of our recent developments in assimilation of IT data into numerical models with an emphasis on the ensemble Kalman filter technique as well as tomography and DA-based calibration of empirical models.

An empirical 3D model of the ionospheric current system based on data assimilation

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The Earth's ionosphere is home to numerous electric current systems driven by the global wind dynamo, gravity, pressure gradients, and coupling to the magnetosphere. Each of these current systems exhibit rich and complex structure on a wide range of both temporal and spatial scales. Improved understanding of the ionospheric current system enables us to predict the effects of space weather events, interpret magnetic field observations on ground and in space, and probe the conductivity structures of the deep Earth interior.

Over the years, researchers have attempted to understand and model the global ionospheric current system using both data-based and physics-based methods. Data-based approaches have used ground and/or space observations of the magnetic perturbations caused by the electric currents, in order to invert for the sources, typically using simplified models of current flow geometries, or using generic basis functions such as spherical harmonics. Physics-based methods have culminated in state-of-the-art models, such as the Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM), which self consistently simulates both the dynamics, energetics and chemistry, and electrodynamics of the upper atmosphere. The ionosphere is not an isolated system, and so advanced models like TIEGCM must be driven by inputs representing the dynamics from the lower atmosphere and the high-latitude energy input from the magnetosphere coupled to the ionosphere and thermosphere. Some research studies have combined observations with self-consistent modeling, developing data assimilation methods to drive physics-based models with real-time observations from ground and in space.

The work we describe here is a data assimilation method which focuses on modeling the ionospheric currents in the diurnal frequency band. We utilize a one year TIEGCM simulation to construct a set of spatial modes which capture the salient 3D structures of the major ionospheric current systems. These spatial modes are then combined with a set of temporal modes derived from the ground observatory network over a 20 year time frame, in order to build a time-continuous 3D model of the global ionospheric current system in the diurnal variation band. This is, in effect, a 4D model of the ionospheric currents and their associated magnetic fields spanning two decades. We will report on the methodology used to build our model, as well as the main features of the model. We will also discuss possible extensions of our method to other frequency bands, in order to capture, for example, higher frequency variations which could occur during geomagnetic storms.

The sami2py model -- overview and applications

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Sami2py is a python module that runs the SAMI2 ionospheric model, as well as archives, loads and plots the resulting modeled values. SAMI2 is a model developed by the Naval Research Laboratory to simulate the motions of plasma in a 2D ionospheric environment along a dipole magnetic field. SAMI2 solves for the chemical and dynamical evolution of seven ion species in this environment (H^+, He^+, N^+, O^+, N_2^+, NO^+, and O_2^+). The python implementation allows for additional modifications to the empirical models within SAMI2, including reduction of the exospheric temperature in the NRLMSIS thermosphere and the input of custom ExB ion drifts.

The code is open source and available to the community on github. The work here discusses the implementation and use of sami2py, including integration with the pysat ecosystem and the growin package for ionospheric calculations. As part of the Application Usability Level (AUL) framework, we will discuss the usability of this code in terms of several ionospheric applications.

Impact of Thermospheric Data Assimilation on Thermospheric and Ionospheric Weather Monitoring

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The upward plasma drift and equatorial ionization anomaly (EIA) in the Earth's ionosphere are strongly influenced by the zonal electric field, which is generated by the wind dynamo. Specification and forecasting of thermospheric winds thus play an important role in ionospheric weather prediction. Thermospheric data assimilation was previously limited due to the lack of continuous observations of the neutral state. Recently, thermospheric wind data from the Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGHTI) on NASA's Ionospheric CONnection (ICON) became available. The ICON/MIGHTI observes the thermospheric zonal and meridional winds at low and middle latitudes between 90-300 km during the daytime, and 90-105 km and above ~210 km during the nighttime. In this study, Observing System Simulation Experiments (OSSEs) with different combinations of observations are performed using the National Center for Atmospheric Research (NCAR) Whole Atmosphere Community Climate Model with thermosphere-ionosphere eXtension (WACCMX) and Data Assimilation Research Testbed (DART) ensemble adjustment Kalman filter. In addition, Empirical Localization Functions (ELFs) of ICON/MIGHTI zonal and meridional winds are also computed and applied to our experiments, enabling improved assimilation of the ICON/MIGHTI wind observations. The results show that assimilating the ICON/MIGHTI wind observations with the ELF improves the specification and forecasting of thermospheric zonal and meridional wind, ionospheric vertical plasma drift, and ionospheric electron density under quiet and low solar activity conditions.

