Model Development for the Next Generation Ionosphere and Plasmasphere Forecasting

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The Ionosphere-Plasmasphere-Electrodynamics (IPE) model is a new, time dependent, 3-D model of ionosphere and plasmasphere recently developed through collaboration between University of Colorado, George Mason University, NOAA Space Weather Prediction Center (SWPC), NOAA Global Systems Division (GSD), and NCAR High Altitude Observatory (HAO). It provides time dependent, global, three-dimensional plasma densities for nine ion species, electron and ion temperatures, and both parallel and perpendicular velocities of the ionosphere and plasmasphere. IPE is capable of producing the climatology of global total electron content (TEC) as well as the storm-time responses in the system, such as Storm Enhanced Density (SED). Driving the IPE with the Whole Atmosphere Model (WAM), an extended version of Global Forecast System (GFS), ionospheric change associated with large scale meteorological events (such as Sudden Stratospheric Warming) and day-to-day varying thermospheric tides can be captured. The WAM and IPE model are currently coupled through using the Earth System Modeling Framework (ESMF) and the one-way coupled WAM-IPE is scheduled to be in operation in NOAA SWPC in fall 2017. In this presentation, an overview of the WAM-IPE model development and its current status will be presented. Furthermore, the preliminary results from several research projects associated with the coupled WAM-IPE model will be discussed.

Keywords: Ionospheric forecast, ionosphere and thermosphere

The ionospheric pre-reversal enhancement electric field modeling by coupled thermosphere-ionosphere data assimilation system

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We report that assimilating total electron content (TEC) into a coupled thermosphere-ionosphere model by using the ensemble Kalman filter (EnKF) results in improved specification and forecast of eastward pre-reversal enhancement (PRE) electric field (E-field). Through data assimilation, the ionospheric plasma density, thermospheric winds, temperature and compositions are adjusted simultaneously. The improvement of dusk-side PRE E-field calculation over the prior state is achieved primarily by intensification of eastward neutral wind. The improved E-field calculation promotes a stronger plasma fountain and deepens the equatorial trough. As a result, the horizontal gradients of Pedersen conductivity and eastward wind are increased due to greater zonal electron density gradient and smaller ion drag at dusk, respectively. Such modifications provide preferable conditions and obtain a strengthened PRE magnitude closer to the observation. The adjustment of PRE E-field is enabled through self-consistent thermosphere and ionosphere coupling processes captured in the model. This study suggests that the PRE E-field that is critical in driving the evening equatorial plasma instability could be better forecasted by assimilation of TECs in the 10 minutes cycling.

Keywords: ionospheric data assimilation model, pre-reversal enhancement, electric field

Recent activity and future plan of ionospheric observation in NICT

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National Institute of Information and Communications Technology (NICT) has been observing ionosphere by ionosondes for over 70 years in Japan. At present, four ionosondes at Wakkanai(Sarobetsu), Kokubunji, Yamagawa, Okinawa(Ogimi) are automatically operated and controlled from Tokyo. We have been replacing the current 10C type ionosondes with Vertical Incidence Pulsed Ionospheric Radar 2 (VIPIR2) ionosondes which can separate the O-mode and X-mode ionospheric echoes automatically. In addition to ionosonde observations, we have developed two-dimensional total electron content (TEC) observation technique over Japan using the dense GNSS network, GEONET since mid-1990s. The TEC maps are now available on a realtime basis using streaming data of GEONET. We have developed ionospheric storm monitoring system based on the realtime observation data and a new ionospheric strom scale, I-scale, which is defined using the long-term ionospheric data in Japan.In addition to the ionospehric observations in Japan, we has developed the Southeast Asia low-latitude ionospheric network (SEALION) for the purpose of monitoring and researching severe ionospheric disturbances, such as plasma bubble. SEALION mainly consists of five FMCW ionosondes in four countries in Southeast Asia: Chiang Mai and Chumphon (Thailand), Kototabang (Indonesia), Bac Lieu (Vietnam) and Cebu (Philippines). We are now developing a new FMCW ionosonde system which is GNU Radio based software defined system. Observations of HF transequatorial propagation between Japan and Australia have also been used to research the generation and propagation characteristics of plasma bubbles. In this presentation, we will introduce recent activity and future plan of ionospheric observation in NICT.

