2026 Workshop: Pathways to Improved Space Weather Predictability

Long title

Cross-Scale Coupling and Variability in the Upper Atmosphere and Ionosphere: Pathways to Improved Space Weather Predictability

Grand Challenge

Conveners

Soudeh Kamali - NSF NCAR, skamali@ucar.edu
Jadwiga Richter - NSF NCAR, jrichter@ucar.edu
Hanli Liu - NSF NCAR, liuh@ucar.edu
Liying Qian - NSF NCAR, lqian@ucar.edu
Hui Shao - UCAR, huishao@ucar.edu
Xian Lu - Clemson University, xianl@clemson.edu
Tomoko Matsuo - University of Colorado Boulder, tomoko.matsuo@colorado.edu
Federico Gasperini - Orion Space Solutions, federico.gasperini@arcfield.com
Anastasia Newheart - NOAA-SWPC/Lynker , ana.newheart@noaa.gov
Koki Chau - Leibniz Institute of Atmospheric Physics in Germany, chau@iap-kborn.org
skamali@ucar.edu

Description

Space weather threatens critical infrastructure by disrupting communications, satellites, power grids, and navigation systems, with broad societal impacts. The ionosphere and thermosphere (IT) system is the region where many space weather effects originate and evolve. Understanding space weather predictability requires a deep understanding of the IT system, improved representation of its drivers from above (solar irradiance, solar winds/magnetosphere) and below (lower atmosphere originated waves across different scales and associated turbulence), and internal physical processes within the IT system. Pathways to Improved Space Weather Predictability demand a coordinated “team science” approach that integrates modeling, data assimilation, observations, and artificial intelligence. A focused effort in this area will strengthen both scientific progress and position the upper atmosphere and CEDAR community to contribute more significantly to future space weather research and funding opportunities.

This workshop aligns with and supports the objectives of the Earth System Predictability Across Timescale (ESPAT) initiative. ESPAT (https://ncarprojects.ucar.edu/predictability) is an NSF NCAR-led initiative that accelerates research to uncover the processes that shape predictability and integrate knowledge across disciplines, time horizons, and scales. ESPAT brings together scientists from NSF NCAR, universities, and other research organizations to advance predictive understanding through coordinated, interdisciplinary research. This Grand Challenge aims to (1) establish connections between ESPAT and CEDAR science and community; (2) identify areas of scientific advancement that could emerge from coordinated ESPAT-CEDAR efforts, aligned with priorities outlined in the

Decadal Survey for Solar and Space Physics 2024-2033 (3) develop ESPAT-CEDAR pathways to address pressing questions related to space weather impacts and national resilience.

Justification

Space weather variability poses significant risks to modern technological infrastructure. It can disrupt communication systems, satellite operations, power grids, and navigation technologies, with impacts that can cascade into broader societal and economic consequences. Improving predictive capability across the coupled Sun–Earth system is therefore not only a scientific challenge, but a matter of societal resilience. Upper atmospheric variability plays a central role in this challenge. Variability in the Ionosphere-Thermosphere (IT) system, driven by solar and magnetospheric forcing, internal processes, lower atmospheric wave dynamics, and their complex interactions, modulates energy and momentum transfer across scales and directly influences ionospheric structure, thermospheric density, and geomagnetic responses. In this way, upper atmospheric variability both contributes to space weather and mediates its impacts. Understanding these cross-scale interactions is essential for improving predictability.

Domain specific expertise and advances in modeling, observation, data assimilation, and artificial intelligence are essential for addressing key science questions that limit space weather predictability. Building on these strengths, progress can be greatly accelerated by fostering integration across disciplines, methodologies, and timescales through team science, convergence, and system-based approaches. Team science and convergence frameworks enable coordinated model development, shared data infrastructures, joint experiment design, and iterative comparison between observations and simulations. A systems approach further encourages treating the atmosphere-geospace environment as an interconnected whole, linking lower atmospheric variability, ionospheric dynamics, and magnetospheric forcing within unified strategies for improving prediction.

Space weather is an increasingly high-profile research area because of its direct relevance to societal resilience and infrastructure protection. As stated in the Decadal Survey for Solar and Space Physics 2024-2033, the need to protect against space weather hazards through advances in scientific knowledge will continue to grow. Positioning the upper-atmosphere community within this broader space weather framework strengthens its scientific visibility and strategic relevance. A focused session on upper atmospheric variability and its impact on space weather would not only advance fundamental understanding but also create a pathway for this community to engage more directly in space weather research efforts and future funding opportunities.

Moreover, this workshop builds upon and expands the previous year CEDAR grand challenges, “Impact of terrestrial weather on the space weather of the Ionosphere-Thermosphere-Mesosphere (ITM)” (entering its 3rd year in 2026) and “ The role of gravity waves in the mesosphere, thermosphere and ionosphere cross-scale coupling and irregularities: Observations and numerical simulations” (ended in 2025). This proposed workshop includes space weather drivers from both above and below, and their resulting space weather phenomena within the ITM system. It takes a broader perspective by focusing on the predictability of space weather within the framework of NSF NCAR’s ESPAT program. The ESPAT program emphasizes team science, convergence, and systems approaches, bringing together researchers across disciplines, to address complex predictability challenges for improved societal resilience. Through this proposed Grand Challenge workshop, we aim to bring the community together to tackle the following three science questions:

1. What are the dominant pathways through which multi-scale drivers from the Sun–magnetosphere system and the lower atmosphere produce variability in the IT system across spatial and temporal scales? Advancing understanding of drivers from both above and below is essential for developing a more complete, system-level view of IT variability.
2. How do IT background conditions (e.g., composition, neutral winds, solar cycle phases, season) modulate the response of the IT system to external forcing and contribute to space weather variability?
3. How can coordinated use of observations (especially those from the CEDAR

community), physics-based models, data assimilation, and AI/ML approaches reduce uncertainty and improve predictive capability for IT variability and its space weather impacts?

Related to CEDAR Science Thrusts:
Encourage and undertake a systems perspective of geospace
Explore exchange processes at boundaries and transitions in geospace
Explore processes related to geospace evolution
Develop observational and instrumentation strategies for geospace system studies
Fuse the knowledge base across disciplines in the geosciences
Manage, mine, and manipulate geoscience/geospace data and models
Workshop format
Short Presentations
Panel Discussion
Round Table Discussion
Other
Keywords
Predictability, Space weather, upper atmosphere, team science
View PDF