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Ingestion of Radio Occultation Data For Ionospheric Data Assimilation

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Radio Occultation (RO) data is one of the most important data sources for many Ionospheric Data Assimilation schemes. For example, COSMIC-2 RO data has dense coverage of the equatorial and mid-latitude regions of the ionosphere. It is usually believed that it is better to ingest raw data into data assimilation scheme and to minimize data pre-processing, therefore, schemes like IDA4D ingest slant total electron content (sTEC) RO data. This study demonstrates that better results can be achieved by performing Abel inversion to invert electron density along tangent points and then ingesting these point density measurements into data assimilation. A 2-D experiment with real RO geometry was performed to directly compare these two methods of data ingestion. The ingestion of Abel inverted point densities is able to better retrieve the hmF2 parameter and the structure of the bottom side of the profile in comparison to the direct ingestion of sTEC data, especially when the hmF2 of the truth is below the hmF2 of the background or when the horizontal gradient is present.

Assimilation of Satellite and Ground-Based Data for 3-D Regional Ionosphere Modeling

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For the first time, a high-resolution regional ionospheric nowcast model over Africa and adjacent areas (-40–40°N in latitude, 30°W–60°E longitude, and 80–1400 km in altitude) is constructed by assimilating ground-based slant total electron content (STEC) from 34 Global Positioning System (GPS) receiver stations and space-based ionospheric F2 peak density (NmF2) from Constellation Observing System for Meteorology, Ionosphere, and Climate-2 (C2) into the International Reference Ionosphere (IRI-2016) model. An Ionospheric Data Assimilation Four-Dimension (IDA4D) optimization algorithm was used to estimate four-dimensional electron density as high as 1.5°×3° in latitude and longitude, 10 km in altitude in the E and F regions, and 15 min in universal time. Two experiments were run for the following data sets: (1) GPS-STEC's only and (2) GPS-STEC's and NmF2's from C2 during geomagnetic quiet time and storm time (06–14 May 2021). The IDA4D assimilation results are validated with C2 electron density profiles (EDPs) and ionosonde foF2. Results show that the average root-mean-square error (RMSE) of the IRI NmF2 is reduced by 23% and 35% under experiment 1 and experiment 2, respectively, compared with the control group of C2 values. Furthermore, under experiment 1 and experiment 2, the IDA4D foF2 values show a 36% RMSE improvement at all ionosonde stations over the IRI foF2 values. Thus, IDA4D is a potential candidate to nowcast the regional ionosphere over Africa by incorporating ground- and space-based data.

3D tomography of ionosphere above the Indian region using InSWIM GNSS network receivers

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To observe the impact of space weather on the terrestrial ionosphere above the Indian region, a set of GNSS receiver systems have been deployed across India, under the Indian Space Weather Impact Monitoring (InSWIM) project [1]. These receivers observe the relative phase difference in radio signals, mainly L1 (1575.42 MHz) and L2 (1227.6 MHz) frequency bands, and provide live variations in the slant total electron content (sTEC) at given locations. Depending upon the population of satellites in the field of view of a receiver antenna at a given time the probed ionospheric regions from the given location may vary as the sTEC is measured along the line of sight of a visible satellite. To get a complete three-dimensional (3D) structure of the terrestrial ionosphere, we have adopted the Algebraic Reconstruction Technique [2] which iterates over the sTEC observations in order to construct the 3D tomogram.

In our study, to generate 3D tomograms, we fixed the grid size of 3°x3° longitude and latitude resolution but different height slabs of 20, 50, 100, and 1900 km. The pixel volume corresponding to one cell is defined as a voxel. For a better estimate, we increased the number of observations (or counts of observed sTEC values) in a given voxel, by approximating the temporal stability of ionospheric density for 15 minutes. As an *a priori* distribution, density profiles from IRI model are used to base the final results on, essentially affecting the voxels through which ray paths do not cross. This technique enabled us to observe the impact of space weather in the terrestrial ionosphere above the Indian region. Observed interesting results from the Indian region will be presented at the symposium.