Keywords: ionospehre, ionospheric storm, space weather, plasma bubble, ionosonde, GPS-TEC

Global Three-Dimensional Ionospheric Data Assimilation Model Using Ground-based GPS and Radio Occultation Total Electron Content

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In this study, an ionospheric data assimilation approach is presented based on the Gauss-Markov Kalman filter with IRI (International Reference Ionosphere) as the background model and designed to assimilate the total electron content (TEC) observed from ground-based GPS receivers and space-based radio occultation of FORMOSAT-3/COSMIC (F3/C) or FORMOSAT-7/COSMIC-2 (F7/C2). The Kalman filter consists of the forecast step according to Gauss-Markov process and the measurement update step. Observing System Simulation Experiments (OSSEs) show that the Gauss-Markov Kalman filter procedure can improve the accuracy of the data assimilation analysis over the procedure consisting of the measurement update step alone. Comparing to F3/C, the dense F7/C2 occultation observation further improves the model accuracy significantly. Validating the data assimilation results with GIMs (Global Ionosphere Maps), the vertical TECs from global ground-based GPS measurements, and the ionospheric F_2-peak height and electron density sounded by ionosondes are carried out. Both the OSSE results and the observation validations confirm that the developed data assimilation model can be used to reconstruct the three-dimensional electron density in the ionosphere satisfactorily.

Keywords: Space Weather, Data Assimilation, Radio Occultation

Global ionosphere map constructed by using total electron content from ground-based GNSS receiver and FORMOSAT-3/COSMIC GPS occultation experiment

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Effects of rapidly changing ionospheric weathers are critical in high accuracy positioning, navigation, and communication applications. A system used to construct the global total electron content (TEC) distribution for monitoring the ionospheric weather in near real time is needed in the modern society. Here we build the TEC map named Taiwan Ionosphere Group for Education and Research (TIGER) Global Ionospheric Map (GIM) from observations of ground-based GNSS receivers and space-based FORMOSAT-3/COSMIC (F3/C) GPS radio occultation observations using the spherical harmonic expansion and Kalman filter update formula. The TIGER GIM (TGIM) will be published in near real time of 4-hour delay with a spatial resolution of 2.5˚ in latitude and 5˚ in longitude and a high temporal resolution of every 5 min. The F3/C TEC results in an improvement on the GIM of about 15.5% especially over the ocean areas. The TGIM highly correlates with the GIMs published by other international organizations. Therefore, the routinely published TGIM in near real time is not only for the communication, positioning, and navigation applications, but also for monitoring and scientific study of ionospheric weathers, such as magnetic storms and seismo-ionospheric anomalies.

Keywords: Global Ionospheric Map, Total Electron Content, FORMOSAT-3/COSMIC, Ionospheric weather, GNSS

GAIA simulations of electric potential variations in the equatorial ionosphere after an intense solar flare

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It has been known that intense solar EUV and X-ray radiation by flares increases the electron density in the dayside ionosphere. The density distribution depends on chemical factors such as the ionization rate determined by the solar zenith angle and the loss rate related to the density of molecular nitrogen and oxygen. In addition, recent satellite measurements and modeling studies have shown that flares vary the zonal electric field to further disturb the electron density. The mechanism of the electric field variations by flares is still unknown. One possible mechanism is the conductivity changes by the enhanced ionization. Another candidate is the neutral wind dynamo developed by solar heating. In order to understand how each candidate varies the zonal electric field, we implemented the Flare Irradiance Spectral Model (FISM) to the GAIA model, a coupled model of whole atmosphere-ionosphere system. We performed simulations for the X17 flare on October 28, 2003. We found that the ionization enhancement creates the strong positive electric potential in the pre-sunset sector. We also found that the heating enhancement creates the strong negative potential in the post-sunset sector. The both enhancements intensify the positive eastward electric field from the afternoon to the evening to sustain the TEC enhancement for more than three hours. The electric field variations were most significant at the sunset terminator, which could encourage the growth of plasma bubbles.

