SESSION DESCRIPTIONS

1. Irregularities and Scintillation Measurements and Effects
Chairs: Keith Groves (Boston College, US), Eurico de Paula (INPE, Brazil)

The occurrence of amplitude and phase scintillations on trans-ionospheric radio wave signals due to scattering by ionospheric irregularities is an important aspect of space weather that affects space-based communications and navigation systems in different ways. Advances and research in irregularities and scintillation measurements and effects are discussed in this session. Relevant topics include the characterization of irregularities focused on their climatology and morphology, spatial and temporal correlations and occurrence patterns, and their associated scintillation effects on radio wave propagation including the relationship between different scintillation indexes, effects of scintillation on new GPS signals (L2C and L5) and spatial/temporal/spectral characteristics and correlations. This section also targets the influence of irregularities and scintillation on GNSS positioning and the potential for threat reduction relative to GPS-only applications. Effects of irregularities on GNSS users are solicited, especially for space- and ground-based augmentation and aviation users, and discussion of important results, outstanding problems and challenges related to GNSS systems is welcome. New measurement techniques and comparisons of scintillation observations with other sensor data are of particular interest.

2. Theory and Modeling of Ionospheric Scintillation and Irregularities
Chairs: Chuck Rino (Boston College, US), Luca Spogli (INGV, Italy)

Radio propagation disturbances regularly observed on low earth-orbiting and GNSS satellites are attributed to intermediate-scale structure (tens of kilometers to hundreds of meters). This scintillation phenomenon is of practical concern because it can degrade satellite communication, navigation, and surveillance operations. The global monitoring capability of the GNSS has stimulated significant advances in our understanding of large-scale ionospheric structure. Several models are in use for predicting GNSS propagation disturbances. However, global ionospheric models have yet to fully reconcile the conditions for generation of intermediate-scale structure and its characterization for diagnostic measurement and performance prediction. This session seeks multi-frequency scintillation data analyses that attempt to reconcile observations with theoretical predictions based on definitive power-law structure and/or in-situ structure measurements.

3. Data Assimilation Modeling
Chairs: Matthew Angling (SPIRE, UK), Bruno Nava (ICTP, Italy)

Many models have been developed to describe the ionosphere. Median empirical models are able to characterize the ionospheric climatology, whilst first-principle models can represent many of the physical processes taking place in the ionosphere. However, in order to specify the ionospheric weather (i.e. processes and structures occurring over periods of hours and over medium spatial scales) data assimilation (DA) techniques must be used. These techniques can combine models with diverse kinds of data such as ground and space-based GNSS derived TEC, in situ electron density measurements, and ionosonde derived parameters. Indeed, many different DA methods have been applied to the ionosphere in recent years. These include Kalman Filters, 3 or 4-

dimensional variational methods and tomographic techniques. Contributions on the assimilation of ionospheric data into empirical or first-principle models are solicited for this session. Of particular interest are papers on the description and validation of new assimilation methods, methods that exploit multi-sensor observations, methods that exploit more than one model such as multi-model ensembles, and methods that use data in novel ways (such as uncombined GNSS measurements).

4. Modeling and Validation

Chairs: Manuel Hernandez-Pajares (UPC, Spain), Anna Belehaki (NOA, Greece)

Advances in observations have revealed anomalies and structure in the ionosphere previously unmodeled. For instance, ground-based GNSS networks and radio occultation have revealed three or four peaks in the F-region plasma density latitude structure, rather than the typical two peaks associated with the traditional equatorial ionization anomalies (EIAs). In addition, during strong geomagnetic activity, storm-enhanced densities at mid-latitudes can dominate the global structure and create steep gradients in plasma density. Furthermore, new ionosonde and digisonde observations, as well as the GNSS observations, have enabled visualization of the complex high-resolution ionospheric wave structure seen as TIDs and MSTIDs, driven by waves from the lower atmosphere and from the auroral sources propagating through the thermosphere. This session targets new modeling capabilities, including thermosphere-ionosphere, whole atmosphere-ionosphere, and magnetosphere-ionosphere-thermosphere models, that are able to capture these anomalies, structure, and features, and potential applications (e.g. tsunami warning). This session also targets the challenge of developing appropriate metrics to validate the existing and new modeling capabilities. Note that this session does not specifically target new data assimilation techniques, or ionospheric structure associated with equatorial irregularities, which are covered by other sessions.

