2024 Workshop: Future coordinated space- and ground-based ITM observations (combined with A Systematic Perspective of Geospace Dynamics through Modeling and Observations)

Long title
Planning coordinated observations of ionosphere, thermosphere, and mesosphere from space and ground
Conveners
Doug Rowland
Guiping Liu
Bea Gallardo-Lacourt
Scott England
Oluwafisayo Owolabi
Wenbin Wang
Mike Wiltberger
Dong Lin
Yue Deng
douglas.e.rowland@nasa.gov
Description

We call for community input and discussions: 1) How to best leverage existing ground- and space-based observations to maximize science return for the ionosphere, thermosphere, and mesosphere (ITM) research; 2) What insights have we gained to develop a future long-range plan of a coordinated observing system of ITM from both space and ground? Presentations on current and upcoming observations and campaigns, data analyses, data and model validations, and OSSE experiments are all invited.

Recent advances in coupled models of the whole geospace system (mesosphere, thermosphere ionosphere and magnetosphere) and their components, as well as new ground and space observations, enables the community to gain new insights into the cross-scale, dynamic response of the geospace, as a system, to varying external driving conditions. This workshop invites both modeling and data analysis presentations that include but not limited to: 1) quantifying energy and momentum inputs to and effects on the upper atmosphere under disturbed solar irradiance and solar wind conditions such as solar flare, eclipse, interplanetary shocks, high speed streams, and coronal mass ejections, and from lower atmospheric waves including gravity waves, tides and planetary waves; 2) investigating regional and global mesoscale and large-scale processes generated in the thermosphere and ionosphere under such conditions and the cross-scale coupling between these processes, 3) understanding the global propagation and evolution of thermosphere and ionosphere structures of multiple temporospatial scales such as traveling atmospheric disturbances (TADs) and traveling ionospheric disturbances (TIDs), and 4) comparing model and data, revealing model-data discrepancy, and guiding model improvement.

Agenda

Invited Talks

- 1000-1025 *Toshi Nishimura* (Boston University) / co-presenter: Joon Kim (Boston University) **High-Resolution Convection for Meso-Scale Flow Science & 3-d Neutral Wind from Tristatic Imaging** (Invited talk, 20 mins + 5 min Q&A)

  Abstract (part 1): We present an approach for creating continental-scale, multi-scale plasma convection maps in the nightside high-latitude ionosphere using the SuperDARN radars. The high-resolution convection has significantly lower velocity errors and shows better agreement with in-situ observations. Convection maps for a substorm event revealed multiple flow channels over >20° of latitude. The substorm onset occurred along one of the flow channels, and the azimuthal extent of the enhanced flows coincided with the initial width of the auroral breakup. During the expansion phase, the meso-scale flows repetitively crossed the oval poleward boundary, and some of them contributed to enhance SAPS. The meso-scale flows had significant (~10-40% on average) contributions to the total plasma transport. These results demonstrate the capability of specifying realistic convection patterns, quantifying the contribution of meso-scale flows, and evaluating the relationship between meso-scale flows and localized auroral forms.

Abstract (part 2): We present a method to reconstruct horizontal distribution of 3-d full components of the F-region neural wind using line-of-sight winds obtained by three Scanning Doppler Imager (SDI) instruments in Alaska and examine how both horizontal and vertical winds change during the geomagnetic activities. Our method provides a significant improvement of specifying horizontal wind distribution and reveals horizontal distribution of the vertical wind. We found that the upward vertical winds became enhanced and the magnitude of vertical winds reached ~ 80 m/s during active aurora. The vertical winds have strong shears near the edges of the aurora. Furthermore, the direction of horizontal winds shows the clockwise pattern around the Harang aurora and it turned southeastward after the Harang structure disappeared.