Keywords: equatorial ionosphere, solar flare, electrodynamics, modeling, GAIA

The July 2012 geomagnetic storm

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Ionospheric storms represent an extreme state of the ionosphere, which are caused by geomagnetic storms, and the complicated ionospheric storm effects are always a research focus for the ionospheric community. The geomagnetic storm occurring on 14-17 July 2012 is an extremely rare event of space weather in solar cycle 24, characterized by a southward interplanetary geomagnetic field lasting for about 30 h below -10 nT.
In this talk, multiple instrumental observations including electron density from ionosondes, total electron content (TEC) from Global Positioning System (GPS), Jason-2, and Gravity Recovery and Climate Experiment (GRACE), and the topside ion concentration observed by the Defense Meteorological Satellite Program (DMSP) spacecraft are used to comprehensively present the regional differences of the ionospheric response to this event. In the Asian-Australian sector, an intensive negative storm is detected near longitude ~120°E on July 16, and in the topside ionosphere the negative phase is mainly existed in the equatorial region. The topside and bottomside TEC contribute equally to the depletion in TEC, and the disturbed electric fields make a reasonable contribution. On July 15, the positive storm effects are stronger in the Eastside than in the Westside. The topside TEC make a major contribution to the enhancement in TEC for the positive phases, showing the important role of the equatorward neutral winds. For the American sector, the EIA intensification is stronger in the Westside than in the Eastside and shows the strongest feature in the longitude ~110°W. The combined effects of the disturbed electric fields, composition disturbances and neutral winds cause the complex storm-time features. Both the topside ion concentrations and TEC reveal the remarkable hemispheric asymmetry, which is mainly resulted from the asymmetry in neutral winds and composition disturbances.
Acknowledgments
This research was supported by National Natural Science Foundation of China (41231065, 41321003).

Keywords: ionospheric storm, negativre storm, electric field

Occurrence climatology of *E*- and *F*-region field-aligned irregularities in the middle latitudes as observed by the Daejeon 40.8 MHz coherent scatter radar in South Korea

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Electron density irregularities in the ionosphere interrupt the propagation of electromagnetic waves and are problematic for navigation and communication systems. For this practical importance, significant efforts have been made to establish information on the occurrence climatology of such irregularities, to understand the onset conditions of such irregularities, and to predict or avoid the impact of these irregularities on the society. While the irregularities occur in all latitudes, less attention has been paid to the irregularities in middle latitudes. This may be because the irregularities in middle latitudes are not as severe as those in other latitude regions. However, middle latitudes are also the place where various forms of irregularities occur. A new 40.8 MHz coherent scatter radar was built in Daejeon, South Korea (36.18º N, 127.14ºE, dip latitude: 26.7ºN) on 29 December 2009, and has since been monitoring the occurrence of field-aligned irregularities (FAIs) in the northern middle latitudes. We report on the occurrence climatology of the *E*- and *F*-region FAIs as observed by the Daejeon radar between 2010 and 2016. We examine the occurrence types of the irregularities and the dependence of the irregularities on geophysical conditions (local time, altitude, season, solar cycle, and magnetic activity). These results can be used as a tool for investigating the onset conditions of the middle-latitude irregularities.

Keywords: VHF coherent scatter radar, E- and F-region field-aligned irregularities, middle-latitude ionosphere

The FORMOSAT-3/COSMIC Global Scintillation Model

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Humans heavily rely on Global Navigation Satellite System (GNSS) for applications of satellite communication, navigation, and positioning on the ground and/or aviation in the troposphere/stratosphere. However, ionospheric scintillations could severely impact on these applications. In this study, an empirical ionosphere scintillation model of the globe is constructed with S4-index data of FORMOSAT-3/COSMIC (F3/C) during 2007-2014 (hereafter F3CGS4 model). The model describes the S4-index as a function of diurnal variations in local time, seasonal variations in day of year, geographic variations in dip-latitude, and solar activities in EUV flux index PF10.7. The model well reproduces the F3/C S4-index observations, and yields good agreements with results of ground-based receiving satellite signals. These confirm that the constructed model can be used to forecast global L-band scintillations on the ground and in the near surface atmosphere.