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Modeling ionograms with deep neural networks and electron densities forecasting

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The state parameters of the ionosphere are of fundamental importance not only for space weather studies but also for technological applications such as satellite radio communications. As with many geophysical phenomena, the dynamics of the ionosphere are governed by nonlinear processes that make ionospheric forecasting a challenging endeavor. However, now, we have available enormous datasets and ubiquitous experimental sources that can help us find the intricate regularities in these phenomena [1].

In this work, we will describe recent progress on two models based on deep neural networks (DNN) to predict ionograms and electron densities. Both models were trained using ionogram data from Jicamarca Radio Observatory Digisonde and geophysical input parameters. The first model predicts virtual heights and foF2. The second model estimates electron densities using physics-informed neural networks based on the first model. The models' hyperparameters were optimized and their accuracy was compared to estimates from IRI and Sami2 models. Our results show that our models can often produce estimates better than those obtained by the empirical and numerical models when trained using the most recent data.

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Support Vector Machine (SVM) for Equatorial Plasma Bubble Detection from VHF Radar Images at Chumphon VHF Radar Station, Thailand

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Equatorial plasma bubbles (EPB) are caused by the Rayleigh-Taylor instability at the bottomside of the F2 layer near the magnetic equator where the density of the lower layer is less than that of the upper layer after sunset [1]. It is well known that EPB disappears before sunrise and it can drift to the higher latitude regions along the magnetic field lines. The VHF radar is an important instrument to observe the ionospheric irregularities exhibiting spatio-temporal characteristics. Recently, a collaboration between the National Institute of Information and Communications Technology (NICT) and King Mongkut's Institute of Technology Ladkrabang (KMITL) was established to install VHF radar station at Chumphon Campus (99.37E, 10.72N, Magnetic Lat. 3.0°N), Thailand, near the Earth's magnetic equator to detect the onset of plasma bubbles. The VHF radar station consists of three-component 18 yagi antennas, starting from the east direction to the west. The distance between each antenna is approximately 5 meters and the frequencies transmitted through the atmosphere are VHF (39.65 MHz). Since the echo information is typically displayed in 2-D images of the range (m) vs. frequency (Hz); therefore, EPB occurrence, characteristics and direction can be studied.

In this work, we construct a multi-label support vector machine (SVM) method to detect the plasma bubbles. The experimental data was based on October 2020 data, divided into three classes: EPB, No EPB, and Unsure. The total of 1000 radar images (RGB) are divided into 70% or 700 images as the training dataset and 30% or 300 images as the testing dataset. We test 4 kernels including linear kernel, sigmoid kernel, radial basis function (RBF) Kernel and polynomial kernel by using Gamma $\gamma = \{0.01, 1, 10, 100\}$ and parameter $C = \{0.01, 1, 10, 100\}$. For both grayscale and color images, the best SVM model is based with the radial basis function (RBF) kernel giving the accuracy of 89.72% and 86.67%, respectively.

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Analysis of solar parameters and foF2 data obtained by Singular Value Decomposition

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Our earth –space environment is made of multi-faceted dynamical phenomena that involve many linear and nonlinear systems. So, to comprehend the process of nonlinearly evolving dynamical system of the magnetosphere and ionosphere, the Time series analysis of some parameters such as foF2, Disturbance Storm Index Dst, Geomagnetic activity Index Ap, etc. during various solar cycles have been carried out. The hourly data of critical frequency of F2 layer (foF2) for two ionosonde stations [Canberra (CB53N) 35.3°S, 149.1°E; Juliusruh (JR055) 54.6°N, 13.4°E] have been noted for 3 solar cycles viz., Solar Cycle 21, 22 and 23 and analysed to attain some functional approaches. As Time Series is a sequential set of data that can be measured over time, and since the data being used for this work had been recorded as a function of time under various conditions, so the presence of missing observations in time series data is a very common issue. So, to vanquish the problem of missing data we have make an effort to estimate the missing value of foF2 data for various stations using the technique of Singular Value Decomposition (SVD). Besides, Lomb Scargle Periodogram (LSP) with 99% confidence level has been executed on the Empirical Orthogonal Functions (EOFs) u1 and u2 (that has been obtained by SVD) along with the solar parameters such as solar flux f10.7, sun spot number (SSN) etc. and geomagnetic indices such as Dst index, Kp index & Ap index etc. for the three solar cycles to find the correlation, if any. The periodicity obtained after performing LSP are divided into three terms namely:– (a) short-term periodicity, in which 27 days periodicity is found to be prominent, (b) mid-term periodicity, in which 1.3 year periodicity is found to be very common and (c) long-term periodicity, in which 11 years periodicity is very regular in almost among all the parameters and in the EOFs.

