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The International Reference Ionosphere and NeQuick – Improving the Representation of the Real-Time Ionosphere | (SMR 4164)

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T01

RECENT DEVELOPMENTS IN MODELLING AND IMAGING OF IONOSPHERIC PARAMETERS

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The International Reference Ionosphere (IRI), International Reference Ionosphere Extended to Plasmasphere (IRI-Plas) and NeQuick are the foremost climatic empirical models of ionsphere and plasmasphere. They provide hourly-monthly median based coefficients that can be applied to any region in the ionosphere and they are very successful in reproducing electron density profiles (Ne) for quite geomagnetic state and usually for midlatitude coordinates, especially for Europe and North America where the contributing ionosondes are mostly located. One of the major drawbacks of these models is the deterministic outcomes that usually fail to represent the variabilities and anomalies of the ionosphere. IONOLAB group have been developing algorithms for better imaging and modelling of ionospheric parameters for almost a quarter of a century. In this study, we will present two of the recent developments in representation of stochastic trend of ionosphere and plasmasphere. In the first group, we introduce planar Total Electron Content (TEC) trend model parameters of 48 midlatitude regions of dimensions 10^0 in latitude and 20^0 in longitude for 25 years starting from Jan 1, 2000 at 00 UT with 2 h time resolution. The three model parameters are available at https://www.ee.hacettepe.edu.tr/~solen/_PlanarTrendModel. The estimated model parameters are an important resource for stochastic modeling and prediction of midlatitude ionospheric trend. In the second group, we demonstrate a novel algorithm for generating Slant Total Electron Content (STEC) maps that inherently include the azimuthal anisotropicity in near-real time. The developed algorithm, IONOLAB-SMAP, produces high spatio-temporal Kriging based interpolation of STEC that can be implemented for any region in the globe. The strength of the algorithm is firstly due a novel preprocessing routine that distributes the STEC values over rough space-time grid, and secondly, implements Ordinary Kriging with Matern semivariogram function whose parameters are estimated using Particle Swarm Optimization automatically. The IONOLAB-SMAPs are to be utilized in high spatio-temporal resolution interpolation of foF2 using novel Co-Kriging in regions that have sparse or no ionosonde stations, namely, IONOLAB-coK, in near-real time. The high spatio-temporal resolution foF2 can then be input into ionospheric model to update the coefficients of IRI, IRI-Plas and NeQuick.

T02

Important aspects relevant to monitoring of Sporadic E Layers

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ABSTRACT

Sporadic E (Es) refers to layers of enhanced electron density in the E region ionosphere between ~90 and 120 km. These layers can be observed with ground-based (ionospheric sounders) and space based (GNSS radio-occultation satellite missions) monitoring techniques which enable the characterisation of the systematic features of Es variability. The ionosonde key parameters related to sporadic E are the ordinary wave critical frequency foEs and the layer virtual height h'Es. Recent findings have highlighted that 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. Moreover, the real Es height, hEs, is typically accepted to be equal to the virtual height (hEs ≃ h'Es) based on the assumption that the ionosonde signal suffers negligible retardation in the lower E region below the Es layer. This approximation is valid during nighttime but not during daytime, especially for weak layers in upper altitudes. To address these two Es related aspects, this presentation will underline recent results over specific European Digisondes highlighting the significance of a new parameter (foμEs), proposed by Haldoupis to better represent the Es layer metal plasma density and the application of a simple method to estimate sporadic E real heights hEs more accurately using the ionosonde-measured Es parameters and E region electron density profiles.

Keywords: Sporadic E layers (Es), foEs, foμEs, hEs, h'Es, real-virtual Es height, sporadic E diurnal variation, metal atom photoionization

Ionosphere specification and long-term variability analysis based on the COSMIC-2 space weather products after 5 years in orbit

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The misrepresentation of the peak ionosphere parameters, along with plasma density vertical distribution of plasma density above the F2 layer peak and electron content within and above the F2 layer is the challenging for empirical and physics-based ionospheric models. The low latitude region with large scale features of equatorial ionization anomaly, its seasonal and solar cycle variations is the most difficult to specify. The long-term datasets of ionospheric observations with stable accuracy are important source to capture climatological dependencies in different regions of the ionosphere and plasmasphere, which is ultimately necessary for the models' validation and improvement.

LEO GNSS radio occultation measurements serve as unique data source to retrieve electron density distributions above the F2 layer peak, as well as electron content above the LEO orbit with a global coverage. COSMIC-2 mission was developed for operational monitoring of the low latitude atmosphere and ionosphere, it offers several high-quality products suitable for retrieving of the topside ionosphere and plasmasphere climatology dependencies over the challenging equatorial region. In particular, accuracy of the electron density profiles (EDPs) and absolute total electron content (aTEC) products were thoroughly validated to be considered as the reference.

