The Abdus Salam International Centre for Theoretical Physics

IAEA International Atomic Energy Agency

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ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Beacon Satellite SYMPOSIUM 2025

BSS 2025 Session Descriptions

1. Modeling and validation

Chairs: Manuel Hernandez-Pajares (UPC, Spain), Gopi Seemala (IIG, India), Dieter Bilitza (GMU, USA)

The ionosphere exhibits complex structures and dynamic processes that challenge existing modeling and validation approaches. Recent observational advances—enabled by ground-based GNSS networks, radio occultation, ionosondes, digisondes, and in situ measurements—have revealed previously unmodeled anomalies. For example, latitude structures in F-region plasma density sometimes display three or four peaks instead of the traditional two associated with equatorial ionization anomalies (EIAs). Additionally, during geomagnetic storms, storm-enhanced densities at mid-latitudes can dominate the global structure, creating steep plasma density gradients. High-resolution observations have also allowed for the detailed study of Large Scale traveling ionospheric disturbances (LSTIDs) and medium-scale TIDs (MSTIDs), which are driven by waves propagating from the lower atmosphere and auroral sources.

To capture these complexities, a variety of ionospheric models have been developed. Empirical median models provide a climatological description of the ionosphere, while first-principle models represent its underlying physical processes. However, to accurately specify ionospheric weather—characterizing structures and variations occurring over hours and medium spatial scales—techniques integrating models and data are essential. These techniques incorporate diverse data sources, including GNSS-derived total electron content (TEC), in situ electron density measurements, and ionosonde-derived parameters, into empirical or first-principle models. Recent DA applications include Kalman Filters, 3D/4D variational methods, and tomographic techniques.

This session welcomes contributions on new and improved modeling capabilities, including thermosphere-ionosphere, whole atmosphere-ionosphere, and magnetosphere-ionosphere-thermosphere models. It also emphasizes the validation of existing and emerging models, as well as the development of robust validation metrics. Special attention will be given to methods that integrate multi-sensor observations, leverage multiple models (e.g., multi-model ensembles), or utilize novel data sources such as uncombined GNSS measurements.

2. Theory, Modeling and Measurements of Ionospheric Scintillations and Irregularities

Chairs: Keith Groves (Boston College, USA), Eurico de Paula (INPE, Brazil), P.T. Jayachandran (UNB, Canada) Luca Spogli (INGV, Italy)

Ionospheric irregularities and the resulting amplitude and phase scintillations on trans-ionospheric radio signals are critical aspects of space weather, influencing space-based communications and navigation. This session explores recent advances in understanding, measuring, and modeling these phenomena, with a focus on their climatology, morphology, and occurrence patterns.

Topics of interest include the spatial and temporal correlations of irregularities, their impact on radio wave propagation, and the relationship between different scintillation indices. Special attention will be given to scintillation effects on emerging GNSS signals (e.g., L2C and L5), as well as their implications for GNSS positioning accuracy and integrity. Contributions addressing the mitigation of scintillation effects in GPS and multi-GNSS applications—particularly for aviation, space-based augmentation, and ground-based augmentation systems—are highly encouraged.

This session also welcomes discussions on new measurement techniques, comparative analyses of scintillation observations with complementary sensor data, and the role of small-scale ionospheric structures in GNSS signal degradation. While global ionospheric models have advanced our understanding of large-scale irregularities, challenges remain in fully characterizing the generation and impact of small-scale structures. We seek contributions that bridge observations with theoretical predictions, particularly those leveraging multi-frequency scintillation data and power-law structure analyses.

3. Space and Ground-based Ionospheric Techniques and Measurements

Chairs: Anthea Coster (MIT Haystack, USA), Babatunde Rabiu (NASRDA, Nigeria), Martin Kriegel (DLR, Germany)

Accurate ionospheric measurements from both ground- and space-based techniques are essential for advancing ionospheric modeling, data assimilation, and space weather applications. A growing number of observational networks, GNSS constellations, and satellite missions are expanding the availability of key ionospheric parameters, including total electron content (TEC), electron density profiles, and ionospheric irregularities. These measurements play a crucial role in characterizing ionospheric conditions, improving forecasting capabilities, and mitigating the impact of space weather on communication and navigation systems.