5. Space and Ground-based TEC Techniques and Measurements

Chairs*:* David Themens (Univ. Birmingham, UK), Babatunde Rabiu (NASRDA, Nigeria), Sandro Radicella (BC/ICTP, Italy)

Availability and quality of ground- and space-based TEC measurements are critical to ionospheric modeling efforts and data assimilative processes. A number of initiatives have led to deployment of ground observational networks capable of measuring TEC in regions hitherto dearth of TEC data. The increasing amount of available GNSS constellations, ground networks of receiving stations and altimetry missions able to increase the number of accessible measurements is an important contribution to the data availability. Space based TEC data are being used more and more to characterize the ionosphere under different solar-geomagnetic conditions mainly through radio-occultation techniques. Differences in performance of different TEC calibration techniques remain a problem particularly when data are used for model validation or assimilation. The session conveners aim to get an updated vision of the availability of ground and space based high quality TEC data and their use to advanced characterization of ionospheric conditions. Authors are encouraged to present their results obtained using TEC ground and space measurements with special attention to multi-station or regional coverage and estimate of data retrieval accuracy.

6. Space-based Radio Occultation Techniques and Measurements

Chairs: Jan-Peter Weiss (UCAR, US), Giorgio Savastano (Spire Global, Luxembourg)

A number of space-based radio occultation (RO) techniques have been exploited to study the structure and properties of the Earth's atmosphere. Phase and amplitude measurements of radio waves transmitted from GNSS satellites (Tx) are collected in an atmospheric limb sounding geometry where the GNSS receiver (Rx) is on a LEO satellite. As the LEO satellite moves in its orbit, the GNSS satellite is seen to rise above or set below the horizon. Thus, the raypath from the Tx to Rx is quasi horizontal and can be characterized by the height of its tangent point. By examining amplitude and phase fluctuations on long slant paths through the ionosphere, researchers have mapped global electron content and scintillation patterns. A number of recent missions, inspired by the successful GPS/MET experiment, have produced fruitful ionospheric RO datasets including the CHAMP, GRACE, SAC-C, FORMOSAT-3/COSMIC, Metop-A/B, C/NOFS satellite, FORMOSAT-7/COSMIC-2, and commercial cubesat missions. The proliferation of satellites and ability to simultaneously record signals from multiple GNSS constellations are exponentially expanding the coverage of RO sensing. The abundant and diverse data require advanced processing techniques to enhance the reliability and accuracy of higher level data products for use in ionosphere specification and forecasting applications. We welcome contributions on techniques to advance and improve the applications of RO for space environment models, innovative methodologies addressing current problems with RO inversion techniques, geolocating ionospheric irregularities along RO slant paths, along with descriptions of improved solutions for identifying and mapping the occurrence of ionospheric perturbations such as sporadic-E and travelling ionospheric disturbances.

7. Polar (high-latitude) Effects on GNSS

Chairs: Lucilla Alfonsi (INGV, Italy), Nicolas Bergeot (Royal Obs. Belgium)

This session solicits contributions on GNSS-based research and applications at high latitudes. Studies dealing with ionospheric irregularities, scintillation and total electron content (TEC) gradients are of interest. Papers dealing with GNSS data collection, data sets, model and processing developments and infrastructure available to support investigations are also welcome, as are those where GNSS is one part of a multi-instrument approach in particular in conjunction with incoherent scatter radars. Finally, papers highlighting and contrasting the differences and similarities at high and low latitudes and bi-polar comparisons are of interest. Impacts of research results on different applications such as positioning, space weather, solid Earth, cryosphere research and remote sensing are also highly encouraged.