- 1025-1050 *Shun-Rong Zhang* (MIT Haystack) **Initial analysis of the global ionospheric disturbances during the super geomagnetic storm on 10-12 May 2024** (Invited talk, 20 mins + 5 min Q&A)

Abstract: Active Region 3664 was extremely active around May 9, 2024, producing numerous M-class flares and several X-class flares. These events caused Earth-directed CMEs that arrived around 1800 UT on May 10, 2024, triggering intense solar and geospace storms with a minimum Dst of -412 nT and Kp 9 disturbances. The global ionosphere experienced significant electron density enhancements, particularly at low latitudes, with EIA crest density surges and poleward expansion primarily in the American sectors during the initial and main storm phases. This was followed by a substantial electron density depletion over the next day or two across almost the entire globe. A SED plume was also observed near the noon sector during the main phase, streaming into the polar cap as a TOI. The global propagation of TIDs was identified as equatorward at mid- and low latitudes and anti-sunward in the polar region, with medium-scale zonal propagation at subauroral latitudes. These results were compared with the November 20, 2003, superstorm, which had a similarly minimum Dst of -422 nT.

This initial analysis is primarily based on GNSS TEC data. However, comprehensive details of the ionospheric disturbances, especially in the topside ionosphere which is expected to be altered due to strong vertical forcing, as

well as thermospheric parameters (such as winds and compositions), are lacking. This prevents a full understanding of the physics in action and calls for space-ground coordinated analysis. New observational capabilities, such as those offered by GDC, are needed to address these important knowledge gaps.

The contributed talks are each 5 min plus 1 min Q&A:

1. 1050-1056 *Joe McInerney* (UCAR) **WACCM-X Update and WACCM-X High Resolution Capability**

   Abstract: The atmospheric global modeling community has made it a priority to work towards increased spatial resolution. The Whole Atmosphere Community Climate Model – eXtended is no exception and has set a course to moving from the current 1 degree or 2 degree (~1 or 2 kilometer) horizontal resolutions to 0.5 degree and 0.25 degree (~0.5 to 0.25 kilometer) horizontal resolutions. Here we describe the current state of the WACCM-X model development and discuss the recent efforts to simulate and examine results at these higher resolutions. The indication is there are a lot of fun and exciting things to analyze at higher spatial model resolutions.

2. 1056-1102 *Dong Lin* (UCAR) **Recent advances in the development of Multiscale Atmosphere-Geospace Environment (MAGE) model at NASA DRIVE Science Center for Geospace Storms (CGS)**

   Abstract: The NASA DRIVE Science Center for Geospace Storms (CGS) has entered its second year of Phase II. As the cornerstone of CGS, the Multiscale Atmosphere-Geospace Environment (MAGE) model aims to describe the geospace and atmosphere as a physically coupled system characterized by properties and processes across a broad range of spatial and temporal scales. MAGE has been actively developed according to its blueprint. In this talk, I will provide an update on the recent milestones achieved by the MAGE model development team and discuss how the model could facilitate aeronomy studies for the CEDAR community.

3. 1102-1108 *Yue Deng* (UT Arlington) **Importance of satellite constellation to the observations of multi-scale temporal and spatial structures in the thermosphere**

Abstract: The Ionosphere-Thermosphere (I-T) system exhibits global variations with intriguing localized and regional features. The implementation of multi-satellite architectures, such as GDC & DYNAMIC, will be essential to cover relevant temporal and spatial scales in the under-sampled region and have the potential to revolutionize our understanding of the I-T system. To underscore the significance of multi-satellite observations for the I-T system, we employ an illustrative example of data analysis involving Grace-A and Grace-B satellites. This example highlights the additional valuable information on temporal and spatial variations that can be derived from the collaborative observations of two satellites. Furthermore, in our study, we fly a series of virtual satellites with different satellite constellation configurations within the global ionosphere-thermosphere model (GITM) simulations. These simulations will evaluate the capabilities of various satellite configurations in resolving cross-scale structures under different geomagnetic conditions.

4. 1108-1114 *Gang Lu* (HAO/NCAR) **Exploring the Global Ionosphere-Thermosphere System Through Coordinated Data Assimilation & Numerical Modeling**

Abstract: The ionosphere and thermosphere (IT) system is closely connected with the magnetosphere above and the lower atmosphere below. Energy input from the magnetosphere via the high-latitude ionosphere plays a major role in regulating ionospheric/thermospheric dynamics and chemistry, especially during storms. An accurate specification of high-latitude energy input via Joule heating and auroral precipitation is critically important to understanding how magnetospheric forcing affects the IT system. To that end, we show advanced data assimilation tools such as the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure can provide more realistic description of high-latitude plasma convection and auroral precipitation compared to empirical models. As an illustration, we compare the simulations of the IT storm responses that are driven by AMIE versus those driven by the conventional empirical plasma convection and auroral precipitation models.