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Automatic Detection and Classification of Low Latitude TEC Structures Observed using Geostationary NavIC and other GNSS satallites

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Detection and classification of structures in total electron content (TEC) has remained one of the challenges for the forecasters. Further, statistical analysis has not been possible largely due to the complex mixture of different types of structures offered by the ever changing ionospheric phenomena at the equatorial and low latitudes. So to overcome this shortcoming, an automatic algorithm is developed to detect and characterize low latitude structures in GPS and NavIC (Navigation by Indian Constellation) derived TEC. Pradipta et al. (2015) have given a method to detrend the GPS-TEC with empirical thresholds to detect the depletions and wave-like modulations. However, NavIC has an advantage over GPS over the Indian region in using three geostationary satellites. So, the NavIC-TEC from these satellites always correspond to a static ionospheric peirce point (IPP), which is different compared with the moving IPP from GPS. Further, we aim to identify the daytime structure in TEC known as “noon-time biteout” in the equatorial anomaly region. Also, the TEC depletions corresponding to the equatorial plasma bubbles as mapped in the NavIC-TEC exhibit very different sturcutres than in GPS-TEC. Thus, the method of Pradipta et al. (2015) requires a few modifications.

We present an automated algorithm which is based up on detrending TEC. This is performed by first obtaining the depletion free TEC intervals which are constructed using barrel roll curve. We then subtract the depletion-free TEC from the time series of diurnal TEC curves for indivual satellite-receiver pairs and get the detrended time series. The segregation of depletions and other features such as noon-biteout, wavelike features, nighttime enhancements etc. is implemented based on the value of |dTEC/dt|. A high value of |dTEC/dt| is classified as depletions due to plasma bubbles with a new set of empirical thresholds. Also, we are able to derive duration and depth of different TEC structures through the present algorithm for various GNSS constellations.

The longitudinal variations in noon-biteouts and plasma depletions are further examined using three geostationary satellites of NavIC corresponding to three constant IPPs. A special classification is also implemented for detection of unusual events such as wavelike structures during geomagnetic storms and anomalous increase in post sunset TEC level over low latitudes. The results from GNSS-TEC using the new algorithm are matching well with NavIC-TEC, giving the confidence regarding the applicability of the algorithm for various constellations. Statistical results and scientific implications will be presented.

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Ionospheric vertical plasma drift model for the Indian and Indonesian sectors: Validation and usefulness

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In the recent past, Patra et al., (2012 and 2014) have been estimated the ionospheric vertical plasma drift using radar observations of daytime 150-km echoes from Gadanki, India and Kototabang, Indonesia. They found that radar measured vertical plasma drifts agreed quite well with those measured using the CINDI onboard C/NOFS, and remarkably different from those of Scherliess-Fejer model. They noticed that plasma drift at Gadanki and Kototabang differed remarkably on many days even though they are longitudinally separated by 20^{o}. The lack of regular observations and realistic model of vertical plasma drift in the Indian and Indonesian sectors, it is continuous to be a limitation for studying/forecasting many equatorial/low latitude ionospheric processes. To overcome this limitations, we have developed a neural network based ionospheric vertical plasma drift model for the Indian and Indonesian sectors using limited observations of vertical plasma drifts derived from radar 150-km echoes. We have used a feed forward neural network with error back propagation to train the network. This model successfully reproduces the daytime vertical plasma drift with a maximum error of ~2.7 ms^{-1}. The model plasma drifts are also found to agree exceedingly well with those measured using the CINDI onboard the C/NOFS. The model seasonal mean drifts are found to differ considerably from those of Scherliess-Fejer model. The neural network-based model presented here is first of its kind from the Indian and Indonesian sectors, presenting local time, day-to-day, and seasonal variations of daytime vertical plasma drifts during magnetically quiet conditions. The validation and usefulness of the model are presented and discussed.