8. Space Weather Effects

Chairs: Endawoke Yizengaw (Aerospace Corp. US), and Joao Francisco Galera (Unesp Presidente Prudente, Brazil), Iwona Stanislawska (Polish Academy of Science, Poland)

Space weather events become noticeable in the geospace system either by the direct action of solar flares onto the atmosphere or through the coupling of the solar wind into the magnetosphere and ionosphere via the geomagnetic field or due to the forcing from lower thermosphere. The resulting effects can impact positioning, navigation, and communications. The best way to prepare for near- and long-term space-weather impacts on modern society is to improve our ability in understanding the physics and forecasting space weather conditions and to fully realize and mitigate its impact on our technological infrastructure. The goal of this session is to provide a forum for discussing space weather driven ionospheric dynamics in the context of radio frequency applications for operations. We welcome papers that fully or partially contribute to the effort of addressing the following questions:

- How can ionospheric monitoring and modelling be utilized to further our understanding of space weather in its complexity?
- How can ionospheric monitoring and modelling help to mitigate the impact of positioning and navigation applications?
- How are ionospheric dynamics impacted by energy inputs, either directly from the sun or indirectly via coupling processes with other geospheres such as the thermosphere and magnetosphere?
- What is the driver of the magnetically quiet time strong ionospheric dynamics that has strong impact on RF communications, is it due to the forcing from below, e.g., gravity wave forcing? If so, how can it be characterized as a function of longitude, local time and season?
- How can ionospheric dynamics be described, benchmarked and forecasted effectively to correct and mitigate the ionospheric impact on applications utilizing trans-ionospheric radio signals?
- How can this information be provided to customers in an appropriate form according to their needs, e.g. considering latency, temporal and spatial resolution, and reliability, taking into account international perspectives on observations, modeling and forecasting?

9. Ionospheric Effects on GNSS Augmentation Systems
Chairs: Sharafat Gadimova (United Nations, Austria), Ashik Paul (Univ. Calcutta, India)
This session will address ionospheric effects on global navigation satellite augmentation systems. Dual-frequency signals transmitted by navigation satellite systems offer an excellent means to monitor and study ionospheric total electron content (TEC) and ionospheric irregularities. Those ionospheric characteristics are of great importance not only for satellite navigation, but also for ionospheric and space weather monitoring and research. Currently, hundreds of global navigation satellite systems (GNSS) receivers around the globe are able to obtain information about ionospheric conditions at any time. That information complements and integrates substantially the amount of ionospheric data available from other sources. A good understanding of the challenges posed by the ionosphere could provide important insights into the development of GNSS augmentation systems. These systems may include regional augmentation systems such as Satellite-Based Augmentation Systems (SBAS) and Ground-Based Augmentation Systems (GBAS). Several SBAS are deployed and provide currently operational signals to their users: the Wide Area Augmentation System (WAAS) of the United States, the European Geostationary Navigation Overlay Service (EGNOS), the System for Differential Corrections and Monitoring (SDCM) of the Russian Federation, the Global Positioning System (GPS) Aided Geo Augmented Navigation (GAGAN) of India, and the Multi-functional Satellite Augmentation System (MSAS) of Japan. Therefore, SBAS providing service to low-latitude regions will be more affected than those at other latitudes. This session invites abstracts related to performance assessments of systems affected by ionospheric effects, mitigation techniques, effects on users and program status of navigation satellite systems.

10. Monitoring Natural Hazards: Signatures of Earth-Ocean Coupling to the Ionosphere
Chairs: Attila Komjathy (JPL, US), Sergey Pulinets (Russian Academy of Sciences, Russia)
Natural hazards, including earthquakes, volcanic eruptions, and tsunamis have been significant threats to humans throughout recorded history. The Global Navigation Satellite System (GNSS)

satellites including GPS, GLONASS, Galileo, BeiDou and others have become primary sensors to measure signatures associated with such natural hazards. These signatures typically include GNSS-derived seismic deformation measurements, co-seismic vertical displacements, and real-time GNSS-measured ocean buoy positioning estimates. Another way to use GNSS observables is to compute the ionospheric total electron content (TEC) monitor post-seismic and pre-seismic ionospheric disturbances caused by earthquakes, volcanic eruptions, and tsunamis using ground-based and spaceborne GNSS measurements. These measurements provide new scientific insight into the geophysical source phenomenology, wave propagation physics, and electromagnetic coupling processes. We solicit observational, theoretical and modeling contributions that specifically address the societal benefits that can be realized through the routine monitoring of atmospheric and ionospheric disturbances. Innovative concepts for the monitoring of seismic and tsunami hazards that make use of Earth to ionosphere coupling via acoustic gravity waves are particularly welcome. Contributions are solicited about the ionospheric impact of Tonga eruption on January 15, 2022 using GNSS measurements. Precursory signals and perturbations consecutive to recent earthquakes are also pertinent. With improved knowledge of the various geophysical processes involved, these means have the potential to enhance natural hazards warning systems in order to save human life and mitigate economic damage.