Among space-based techniques, radio occultation (RO) has proven to be a powerful tool for probing the ionosphere, providing global electron density profiles and insights into ionospheric dynamics. RO measurements rely on phase and amplitude observations of GNSS signals as they traverse the atmosphere toward receivers onboard low Earth orbit (LEO) satellites. Inspired by the pioneering GPS/MET experiment, recent and ongoing RO missions—including

CHAMP, GRACE, SAC-C, FORMOSAT-3/COSMIC, Metop-A/B, C/NOFS, FORMOSAT-7/COSMIC-2, and commercial CubeSat constellations—have significantly enhanced the spatial and temporal coverage of ionospheric observations. The ability to track multiple GNSS constellations simultaneously is further revolutionizing ionospheric sensing, but advanced data processing techniques are needed to ensure the accuracy and reliability of higher-level products.

This session aims to provide a comprehensive overview of the availability, quality, and applications of both ground- and space-based ionospheric measurements. Topics of interest include advancements in GNSS-based monitoring, ionosonde networks, incoherent scatter radar, and RO techniques for ionospheric characterization. We encourage contributions that address multi-station or regional data integration, improved calibration methods, and innovative processing techniques for RO and other remote sensing methods. Additionally, studies focusing on the detection and mapping of ionospheric irregularities—such as sporadic-E layers and traveling ionospheric disturbances—are particularly welcome.

4. Effects of the polar (high latitude) atmosphere on satellite signals

Chairs: Lucilla Alfonsi (INGV, Italy), Wojciech J. Miloch (UiO, Norway)

This session invites contributions on satellite signals-based research and applications in high-latitude atmospheric regions. Topics of interest include the study of ionospheric irregularities, scintillation, and total electron content (TEC) gradients, all of which have significant impacts on satellite performance in these areas. We also welcome papers about ionized and neutral atmosphere coupling based on combination of in situ satellite, GNSS data and supported by ground-based measurements. Data collection efforts, development of data sets, modeling and processing techniques, and exploitation of infrastructures supporting high-latitude investigations are also of great interest.

Additionally, papers contrasting the ionospheric behavior at high and low latitudes, as well as interhemispheric comparisons, are encouraged.

We also seek contributions that highlight the implications of high-latitude research on a range of applications, including GNSS positioning, space weather forecasting, solid Earth and cryosphere studies, and remote sensing. Papers exploring these connections and their broader impact are welcome.

5. Space Weather Effects on GNSS

Chairs: Endawoke Yizengaw (Aerospace Corp. USA), and Joao Francisco Galera Monico (Unesp Presidente Prudente, Brazil), Sharafat Gadimova (ICG-UNOOSA, Austria)

Space weather events, caused by the coupling of solar wind into the magnetosphere and ionosphere (forcing from above) or by interactions between the lower thermosphere and ionosphere (forcing from below), significantly affect various GNSS applications, including

Positioning, Navigation, and Timing (PNT), communication systems, precision agriculture, and other applications. To effectively prepare for both short-term and long-term space weather impacts on modern society, it is crucial to enhance our understanding of space weather physics, improve forecasting capabilities, and develop strategies to mitigate its effects on technological infrastructure.

The goal of this session is to provide a platform for discussing space weather-driven ionospheric dynamics, particularly their impact on radio frequency applications. We welcome both observational and modeling contributions that deepen our understanding of the complexities of space weather effects, including studies on the drivers of strong ionospheric dynamics during magnetically quiet periods. We also invite papers that introduce techniques for mitigating the impact of space weather (with particular focus on low-latitude regions) on GNSS applications, including on the ground and space-based augmentation systems (SBAS/GBAS).

