2022 Workshop: Space weather nowcast and forecast

Long title
Tools and methods for improving space weather nowcast and forecast
Conveners
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Description

The space weather products at NOAA Space Weather Prediction Center (SWPC) are used to provide nowcast and forecast information to our customers in the power grid, communication, navigation, and satellite tracking and operation systems. For the interests of the CEDAR community, multiple ionosphere-thermosphere models have been developed and transitioned into operation to support SWPC's needs. Working with NASA and other federal partners, it has been identified that improving the research to operation (R2O) process is a key to enhancing our Nation's nowcast and forecast capability. We would like to use this session to communicate the needs of SWPC to advance our current thermosphere and ionosphere services and to encourage the usage of both space and ground observations to improve space weather models and forecasting capability. We will invite awardees from NASA's Space Weather Science Application Research-to-Operations-to-Research Program (R2O2R) to describe their projects and progress, as well as to provide a platform to the community with a two-way discussion on these requirements and goals.

Agenda

10:00-10:10 The R2O2R Program

John McCormack (NASA HQ)

Tzu-Wei Fang (NOAA)

10:10 - 10:40 Neutral Density

Richard Linares (Presented by Philip Erickson)

Eftyhia Zesta (Presented by Marcin Pilinski)

Margaret Chen (Join virtually from GEM)

Jeff Thayer (Presented by Eric Sutton)

10:40 - 11:40 Ionospheric Measurement and Specifications

Eric Sutton (O2R)

Nathaniel Frissell

Kenneth Obenberger

Jade Morton

Aaron Ridley

Victoriya Makarevich

Erin Lay

11:40 - 12:00 Ionospheric Irregularity and Scintillation

Alex Chartier

Eric Sutton (SWQU)

Justification

CEDAR science addresses the importance of understanding and predicting the dynamic environment in the ionosphere and thermosphere. These have also been emphasized in several CEDAR strategic science thrusts (#1, #2, #3, and #6). However, research efforts on establishing predictive models and extending forecast capability have not been largely carried out and prioritized. Without being able to properly combine the ground and space measurements to improve our models, the

current ability to forecast ionospheric and thermospheric conditions is still rather limited. NASA's R2O2R grant has targeted these needs and provided research funding to the community. The session will provide in-depth discussions on what SWPC needs and what the research community can help in order to improve the R2O processes and ultimately enhance our capability in predicting the upper atmosphere environment.

Summary

The overarching theme of the workshop was the research-to-operations and operations-to-research (R2O2R) loop, which refers to the interaction between the science community conducting fundamental research and the operations community that applies those findings to monitoring and forecasting space weather. Developments in space physics can be integrated into operational models and systems, and the needs of operators provide focus to research and funding agencies. This workshop will continue to be held each year to keep the community up to date on NASA and NOAA priorities.

NASA R2O2R Program Element

Presenter: John McCormack (NASA)

The NASA R2O2R program element (formerly Space Weather O2R) is now part of the Research Opportunities in Earth and Space Science (ROSES) funding program. The name change to R2O2R reflects the new emphasis on transitioning research to operations in addition to deriving research goals from operational needs. R2O2R grants now can fund the "Transition Step" or "T-Step", which supports an additional year of work for the purpose of converting research results into operational tools. This requires a TRL advancement (or equivalent).

Ionosphere and Thermosphere Requirements at NOAA Space Weather Prediction Center

Presenter: Tzu-Wei Fang (NOAA SWPC)

NOAA SWPC is interested in work that will translate to improved forecasts and nowcasts of space weather effects. Operator priorities include: a) minimum and maximum usable frequency for HF communications systems, b) position, navigation, and timing impacts on GNSS systems and c) neutral mass density for satellite drag. NOAA is also interested in ionosonde and commercial data that can be used to address these impacts. One use case of a NOAA resource is the WAM-IPE coupled atmosphere-ionosphere model, which is used by SpaceX Starlink to evaluate satellite neutral atmosphere satellite drag.