11. GNSS for Atmospheric Measurement and Modeling

Chairs: Richard Langley (Univ. New Brunswick, Canada), Ron Caton (AFRL, USA)

While ionospheric measurements using multi-frequency GNSS observations have been instrumental in ionospheric science, GNSS measurements of the atmosphere are similarly valuable for atmospheric monitoring. From its first use in the estimation of tropospheric zenith wet delay and perceptible water vapour, GNSS has seen renewed application in atmospheric science through radio occultation missions, such as COSMIC I/II and CYGNSS. Now with emerging techniques in GNSS reflectometry (GNSS-R), GNSS has found further utility for atmospheric and oceanic measurement and monitoring. This session invites participation from those who conduct atmospheric measurements using GNSS or who apply these measurements to further our understanding of the atmosphere and improve our capacity to forecast its impacts.

12. Recent Advances in Radio Science Techniques, Measurements, and Capabilities for Geospace Remote Sensing

Chairs: Anthea Coster (MIT Haystack,US), Andrzej Krankowski (Univ. Warmia and Mazury, Poland) and Jade Morton (Univ. of Colorado, USA)

The 21st century has seen a rapid increase in new hardware and software techniques for radio based remote sensing of Earth's atmosphere. Many advances have been made due to the development of network capable software defined radios (SDRs), the development of large and sensitive phased array technologies, and the further advancement of digital signal processing techniques for adaptive sensing. Work on these capabilities has often occurred in areas beyond ionospheric science. For example, radio astronomy science requires measuring lower level signals from the epoch of reionization, fast radio bursts, and pulsars, and these drivers have resulted in a new suite of flexible, multi-role radio telescopes operating below 300 MHz with wideband capabilities across the entire lower VHF band. In general, the rapid advance of network bandwidths combined with radio sensor technology has unlocked new synergies that enable

common radio apertures and analysis techniques with near-simultaneous applications in astronomy, aeronomy, and space weather. This session seeks presentations that discuss the advantages and opportunities provided by these new techniques, especially when applied to critically important measurements of the ionosphere and space weather effects.

13. Data Science Analysis (Advanced Statistical and Machine Learning Techniques) Applied to Ionosphere Specification, Forecast and Effects on Radio Propagation
Chairs: Ryan McGranaghan (ASTRA, US), Shasha Zou (Univ. of Michigan, US), Claudio Cesaroni (INGV, Italy)
Ionospheric effects on radio propagation are well known, but the accurate modelling of the corresponding phenomena is not always possible due to their complexity, unknown aspects of ionospheric phenomena or the incomplete understanding about them. Recent decades have seen widespread application of advanced statistical and machine learning techniques in many areas of science in which complex physical situations require more expressive model capacity. Key areas of progress have been insights into the correlations between different data and computationally efficient predictions, to name a few. Tools and knowledge about these techniques within the geosciences are now leaving a 'proof of concept' phase and can be applied to create research and operational impact. Therefore, this session seeks to highlight this new phase of application of advanced statistical and machine learning approaches to the ionosphere. Presentations will encompass examples of those techniques related to ionosphere specification, forecast and effects on radio propagation. We welcome contributions that span the full breadth of data science for the ionosphere: data collection, management, analysis, and communication. Topics include, but are not restricted to, correlation analysis between data related to different phenomenon, prediction/forecast of critical ionospheric variables using data-oriented models, establishing casualty between different phenomena/data focusing on ionospheric data, and comparison of observed and model-generated ionospheric data. We welcome novel thinking about the role of data science and machine learning in ionospheric studies.

14. Emerging Topics of Interest to Beacon Satellite Studies
Chair: Patricia Doherty (Boston College, US), Andrzej Krankowski (UNiv. Warmia and Mazury, Poland), and 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 Symposia 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.

15. Poster Session
Chairs: Teddy Surco (BC, USA), Yenca Migoye Orue (ICTP, Italy), Kacper Katulak (Univ. Warmia and Mazury, Poland)
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. If you prefer a poster presentation, please submit your abstract to this session. Due to limited oral presentation time slots and the number of papers for each session, some accepted papers that cannot fit in as oral presentations will be offered an opportunity to present the paper in a poster format.