Artificial Neural Network-Based Model for Equinoctial Evening Upward Ionospheric Plasma Drift in Equatorial Southeast Asia

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This study attempts to develop a generalized model of the speed of evening upward ionospheric plasma drift (*v*) for equinox seasons in equatorial Southeast Asia using an artificial neural network (ANN). Data of *v* is retrieved from the change of virtual height of F layer (*h'*) from 18:30 to 19:00 LT observed by the ionosonde. We collected 1045 data points of *v* during the equinox seasons (March, April, September, and October) from 2003 to 2016 from three ionosondes, at Chumphon (99.4°E, 10.7°N, magnetic latitude/MLAT: 3.0°N) in Thailand, Bac Lieu (105.7°E, 9.3°N, MLAT: 1.5°N) in Vietnam, and Cebu (123.91°E, 10.4°N, MLAT: 3.0°N) in the Philippines. In addition to *v* data, we complement our dataset with daily solar $F_{10.7}$, Kp index, and day of year (DOY). 70% of the dataset has been used to build the ANN architecture, and the remaining 30% has been used to validate the ANN model. As a result, our ANN architecture consists of the input layer with three features (Daily solar $F_{10.7}$, Kp index, and DOY), one hidden layer with 7 nodes or neurons, and one output layer to generate *v*. The performances of our ANN model in modeling *v* in both training and testing datasets have a Pearson correlation coefficient (*R*) of 0.75. Furthermore, the performances of the ANN model in both training and testing sets have the same capability to capture the effects of solar and geomagnetic activities on the strength of *v*. The ANN model can capture the positive and negative correlations for the relationships of *v* against solar and geomagnetic activities, respectively. Remarkably, our ANN model can reproduce the equinoctial asymmetry in the solar activity dependence of *v*; that is, the strength of *v* strongly depends on the solar activity in the March equinox rather than in the September equinox (as reported firstly by the study [1]). In conclusion, the performance consistency between the training and testing sets infers that our ANN model could be a generalized model of *v* in equinox seasons for the equatorial region of Southeast Asia.

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Latitude-Weighted Total Electron Content Map Using GNSS Network in Thailand

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Total Electron Content (TEC) is one of the significant parameters to characterize the ionosphere and, importantly, the changes in TEC is a proxy to indicate the local ionospheric regularities such as equatorial plasma bubbles. To monitor the ionosphere in space weather studies, global and local TEC maps are developed using data from GNSS receivers. In the magnetic equatorial and low latitude regions, TEC highly fluctuates during the occurrences of equatorial plasma bubbles (EPBs). Therefore, a local TEC map with high resolution can be useful for classification and forecasting ionospheric regular events and precise positioning. In this work, we construct high-resolution GNSS TEC maps over Thailand by spatial adjustment of TEC values. The adjusted algorithm is weighted following the equator (at Chumphon, south of Thailand) and sideway (at Chiangmai, north of Thailand) trend. The GNSS observations were obtained from 18 receivers over Thailand with high spatial and temporal resolutions over 0°-25°N latitude and 95°-110°E longitude. The proposed map can monitor the TEC trends and disturbance effects. The results are calculated using the difference between the VTEC measured with the geometry-free combination method and the grid VTEC estimated from the precise grid TEC map. Then we compare the results to the Global Ionospheric Map (GIM). The evaluation results indicate that the precise GNSS TEC map is approximately 70 percent more accurate than the GIM TEC map, which is 54 percent accurate in low latitude region.