During more than 5 years of COSMIC-2 operation in orbit, UCAR CDAAC collected valuable dataset covered continuously temporal intervals corresponded to low, mid, and high levels solar activity including solar maximum of the current solar cycle 25.

With combination of the COSMIC-2 EDPs and aTEC products, we retrieved climatological dependencies of key parameters around F2 layer peak, topside ionosphere and plasmasphere. We investigated seasonal and solar cycle driven climatological dependencies of F2 layer peak parameters (used as the main anchor point in the ionospherc models), climatology of electron content below (bottomside) and above (topside) F2 peak, as well as contribution of bottomside and topside regions of the ionosphere to the ground-based TEC by combination of the COSMIC-2 ionospheric measurements with IGS global ionospheric TEC maps.

Using observational results for various seasons and solar activity levels, we assessed performance of the empirical ionospheric models, IRI and NeQuick, revealing discrepancies that require improvement to properly represent the topside ionosphere and plasmasphere by these models.

T04

The use of NeQuick and IRI models in support of NanoMagSat mission design and prospect on its ionospheric data

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3D empirical ionospheric models like NeQuick and IRI are extremely important for assessment studies involving radio propagation through the ionosphere. Implementing specific algorithms to compute electron density profiles along any satellite-to-satellite line-of-sight enables to simulate future space missions, for instance for ionospheric radio-occultation or topside TEC. We followed this approach to evaluate the ability of the upcoming NanoMagSat mission to record ionospheric occultations with GPS and Galileo constellations. This mission will be dedicated to the observation of the Earth magnetic field and the ionospheric environment, using scalar and vector magnetometers associated with star cameras, Langmuir probes, and dual frequencies GNSS receivers and antennas. NanoMagSat mission will deploy three identical satellites on Low Earth Orbits: one polar, the other two inclined at 60°. The launches are planned at the end of 2027 and in 2028, when the Swarm satellites will still be in orbit, providing an unprecedented spatial coverage for monitoring the geomagnetic environment. NanoMagSat will acquire magnetic field data at 2 kHz sampling rate, enabling the observation of ELF signals propagating through the ionosphere. This will enable the observation of lightning-generated whistlers. We recently demonstrated that it is possible to use these signals to obtain a measurement of the ionospheric environment below the satellite altitude. Radio propagation in this frequency band is strongly dependent on the direction of the Earth magnetic field and at first order the group delay is proportional to the integral of the square root of the electron density along the propagation path. We defined this quantity as TREC and both Swarm and NanoMagSat have capabilities for measuring it. We present the opportunities that Swarm and NanoMagSat space missions have to monitor the ionospheric environment and the data they offer to test, validate and improve IRI and NeQuick models.

T05

Global Empirical Model of Sporadic-E Occurrence Rates: GEMSOR

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Global sporadic-E (Es) observations and models have historically relied on ionosonde observations, which provide direct measurements of parameters such as foEs, fbEs, and h'Es. While global networks of ionosondes have been used to develop worldwide Es Occurrence Rate (OR) models [1], large gaps in coverage over the oceans and high-latitudes require interpolation to predict ORs between widely separated ionosonde sites. With recent improvements in Global Navigation Satellite System (GNSS) Radio Occultation (RO) techniques for monitoring sporadic-E, truly global coverage is currently available for the vertically thin Es disturbances that strongly perturb GNSS-RO signals. However, interpretation of GNSS-RO observations is non-trivial, requiring a comparison to trusted ionosonde observations to refine Es monitoring techniques. In this talk, we discuss the development of the Global Empirical Model of Sporadic-E Occurrence Rates (GEMSOR), which uses a combination of GNSS-RO and ionosonde data to provide worldwide empirical ORs for blanketing sporadic-E with fbEs ≥ 3 MHz [2]. GEMSOR enhances the spatiotemporal resolution of a global dataset of monthly ORs as a function of both geomagnetic latitude and local time [3] through the use of a Karhunen–Loéve Expansion (KLE). This driving global OR dataset was developed by combining modern ionosonde observations from the Global Ionosphere Radio Observatory (GIRO) [4] with an appropriate GNSS-RO technique that shows strong agreement with ionosonde-based ORs for fbEs ≥ 3 MHz [5]. The ionosonde and GNSS-RO techniques will be introduced along with the KLE approach and interpolation used to enhance spatiotemporal resolution. Global seasonal and diurnal trends will be presented with a preliminary comparison against ionosonde observations to highlight model performance, uncertainties, and areas for improvement. While GEMSOR is limited to ORs for blanketing sporadic-E with fbEs ≥ 3 MHz, the model provides an empirical estimate for this important ionospheric disturbance that can be easily implemented and rapidly executed in a manner similar to IRI and NeQuick.