Composable Next Generation Software Framework for Space Weather Data Assimilation and Uncertainty Quantification

Presenter: Philip Erickson (MIT Haystack)

This work includes multiple projects, all of which use data assimilation to improve thermosphere-ionosphere forecasting and to quantify forecast uncertainties. 1) A machine learning-based reduced order model technique was developed to assimilate satellite orbit elements to provide neutral density predictions. 2) A study compared different model predictions of satellite orbit lifetimes, including for the February 2022 Starlink incident, and suggested that issues with model boundary conditions caused the models to overestimate orbit lifetimes. 3) A new regional 3D and global 2D model called TIDAS was developed that ingests ionosonde, TEC, and ISR data to specify the ionosphere. 4) A real-time debiasing scheme was implemented into GITM to automatically correct for forcing errors by adjusting the heat conduction term. 5) A high-fidelity atmosphere model on a cubed-sphere grid was developed. 6) A data-driven reduced order model of the solar wind was developed that outperforms reduced-physics techniques. 7) An algorithm for Bayesian filtering of chaotic systems was developed. 8) Packages for the Julia programming language were developed to facilitate reduced order modeling.

Evaluating Thermospheric Storm Response Above 500 km Altitude

Presenter: Marcin Pilinski (CU LASP)

Most objects in LEO have altitudes above 500km. Satellite drag is a major source of uncertainty in orbit prediction, including at these altitudes. Sun-earth driving, the associated atmospheric response, gas-surface physics, and techniques for assimilating data need to be considered. This work assimilated years of historical satellite orbit records into HASDM to provide improved mass density specification during storms, outperforming standalone empirical models.

Modeling Diffuse Auroral Precipitation Effects on Thermospheric Neutral Density and Orbit Propagation at Low Earth Orbit

Presenter: Margaret Chen (Aerospace Corp.)

Particle precipitation from diffuse aurora is a heating source for the neutral atmosphere. This work coupled physics-based particle precipitation to a general circulation model to improve the specification of the neutral atmosphere storm response. The physics-based storm time heating reduced in-track orbit propagation errors for three different objects, outperforming empirical models and the general circulation model in an empirical heating configuration.

High-Cadence, Global Mass Density Retrievals for Improved Satellite Drag Specification and Forecast

Presenter: Eric Sutton (CU SWx TREC)

This work focused on using satellite orbit data to derive thermosphere mass density. Ground-based tracking, onboard GNSS positioning, and dedicated onboard instruments are options for this task. Spire commercial orbit data was compared with HASDM as an example of a use case for GNSS data. Methods can be used to improve orbit data processing, such as averaging over orbits to reduce noise in the density estimates and by using the GEODYN software package to include non-drag accelerations on the satellites.

Measurements of Thermospheric Density and Temperature from SUVI Solar Occultations

Presenter: Eric Sutton (CU SWx TREC)

This work used solar EUV images from the SUVI instrument on GOES. When SUVI images are occulted by the limb of Earth’s atmosphere, they can be processed to extract a composition altitude profile of the thermosphere. The line-of-sight O and N_2 densities showed a response to geomagnetic activity.

A Data Assimilative Framework for WAM-IPE

Presenter: Eric Sutton (CU SWx TREC)

In this work, a physics-based data assimilation method was implemented in the WAM-IPE model. Currently, neutral mass density is assimilated to correct the external solar and geomagnetic drivers to better specify the neutral atmosphere. Ionosphere data assimilation is under development, and will include radio occultation and GNSS TEC measurements.

HamSCI Observations for Ionospheric Measurement

Presenter: Nathaniel Frissell (U. Scranton)

This work used ham radio signal propagation data from the global network of amateur radio operators as a means of remote sensing the ionosphere. The networks show visible blackouts during solar flares, and the length of time needed for communications to recover gives an indication of the time scales of the ionosphere response to the flare. Ray-tracing data from the 2017 solar eclipse path across the continental United States agree well with SAMI3 simulations. Two personal space weather monitoring station designs are being developed, one at low cost and one at medium cost, that amateur operators can purchase and use.