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Time Series Prediction of the Equatorial Spread-F Occurrence using the LSTM network

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In low latitude regions, equatorial spread-F (ESF), which are noisy traces of ionogram, indicate the instability at the bottomside of the ionosphere. The ESF often indicates the the occurrence of equatorial plasma bubbles (EPBs). As high frequency (HF) communication systems and Global Navigation Satellite Systems (GNSS) signals can be degraded due to such phenomenon, there is a need to develop ESF forecasting model for space weather study as well as industrial users. Therefore, in this work, we propose a forecasting model for the local ESF events using the long short-term memory (LSTM) networks. The input parameters to the LSTM include equinoctial month variations, night-time variations, solar activity, magnetic activity and local F-layer paremters. The LSTM structure has 20 cells. Furthermore, the local ionospheric F-layer height and vertical drift velocity parameters are utilized for helping the model's ability in recognizing the significant spatial and temporal features of the inputs in relation to the ESF events. The ESF data covers 2008 to 2019 from the FMCW ionosonde at Chumphon station (10.7°N, 99.4°E; MLAT: 3.0°N) are considered. The data in 2008 to 2018 are used in train, while the data in 2019 are used for testing. We vary the loop back number from 1 hour to 5 hours. The minimum mean square error (MSE) of the model training reaches at 0.15. The testing results of the model performance at each time are decreased from post-sunset to post-midnight, respectively. The proposed LSTM model can provide the ahead prediction of the ESF events based on current historical learning data. After training with 3 hours of timesteps, the model achieves 78.2% accuracy of the ESF occurrence prediction for 30 minutes in advance. When compared with the simple neural network, the accuracy performance improvement is 1.2 %. We obtain the F1-score value of each model as 0.57 (LSTM), 0.55 (RNN), and 0.48 (ANN).

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How does long-term changes in the geomagnetic activity regulate the CO2-driven trend in the thermosphere and ionosphere

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Increasing CO2 in the atmosphere is predicted to produce long-term trend in the thermosphere and ionosphere, along with tropospheric warming. However, the thermosphere and ionosphere are first and foremost dominated by the solar and geomagnetic activity (GA) forcing, making it challenging to search CO2-driven signal in observations. In this study (Liu et al, 2021), we examine the interaction between GA forcing and CO2 forcing using the GAIA whole atmosphere model. The model reveals three salient features. (1) increasing GA always weakens the CO2-driven trend at a fixed altitude. (2) increasing GA forcing can either strengthen or weaken CO2-driven trend in hmF2 and NmF2, depending on local time and latitudes. This renders invalid the widely used linear fitting methods for GA removal. (3) An interdependency exists between the efficiency of CO2 and GA forcing, with the former enhances at lower GA levels while the latter enhances at higher CO2 concentration. This implies that the CO2-driven trend would accelerate in periods of declining GA, while effects of magnetic storms will become larger with increasing CO2 in the future. These effects are closely related to circulation and tidal changes in the thermosphere as well (Liu et al. 2020). These model experiments provide a preliminary framework to understand interactions between meteorological forcing from from below and the geomagnetic forcing from above.

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Improving the representation of the ionosphere-thermosphere through data assimilation

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By statistically combining observations with a background numerical model, data assimilation systems can greatly benefit scientific understanding of the middle and upper atmospheres. They are additionally useful for initializing short-term space weather forecasts. Using examples from experiments performed using the Whole Atmosphere Community Climate Model with thermosphere-ionosphere eXtension (WACCMX) with data assimilation capability provided by the Data Assimilation Research Testbed (DART) ensemble Kalman filter, we demonstrate the impact of assimilating COSMIC-2, ICON, and GOLD observations on the ionosphere-thermosphere state. Particular emphasis is placed on the impact of observations on quantities that are not directly observed. For example, we show that assimilating ICON neutral winds can have a positive impact on the equatorial electrodynamics. The possibility of leveraging data assimilation systems to extend the capabilities of new observations will also be discussed. The results and discussion serve to demonstrate the importance of continuing to develop physics-based data assimilation systems for improved scientific understanding of the ionosphere-thermosphere.