6. Monitoring Natural Hazards: Signatures of Earth and Ocean Coupling to the Ionosphere

Chairs: Attila Komjathy (JPL, USA), Elvira Astafyeva (IPGP, France)

Natural hazards such as earthquakes, volcanic eruptions, and tsunamis have long posed significant threats to human societies. Recent advancements in the use of Global Navigation Satellite Systems (GNSS), including GPS, GLONASS, Galileo, BeiDou, and others, have revolutionized the way we monitor and analyze these hazards. GNSS satellites now serve as crucial tools for detecting key signatures associated with natural events. These include seismic deformation measurements, co-seismic vertical displacements, and real-time ocean buoy positioning estimates.

Another exciting application of GNSS technology is the monitoring of ionospheric disturbances linked to seismic activity, volcanic eruptions, and tsunamis. By analyzing the total electron content (TEC) through both real-time and processed observations using ground-based and spaceborne GNSS measurements, we can observe ionospheric anomalies both before and after these events. The abundance of GNSS observations offers valuable insights into the geophysical mechanisms at play, the physics of wave propagation, and the electromagnetic coupling processes between Earth and the ionosphere.

We invite contributions that explore the societal benefits of routinely monitoring ionospheric and atmospheric disturbances linked to natural hazards. Submissions focusing on innovative approaches including e.g. parameter retrievals via ML/AI algorithms, to leveraging Earth-ionosphere coupling, particularly through acoustic gravity waves for monitoring seismic and tsunami risks, are especially encouraged.

7. Data Science (Advanced Statistical and Machine Learning Techniques) Applied to Ionospheric Studies.

Chairs: Jade Morton (Univ. of Colorado, USA), Claudio Cesaroni (INGV), Maria Graciela Molina (FACET-UNT, Argentina)

The ionosphere's impact on radio propagation is well-established, but accurately modeling these phenomena remains a challenge due to their complexity, many unknown aspects, and the incomplete understanding of ionospheric processes. Over the past few decades, advanced statistical and machine learning techniques have found widespread application across scientific fields, offering powerful tools to address complex physical scenarios that require more flexible and sophisticated modeling. Key advancements include uncovering correlations between diverse data sets and enabling computationally efficient predictions.

The application of these techniques to geosciences has evolved from a "proof of concept" phase to one where real-world research and operational applications are now possible. This session aims to showcase the current and next phase of applying advanced statistical and machine learning methods to ionospheric studies. Presentations will focus on using these techniques for ionospheric characterization, nowcasting and forecasting, and understanding their effects on radio propagation.

We invite contributions that explore the full spectrum of data science applied to the ionosphere, from data collection and management to analysis and communication. Topics of interest include, but are not limited to, efficient data management, correlation analysis between various ionospheric phenomena, prediction and forecasting of critical ionospheric variables using data-driven models, establishing causal relationships between ionospheric data and other phenomena, and comparing observed versus model-generated ionospheric data. We particularly encourage innovative ideas on how data science and machine learning can reshape the future of ionospheric research.

8. Emerging Topics of Interest to Beacon Satellite Studies

Chairs: Andrzej Krankowski (Univ. Warmia and Mazury, Poland), Bruno Nava (ICTP, Italy)

This session welcomes papers on emergent topics relevant to the Beacon Satellite Community. These papers can focus on new missions, new techniques and innovative applications of interest to the Beacon Satellite Community. The Beacon Satellite Symposium is historically meaningful as it has been a forum to present and discuss innovative topics relevant to radio propagation in our international community of radio scientists since the 1970s. This session also welcomes contributions relevant to Beacon Satellite Studies, particularly for topics not covered in other sessions.

9. Poster Session

Chairs: Yenca Migoya Orue' (ICTP, Italy), Claudio Cesaroni (INGV), Bruno Nava (ICTP, Italy)

This session will accommodate all BSS topics in a poster presentation format. This poster session will allow participants to disseminate research results and discuss in an interactive forum. Please submit your abstract to this session if you prefer a poster presentation. Due to limited oral presentation time slots and depending on the volume of accepted papers for each session, some authors will have the option to present their work in a poster format instead of an oral presentation. The poster session will also include the presentations by the students attending the pre-symposium Capacity Building Workshop.