5. 1114-1120 *Maosheng He* (National Space Science Center, Chinese Academy of Sciences) **Planetary Scale waves observed via a Dual-Station Approach**

Abstract: Planetary waves (PWs) and tides are common occurrences in the mesosphere and lower thermosphere, yet their study faces challenges due to limited data availability. Traditional methods, often relying on single-station and single-satellite analyses, struggle to capture the full time and horizontal scales of these phenomena. To overcome this limitation, we developed the phase difference technique (PDT), a novel dual-station method. Unlike conventional approaches, the PDT utilizes intercontinental spectral coherence to estimate the zonal wavenumber of the underlying waves. This methodological innovation enables the identification of normal modes (NMs) among PWs, distinguishes migrating from non-migrating tides, and provides insights into wave-wave nonlinear interactions within defined spatial boundaries. By applying PDT to various two-station setups of meteor radars across different longitudinal sectors, we have uncovered several intriguing phenomena. These include the identification of 4.8- and 4-hour migrating tides and various nonlinear interactions between PWs and tides, particularly the generation of PW second harmonics. Additionally, our analyses have revealed statistical properties of planetary waves and tides, including their responses to seasonal variations and sudden stratospheric warming events (SSWs).

6. 1120-1126 *Quanhan Li* (National Space Science Center, Chinese Academy of Sciences)"**Global Distribution of Ionospheric Topside Diffusive Flux and Midlatitude Electron Density Enhancement in Winter Nighttime**"

Abstract: Ionospheric topside O^+ diffusive flux is derived using Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) radio occultation data, to investigate its global distribution and also its role in winter nighttime enhancement (WNE) of electron density. The flux of the winter hemisphere maintains downward throughout the night. It is much larger between 30° and 50° geomagnetic latitudes and keeps increasing until 22:00-00:00 LT. It peaks at 60°W and 60°E-120°E geographic longitudes during the December solstice, and at 180°E during the June solstice. These features are similar to those of WNE in NmF2. Furthermore, the derived flux is applied as the upper boundary condition to run the Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM). The simulated spatial-temporal variation of WNE are consistent with the observations. The results indicate that downward plasma diffusion from the plasmasphere is the major mechanism of WNE, and the simulation quantifies its contribution.

7. 1126-1132 *Sneha Yadav* (UCLA) "**Investigating the Spatiotemporal Development of Substorm Expansion Phase Aurora: Successive Onsets or Poleward-Boundary Intensifications?**"

Abstract: This study focuses on understanding the auroral intensifications that drive the spatiotemporal development of the substorm expansion phase active aurora. It is important to understand what drives the spatiotemporal development of the substorm expansion phase because the larger its duration and spatial extent, the larger the disturbances in the Earth's ionosphere-thermosphere system in terms of total energy deposition. Our results help quantify the energy input in the ionosphere-thermosphere system and understand the coupling between mesoscale processes and global substorm processes.

8. 1132-1138 *Ravindra Desai* (University of Warwick, UK) **ROARS: Revealing Orbital and Atmospheric Responses to Solar activity**

Abstract: The accumulation of space debris, and congestion of near-Earth orbits, represent an outstanding challenge to the safe use of our space environment. Satellite drag from the Earth’s upper atmosphere is a primary perturbative force on near-Earth orbiting satellites, and its accurate characterisation is essential to predicting and preventing further collisions and the run-away proliferation of space debris. Atmospheric drag in Low Earth Orbit (LEO) is highly sensitive to solar activity and the solar wind-magnetosphere interaction. Magnetospheric current systems close through the ionosphere and associated ion-neutral collisions, i.e. Joule heating, can drastically modulate the spatially- and temporally-varying outer extent of the atmosphere. Unlike the many isolated in-situ measurements carried out by space missions so far, distributed neutral, plasma and magnetic field observations by a swarm of satellites across LEO, in tandem with precise tracking of their orbital dynamics, offer the global view necessary to disentangle the influence of the coupled