Development of the Equatorial Plasma Bubble Alert System

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The current solar cycle is expected to reach its peak around 2025. We are approaching a year of high solar activity, which is expected to activate or amplify many space weather phenomena. Among them, Equatorial Plasma Bubble (EPB) that occurs in the ionosphere is one of the notable phenomena. One of the most significant impacts of space weather on society is the increase in satellite positioning errors due to ionospheric disturbances. Positioning errors are caused by multiple factors, including the ionosphere that covers the earth and ground-based obstructions such as mountains and buildings. Plasma in the ionized area affects the passing electromagnetic waves such as delay and fluctuation. As the satellite signal passes through the ionosphere, its velocity decreases according to ionospheric plasma density, and the arrival of the electromagnetic wave signal to the ground is delayed. EPB creates a sizeable spatial gradient in the surrounding plasma density, which increases positioning error. In addition, the irregular plasma structure inside the EPB can cause fluctuation in the strength of the satellite signal, called scintillation, resulting in the loss of lock of the signal. EPB results in the inability to receive stable positioning signals. It is foreseen that GNSS will become an important technology required for autonomous driving technology. Services using location information such as drone and robot smart delivery has been piloted by several companies, and smart agriculture has also started in several countries. If an error in acquiring position information by GNSS occurs, various troubles will hinder using of these services in real life. Since the EPB has a large spatial scale not limited to the sky above any country, international cooperation is essential to understanding the phenomenon and reducing its obstacles.

To demonstrate the use of space weather knowledge and technology to challenge the real-world problem, we have been developing the "EPB Alert" system prototype. EPB Alert development was initiated in mid-2021 under the SouthEast Asia Low-latitude IOnospheric Network (SEALION) project [1]. It aims to provide a basic knowledge of EPB and user-friendly information derived from ground-based ionospheric observations to the public, e.g., an alert of EPB detection in Thailand, Indonesia, Vietnam, and Laos, and positioning errors in Thailand and Laos. We wish EPB Alert would be another step to promote the use of the GNSS technology in the real world.

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An electromagnetic calculation of electric-field mapping that seems to override electrostatic theory, and which injects wave-like effects into E-F coupling

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We derive a steady-state, electromagnetic solution for collisional plasma and apply it to computing the total conductance for a vertically stratified ionosphere, which crucially involves electric-field mapping. We find that for transverse scales of 100 km and below, the parallel wavelength becomes comparable to the distance between the E and F regions. This means that rather than mapping unchanged, the electric field goes through a phase progression such that there can be a standing wave, or related effects that are more modest. In the E region, the Alfven and Whistler waves can both be supported, which further complicates the behavior. The results are important at both high and low latitudes, but in this talk we will focus on the mid- and low-latitude regions and discuss wavelike effects in E-F coupling.

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Towards a New Arecibo Radar and Radio Telescope in Puerto Rico and the U.S. Virgin Islands

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Since beginning observations in August 1963, the Arecibo Observatory has been at the forefront of research in atmospheric and geospace science, planetary science, and astronomy. The collapse of the observatory's 900-ton instrument platform on December 1, 2020, resulted in the loss of the world's most sensitive atmospheric incoherent scatter and planetary radar systems, as well as the loss of the only mid- and low-latitude high-power high-frequency ionospheric research transmitter, and of all of the associated radio astronomy receivers.

Work is now underway on projects and proposals for building new radar and radio systems in Puerto Rico: an extensive white paper advocating the construction of new radar and radio systems was published in February 2021; the U.S. National Science Foundation held a workshop during June 2021 on future options for Arecibo Observatory; plans are underway to restore the HF transmitting capabilities of the Observatory; proposals have been submitted and are being developed for new high-frequency (HF), very-high-frequency (VHF), and ultra-high-frequency (UHF) radars and new radio astronomy instruments; and a proposal for a remote observing site with a new HF radio imaging array and other atmospheric instruments has been submitted.

The Arecibo incoherent scatter and planetary radars were UHF systems, operating at 430 and 2380 MHz, respectively. Both radars were used for both atmospheric and planetary science. New, modern radar systems could have transmitters at VHF, UHF, and perhaps higher frequencies, with receivers located both at the current Observatory site, where they would be protected from radio interference, and elsewhere in Puerto Rico and the U.S. Virgin Islands. The inclusion of a multistatic low-band VHF radar in a restored Arecibo Observatory would be groundbreaking for research in the neutral atmosphere and the ionosphere, as well as in in meteor physics and meteoroid astronomy, and for radar studies of the moon and the sun.