Keywords: FORMOSAT-3/COSMIC, S4, Scintillation

Medium scale traveling ionospheric disturbances using FORMOSAT-2/ISUAL 630.0 nm airglow images

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In this work characteristics of nighttime medium-scale travelling ionospheric disturbances (MSTID) are investigated using 630.0 nm limb images by Imager of Sprites and Upper Atmospheric Lightnings (ISUAL), onboard FORMOSAT-2 satellite. The limb integrated measurements, when projected to a horizontal plane, reveal bands of intensity perturbation with distinct southwest to northeast orientation in the southern hemisphere. Airglow simulations are carried out to confirm that such azimuthally oriented features are related to MSTID. Further statistical analysis shows more MSTID occurrence in solstices with peak in June-July months. The wavelengths of the observed perturbations were in the range 150-300 km. The wave fronts were oriented about 30˚-50˚ from the east-west plane, indicating that coupled Perkins and Es-layer instability might be important in the MSTID generation. The results demonstrate that spaced based airglow imaging is an effective method for global investigation of MSTID events that are appropriately aligned with the viewing geometry.

Keywords: MSTID, Ionospheirc disturbances, FORMOSAT-2/ISUAL, Space based airglow imaging

Mid-latitude sporadic-E detected by L-band InSAR and their dispersive and non-dispersive components inferred from split-spectrum technique

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Sporadic E (Es) is known to generate unusual propagation of VHF waves over long distances, and is caused by a layer of ionization that irregularly appears within the E region of the ionosphere. However, the generation mechanism of Es remains unclear, because the conventional ionosonde observation of Es has limited spatial resolution. Maeda et al. (2016, GRL) succeeded in demonstrating mid-latitude Es signal over Japan two-dimensionally as an image, using interferometric synthetic aperture radar (InSAR) based on the L-band ALOS/PALSAR data. Although it is known to be a useful geodetic technique to measure ground and ice displacements, L-band InSAR can image the structure of Es with unprecedented spatial resolution when displacement signals are absent. Following Maeda et al. (2016), we aim to detect mid-latitude Es over Japan by InSAR based on the follow-on ALOS2/PALSAR2.
Because the SAR satellite has rather long recurrent intervals, 46 days for ALOS and 14 days for ALOS2, we need to search adequate SAR data sets that are very likely to detect Es signals. First, we chose the dates whose critical frequencies of Es (foEs) were more than 15MHz at ionosonde in Kokubunji, Wakkanai and Yamagawa in the morning and noon in 2016 from May to June; Es is known to be frequent in the local daytime of summer season. Secondly, we chose the ALOS-2/PALSAR-2 data sets whose observation area, dates and time matches the data above as closely as possible. Thirdly, we generated Global Navigation Satellite System –Total Electron Content (GNSS-TEC) map whose areas, dates and time are the same as the above and if Es appeared in the GNSS-TEC map, we do generate interferogram. As a result, we could detect the phase changes in the pair of February 17, 2016 (Master) and May 25, 2016 (Slave) along a track from Tottori to Okayama, western Japan. The location of the phase shift is close to the Es on the GNSS-TEC image. Therefore, we can consider the phase shift as the edge of Es.
Meanwhile, we also separated the Es signals into both dispersive and non-dispersive signals, using split-band InSAR technique; dispersive components are due to the free-electrons. We applied this technique to the results by both Maeda et al and the present study. As a result, it turns out that both the dispersive and non-dispersive signals indicated similar spatial patterns, suggesting that the non-dispersive signals were closely related to the dynamics of dispersive free-electrons. The non-dispersive signals may be attributable to positively charged ions associated with the generation of Es episods.

Keywords: ionosphere, Sporadic-E, InSAR

4D-var estimation of exhaust emissions by North Korean rockets

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In this paper, a four dimensional variation (4D-Var) data assimilation technique is used to characterize ionospheric holes created by North Korean ballistic missiles/rockets launched over South Korea. The ionospheric holes were assumed to be created due to a chain reaction between ions, electrons and neutral molecules (in this case H_2O and H_2) deposited in exhaust plumes. The neutral molecules dispersion model was developed based on advection-diffusion equation, and spherically symmetric diffusion assumed. Synthetic data (slant total electron content; STEC) that were generated using the exact GPS-receiver geometry over the South Korean region were utilized in validating the 4D-var technique. The reconstructed three dimensional structures nearly matched the original assumed ionospheric holes. Furthermore, applying the adjoint optimization technique to the observed STEC data we were able to estimate the amount of rocket emissions.

Keywords: 4D-var, Ionosphere, Rocket, Total Electron Content (TEC)