magnetosphere-ionosphere-thermosphere system on satellite orbits. The ROARS mission architecture aims to obtain the first coordinated measurements in LEO across a range of altitudes, latitudes and longitudes to understand the evolution of field-aligned and ionospheric currents, Joule heating and the response of the neutral atmosphere. Coordinated orbit- and ground-based space surveillance and tracking campaigns (GNSS, laser, optical) will simultaneously relate the CubeSats' orbital dynamics to the in-situ measurements, whilst laser inter-satellite-links can continuously relate meso- and micro-scale atmospheric drag variabilities to orbital perturbations. In this talk, we present the outcomes of our ESA-funded Pre-Phase A study.

9. 1138-1144 *Jiaojiao Zhang* (National Space Science Center, Chinese Academy of Sciences): **Development of CN-DARN and Preliminary Results**

   Abstract: Led by National Space Science Center, Chinese Academy of Sciences, we have built a mid-latitude dual auroral radar network (CN-DARN) in northern China. CN-DARN consists of three pairs of HF radar, which is one of key parts of Chinese Meridian Project Phase II. The radars adopt full digital phased array and beam forming technique in hardware design of the radar system, making them agile in operation. It has been fully constructed and started trial operation by the end of 2023. Its detection range extends about 9 local time in longitude, covering the mid to high latitudes of the entire Asia region above 40degree. A brief introduction of CN-DARN and present the preliminary results will be presented. CN-DARN has observed ionospheric irregularities, sub-auroral polarization streams (SAPS) and traveling ionospheric disturbances (TIDs) and provided excellent measurements and better specification of the flows in Asia sector, improving the global-scale ionospheric convection pattern in Northern Hemisphere derived by SuperDARN. CN-DARN will contribute to SuperDARN data stream after the final check and acceptance of Chinese Meridian Project Phase II in October this year.

10. 1144-1150 *Rafael Luiz Araujo de Mesquita* (JHU/APL) **EZIE-Mag: a low-cost science-grade magnetometer**

   Abstract: As a part of the NASA Electrojet Zeeman Imaging Explorer (EZIE) mission and with the miniaturization of single-board computers, we have developed a citizen science initiative called EZIE-Mag. EZIE-Mag is an

instrument suite that can generate science-grade measurements of the Earth's magnetic field to low noise levels (~10nT) and high-precision (~3nT) with proper calibration. This instrument was designed to be deployed in schools and be assembled and deployed by anyone from middle schoolers to graduate students. We will show how this instrument operates, how the calibration transforms a magnetic field variometer into science-grade B-field measurements, and our plans for this instrument in the development of critical infrastructure/networks.

11. 1150-1156 *Katelynn Greer* (CU/LASP) **Chasing TEC: Coordinated Ground-based & Space-based Science**

    Abstract: The ionospheric density, as measured by TEC, is entagled with the neutral thermosphere. To understand the evolution of TEC, we must have coordinated observations of thermospheric composition, thermospheric winds, ionospheric densities, electric fields, as well as geomagnetic fields. Here we discuss a plan to coordinate these observations during strong vortex case studies.

File upload
Katelynn Greer's talk (367.84 KB)
Justification

The ionosphere-thermosphere-mesosphere (ITM) is a highly dynamical region but remains poorly understood due to lack of sufficient observations. Developing an advanced observing system including coordinated ground- and space-based observations is thus crucial to improve our understanding of the ITM. This session invites presentations to stimulate future long-range plans of the complete ITM observing system. We specifically invite discussions on organizing campaigns and experiments in support of international and interagency efforts such as International Polar Year (IPY 5) in 2032.

Related to CEDAR Science Thrusts:
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Explore exchange processes at boundaries and transitions in geospace
Explore processes related to geospace evolution
Develop observational and instrumentation strategies for geospace system studies
Workshop format

Short Presentations

Keywords

ITM observing system, ground and space observations, long range plan

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