Arecibo's Caribbean location, at 18 degrees north latitude and roughly 45-degree magnetic dip angle with conjugate point in northern Argentina, and its diverse space weather connections to the equatorial atmosphere, point to the many contributions that a rebuilt, modern Arecibo Observatory would make to equatorial aeronomy.

Distributed arrays of small instruments: Results, opportunities, and lessons learned from an ongoing effort that employs low-cost ionospheric sensors

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It has been recognized that distributed arrays of small instruments (DASI) can play an important role in advancing observations and understanding of the space environment near Earth. Deploying and operating DASI, however, can be less than straightforward. In this presentation we will share some results, opportunities created, and lessons learned from our experience with the development, deployment and operation of low-cost GNSS-based ionospheric scintillation and total electron content (TEC) monitors (ScintPi). We will start by describing the different versions of ScintPi that we have developed and some of the deployment initiatives we have carried out. Then, we will present examples of observations that have been made at equatorial and low latitudes. During the presentation, we will discuss some of the observational challenges that such sensors can help to overcome and challenges that have yet to be addressed. We will also highlight scientific and educational opportunities that have been created by ScintPi. Scientific opportunities include, for instance, the deployment of local arrays for spaced-receiver scintillation observations. Educational opportunities include engagement of undergraduate students in space sciences and the student-led development of an autonomous ScintPi platform.

Observations of Ionospheric Disturbances - From Space Weather Events to Tonga Volcano Eruptions

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The global low-latitude ionosphere observations given by the Tri-GNSS radio occultation system (TGRS) and ion velocity meter (IVM) onboard the FORMOSAT-7/COSMIC-2 (F7/C2) have been applied to study the ionosheric responses to the moderate geomagnetic storms. Results show that the ionosphere responses are much greater than expectation as the moderate storms could double or triple the electron density, which was only possible during major magnetic storms under higher solar activity conditions. On January 15th 2022, the Tonga volcano eruption unleashed a strong global atmosphere perturbations and coincided with a moderate geomagnetic storm. The ensuing thermospheric variations created a rare display of extreme poleward-expanding conjugate plasma bubbles in rate of total electron content indices over 100-150°E, also causing ion-density fluctuations in IVM measurements reaching ~40°N geographic latitude. This was preceded by an unusually strong pre-reversal enhancement (PRE) of low latitude ionosphere as seen from the global ionospheric specification (GIS) which is constructed based on the TGRS observations. The GIS further revealed sharp decrease of equatorial ionization anomaly (EIA) crest density due to the storm impact. The enhanced F-region wind over EIA by the negative storm, when combined with volcano induced E-region westward disturbance wind, apparently intensified the PRE. In presence of the strong PRE, seed perturbations from volcano induced variations triggered the super plasma bubble activity.

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A High-Frequency Receiving Array for Radar and Radio Imaging of the Ionosphere

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We are developing a 2 to 25 MHz, medium and high frequency (MF/HF) radio receiving array, for radar and radio imaging of the ionosphere. The array will consist of 64 active crossed antenna elements arranged in a partly ordered and partly random pattern providing a good distribution of baseline vectors. Minimum antenna spacing of 7 meters will eliminate spacial aliasing up to 21 MHz, and a maximum antenna spacing of 400 meters will provide good imaging resolution.

The proposed location for the array is at the site of the former U.S. Air Force Ramey Solar Observatory (RSO), in Aguadilla in northwest Puerto Rico. Radar imaging will be done in collaboration with the University of Colorado and NOAA HF radar system located at the USGS San Juan Observatory in Cayey, 110 km from Aguadilla.

Fourteen relocatable cable-less antenna elements will also be included, with phase maintained through the use of GPS-disciplined rubidium clocks. These elements may be used independently, or together with the main array for improved imaging resolution.

Science goals include the study of space weather, ionospheric structure and dynamics, meteors, lightning, radio propagation, and plasma physics. The imaging array will be an ideal instrument for collaboration with local and regional instruments, and with overflights by instrumented satellites. Radio imaging is ideal for the study of stimulated ionospheric radio emissions, such as those induced by the Arecibo Observatory high-power HF radio transmitter, which may be restored to operation in 2024.

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