Tracking Sporadic E with the LWA Radio Telescopes

Presenter: Kenneth Obenberger (AFRL)

Electromagnetic noise generated by the power grid is present nearly everywhere, and measuring its reflection from sporadic E clouds can give information on the motion and evolution of the sporadic E. This work converted all-sky images of the power grid noise to map sporadic E to geodetic coordinates, allowing predictions of its motion and monitoring of its intensity. The team is currently operating LWA stations in western Texas for this purpose, has set up a digisonde for validation, and is working on miniaturized LWAs that can be deployed cheaply anywhere.

Utilizing GNSS Reflectometry Measurements For High Latitude Ionospheric TEC Observation

Presenter: Yang Wang (CU Boulder)

GNSS TEC data is line-of-sight, directed from the transmitting satellite to receivers on the ground or on other satellites. In this work, a new data source was used to give coverage of the poles and oceans: reflected navigation signals that arrive at a satellite GNSS receiver from below. The signals can reflect off the ocean surface or off ice at high latitudes, and as a result include information on the ionosphere along the path from transmitter to the reflection surface and from the reflection point up to the receiver. The measurements were converted to vertical TEC by fitting spherical harmonics to the observations.

Aether: A New IT Model

Presenter: Aaron Ridley (U. Michigan)

Aether is a new ionosphere-thermosphere model under development that is focused on ease of use, open and accessible development, and being highly configurable. The model is written in C++, which is more widely known than the Fortran of other global models. Inputs to the model use the JSON standard format, which is easy to use and has many supporting libraries available. Model configurations can be altered by simple modifications to lines in .csv files, including the planet type, chemistry, gas collision parameters, and solar EUV irradiance. Spherical and cubed-sphere grids are available, with the neutral grid extending from 100 to 600 km in altitude. A team at NASA GSFC is developing a field-aligned grid for higher altitudes. The model’s

configurability allows users to tune it to fit their research needs and computational resources.

Ingestion of Radio Occultation Data For Ionospheric Data Assimilation

Presenter: Victoriya Forsythe (NRL)

This work investigated the optimal method for ingesting radio occultation (RO) data to provide a bottomside ionosphere nowcast. The model and data assimilation system were the NRL NIMO system, which is based on SAMI3 with IDA4D data assimilation. Two methods were compared: direct assimilation of the slant TEC RO data, and assimilation of the electron density at the RO tangent point after performing an Abel inversion. The slant TEC method gave larger errors than the Abel inversion technique.

New Lightning-Derived Vertical Total Electron Content Data Provide Unique Global Ionospheric Measurements

Presenter: Erin Lay (LANL)

A new slant TEC dataset has been produced by LANL and multiple agencies that can now be requested. The measurements are derived from lightning emissions received by detectors on GPS satellites, and the results have been validated against the JPL vertical TEC and Madrigal TEC datasets. The measured signals are in the MHz range, which gives a reduced TEC error relative to GNSS TEC. The data coverage is sparse, but fills significant gaps in the Madrigal TEC coverage in regions where ground-based GNSS receivers are scarce.

High-Latitude Electrodynamics Specified in SAMI3 Using AMPERE Field-Aligned Currents

Presenter: Alex Chartier (APL)

The SAMI3 global ionosphere model is now running at APL and NASA CCMC. SAMI3 takes its high-latitude conductance from empirical models, and this was combined

with AMPERE magnetometer measurements to specify the high-latitude electric potential. The calculated potential showed good agreement with independent DMSP data in the evening, but less agreement in the morning. Further work will validate the model using ham radio data and implement particle precipitation and signal scintillation with a machine learning approach.

Forecasting Small-Scale Plasma Structures in the Ionosphere-Thermosphere System

Presenter: Eric Sutton (CU SWx TREC)

The WAM-IPE model is being coupled with the high-resolution Cornell plasma instability model to give a global view of equatorial plasma bubble formation and evolution.

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