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T06

Ionospheric modelling: irregularities and impact

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The electron density in the ionosphere is a function that varies not only in height but also in the other two coordinates. These variations lead to an inhomogeneous and non-uniform spatial function that also evolves in time. The presence of inhomogeneities in the ionosphere is due to the action of various plasma instability mechanisms: these instabilities can produce inhomogeneities characterised by gradients in the electron density function occurring over different spatial scales.

When radio waves propagate through inhomogeneities (or irregularities) in the ionosphere, various propagation effects can be observed. In particular, radio wave scintillation arises from the scattering through irregularities with spatial scales within the inertial subrange (which depends on the radio wave frequency).

This contribution will illustrate examples of attempts to characterise ionospheric irregularities and propagation effects such as scintillation. An interesting aspect related to ionospheric propagation effects is their role in a variety of systems: these propagation effects can indeed affect the technology behind a particular system. This is the case of GNSS and applications reliant upon GNSS, Earth observation, radio astronomy. This contribution will share reflections on the impact that ionospheric irregularities can have on systems in the presence of adverse space weather conditions.

T07

Performance of TEC models aided by IRI and NEDM in single point positioning

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Dual-frequency altimetry missions, such as TOPEX– Poseidon and Jason, are excellent sources of vertical total electron content (TEC) data that can be directly observed over the oceans independently of the Global Navigation Satellite System (GNSS) systems. In contrast to GNSS techniques, the altimeter measurements are naturally vertical, so no mapping function is required to convert them to the vertical. However, the altimeter data contains TEC data from the sea surface up to satellite orbit height. That means, the altimeter data does not include the topside ionosphere/plasmasphere contribution above the satellite height in contrast to the GNSS TEC data. In the current work, the topside TEC contribution above the altimeter satellite is derived using empirical 3-D ionosphere models such as the International Reference Ionosphere (IRI) and Neustrelitz Electron Density Model (NEDM2020) and added to the altimeter data for obtaining GNSS equivalent TEC data. Later machine learning based TEC models are developed from corrected altimeter data [1]. We will present the comparison between the IRI and NEDM aided models in single point positioning applications.

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T08

The May 2024 Mother's Day superstorm: an ionosonde synoptic view

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ABSTRACT

The geomagnetic storm that occurred in May 2024 was the most intense event recorded since the major storm of November 2003, reaching a minimum value of the Disturbance Storm Time (Dst) index of –412 nT. This paper presents a comprehensive synoptic view of the ionospheric response to this event, focusing on variations of the critical frequency of the F2 layer (foF2). The analysis is based on validated data collected from 34 ionosondes distributed globally, covering the time period from 10 to 14 May 2024. This time window includes both the main phase of the storm and the subsequent recovery phase, providing a detailed temporal and spatial perspective of the ionospheric disturbances. In addition to the observational analysis, the study includes a comparative assessment with the International Reference Ionosphere (IRI) model. Differences between the observed data and model predictions are discussed in the context of storm-time dynamics, highlighting the limitations of IRI under extreme geomagnetic conditions. This comparison also aims to identify possible pathways for improving ionospheric modeling capabilities, particularly during space weather events of this kind.

Keywords: Mother's Day superstorm, Ionosonde, IRI, foF2

T09

Improving the NeQuick model in the topside ionosphere and plasmasphere through COSMIC-1 radio occultation and POD TEC observations

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The NeQuick model utilizes three empirical parameters (H_0, g, and r) to define the effective scale height, which drives vertical electron density variations, in the topside ionosphere and plasmasphere. Previous studies have identified some weaknesses in the NeQuick topside model connected to a sub-optimal description of the effective scale height; in particular, the underestimation of the plasmaspheric contribution to the total electron content (TEC). The present study tries to address these shortcomings using radio occultation (RO) electron density profiles from COSMIC-1 satellites and TEC measurements from the same mission derived from precise orbit determination (POD) antennas.
We developed a novel two-step optimization procedure for the NeQuick r parameter, which is critical for describing the plasmaspheric electron density. This process initially derives H_0, g, and r from RO observations and subsequently refines the r parameter by incorporating POD-derived TEC data, yielding a more robust representation of the plasmasphere. The optimized r parameters, derived from a dataset spanning from 2006 to 2018, demonstrate improved consistency with effective scale height observations in the plasmasphere from the Van Allen Probes. The results reveal that the improved parametrization of r better captures the spatial, temporal, and solar activity-dependent variations in the topside ionosphere and plasmasphere compared to the fixed value traditionally used in the NeQuick model.
The proposed updates to the NeQuick topside model provide a more accurate framework for modeling the electron density in the topside ionosphere and plasmasphere, by potentially reducing errors in TEC estimates and advancing the NeQuick model use in space weather and trans-ionospheric propagation applications. Results derived in this study are the basis for the future development of a revised version of the NeQuick topside model.

T10

1990-2020, thirty years of ionosphere modelling at ICTP

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The Aeronomy and Radio Propagation Laboratory of ICTP was created in the year 1990. During the following thirty years the activities in the field of ionosphere research of this laboratory was heavily concerned with modeling 3D ionosphere electron density at regional and global scale. ARPL was involved in the ionosphere research European COST (Co-operation in the field of Scientific and Technical Research) Actions from 1990 to 2004. The ionosphere modeling contributions of ARPL to these actions will be summarized. An important electron density modeling effort of the ICTP ARPL was to carry out yearly International Reference Ionosphere (IRI) Task Force activities in Trieste from 1994 to 2004 to contribute actively to the IRI electron density The cooperation between the ARPL and the IRI continued during the next twenty years. model development. The approach used and the main contributions of this series of Activities held at ICTP will be summarized. The cooperation between the ARPL and the IRI continued during the next twenty years. Since the start of the new century the ICTP ionosphere team contribution to ionosphere modeling was strongly related to the European Space Agency (ESA) and European Commission efforts in the area of satellite navigation and positioning. This contribution was given through the development of “climate” electron density models and the strategies to adapt such models to “weather like” conditions of the ionosphere for both the EGNOS and Galileo satellite navigation programs of ESA and the European Commission. These models and strategies will be briefly described.

T11

Comparison of Sporadic E Occurrence using COSMIC and Ionosonde data in Thailand region

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Abstract

Sporadic E phenomenon is an important ionospheric parameter to characterize the E-layer irregularity. Recently, global sporadic E occurrences receive much attention as a potential new addition to the IRI model [1-2]. In this work, we analyze the sporadic E occurrences from ground-based ionosonde station and space-based COSMIC-2 satellite data. Some datasets during the 24th solar cycle from Frequency Modulated Continuous Waves (FMCW) ionosonde at Chumphon (CPN) station in Thailand are used in this work. For COSMIC-2 data, we select the altitudes between 90 and 130 km, and the area in Southeast Asia region, i.e., longitudes between 90 and 120 degrees, and latitudes between 0 and 20 degress. Preliminary results show that the sporadic E occurrence rate from both data sources are comparable although there are occasional discrepancies.

Keywords: Equatorial Spread-F, Cubic B-splines, FMCW ionosonde, Virtual height of F-layer.

Acknow;edgement:

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T12

Real time IRI and NeQuick Data Assimilation with TOMIRIS and AIDA

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The International Reference Ionosphere (IRI) and NeQuick models are well known for their capacity to represent ionospheric climatology and generally outperform most other non-data assimilation ionospheric models; however, during active periods, when the ionosphere is not well represented by climatology, these models can suffer reduced performance. To remedy this, a number of groups have pursued the development of data assimilation systems that update these models with observations to better represent real ionospheric conditions. Many such models currently exist, but only relatively few operate in real time, the most popular of which, being the IRTAM system. IRTAM takes advantage of the original structure of the IRI's foF2 and MUF(3000)F2 maps to generate updates that can be directly used with the IRI. This structure, however, sets some limits on the types and distribution of data that can be used in that system, mainly that there must be a 24-hour time history of observations at a particular location and those observations must be direct measurements of the assimilation's modeled variables.

An alternative to this approach, while still using a highly parameterized state, has been developed for high latitudes in the form of the Assimilation Canadian High Arctic Ionospheric Model (A-CHAIM). A-CHAIM uses a particle filter to ingest a wide array of different ionospheric observations, including Global Navigation Satellite System (GNSS), ionosonde, radio occultation, altimeter, riometer, and UV imager data, to generate a real time reconstruction of the high latitude ionosphere by updating the internal parameterization of the Empirical Canadian High Arctic Ionospheric Model (E-CHAIM). This model, however, is limited solely to high latitude regions.

More recently, we have created new data assimilation systems using the A-CHAIM framework but with global background models, specifically NeQuick (AIDA) and the IRI (TOMIRIS). In this presentation, I'll give an overview of these new systems, discuss their validation, provide information on how to access and use the output, and discuss the relative merits of real time vs. near real time data assimilation under varying geomagnetic activity conditions.

T13

Near-real time modelling of the ionospheric electron density based on satellite and ionosonde observations

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In this study we proposed a near-real time modelling for describing the three-dimensional ionospheric electron density distributions. Observations have been taken from the electron density profiles of radio occultation data of COSMIC. Five sub-models, including the F2 peak maximum electron density (NmF2), height (hmF2), scale height around the F2 peak, as well as above and below the F2 peak have been constructed. Near-real time observations of the NmF2 and hmF2 from the ionosonde has been used to drive the corresponding sub-models, in order to realize the near-real time prediction of the ionosphere. To achieve the best performance, multi-parameter least-square fitting as well as the machine learning approaches have been used for comparison. Our results indicate that the machine learning technique has its advantage for near-real time prediction of ionospheric electron density.