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NASA/NSF Space Weather Modeling Collaboration: Advancing Space Weather Modeling for Improved Specification, Forecasting and Mitigation

Key Points:
- There is a need to elucidate processes that lead to space weather disturbances
- Effort is needed to both mitigate and forecast near-Earth space weather
- Ensemble modeling will lead to a shift in how physical processes are studied

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Ensemble Modeling with Data Assimilation Models: A New Strategy for Space Weather Specifications, Forecasts, and Science

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1. Introduction

The Earth's Ionosphere-Thermosphere-Electrodynamics (I-T-E) system varies markedly on a range of spatial and temporal scales and these variations have adverse effects on human operations and systems, including high-frequency communications, over-the-horizon radars, and survey and navigation systems that use Global Positioning System (GPS) satellites. Consequently, there is a need to elucidate the underlying physical processes that lead to space weather disturbances and to both mitigate and forecast near-Earth space weather.

The meteorologists and oceanographers have shown that data assimilation models are superior to global physics-based models for specifications and forecasts, but only during the last 15 years have they been used for near-Earth investigations as more global (space and ground-based) measurements became available. Although data assimilation models produce better specifications and forecasts than global physics-based models, there is still a spread in results for a given simulation scenario when different data assimilation models are used. This spread occurs because the different data assimilation models use different data types, data amounts, assimilation techniques, and background physics-based models.

This data assimilation issue is being addressed with the launching of the "NASA/NSF Space Weather Modeling Collaboration" program. Currently, our team has seven physics-based data assimilation models for the ionosphere, plasmasphere, thermosphere, and electrodynamics. These models assimilate a myriad of different ground- and space-based observations, and there is more than one data assimilation model for each near-Earth space domain. These data assimilation models are being used to create a Multimodel Ensemble Prediction System (MEPS), which will allow ensemble modeling of the I-T-E system with different data assimilation models that are based on different physical assumptions, assimilation techniques, and initial conditions. The application of ensemble modeling with several different data assimilation models will lead to a *paradigm shift* in how basic physical processes are studied in near-Earth space, and it is expected to lead to a significant advance in space weather specifications and forecasts.

2. Data Assimilation Models

Our seven data assimilation models are summarized in Table 1 [cf. *Eccles et al*., 2011; *Komjathy et al*., 2010; *Pi et al*., 2009; *Scherliess et al*., 2009; *Schunk et al*., 2005; *Wang et al*., 2004; *Zhu et al*., 2012]. GAIM stands for Global Assimilation of Ionospheric Measurements for USU models and Global Assimilative Ionospheric Model for JPL/USC models. Except for high latitudes, there are two or more data assimilation models for the different ionosphere domains. For middle and low latitudes, there are five data assimilation models that can be used for a specific geophysical event. Some of the data assimilation models also provide the self-consistent drivers of the ionosphere, including neutral winds and composition, magnetospheric and dynamo electric fields, and particle precipitation. The deduced neutral parameters obtained from the ionosphere data assimilation models can then be compared to those obtained from the thermosphere data assimilation model. Some of the models also have regional and nested grid capabilities.

Figure 1 shows an example from a midlatitude to low-latitude ionosphere reconstruction with the GAIM-4DVAR data assimilation model. The study was conducted to estimate equatorial electric field/plasma drift, ion production factor, and wind. The solid black circles (Figure 1, left) indicate incoherent scatter radar (ISR) measurements made at the Jicamarca Radio Observatory. The red curve presents estimated vertical drift and a single-ion production factor (Figure 1, right, red diamond). The analysis indicates that

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Table 1. Data Assimilation Models

GAIM-band limited (BL)	Midlatitude to Low-Latitude Ionosphere
GAIM-Gauss Markov (GM)	Midlatitude to Low-Latitude Ionosphere
GAIM-4DVAR	Midlatitude to Low-Latitude Ionosphere with Drivers
GAIM-full physics (FP)	Midlatitude to Low Latitude Ionosphere-Plasmasphere with Drivers
Middle-low electro-DA	Midlatitude to Low Latitude Ionosphere with Drivers
IDED-DA	High-Latitude Ionosphere with Drivers
GTM-DA	Global Thermosphere Model-Data Assimilation

data assimilation helps GAIM-4DVAR catch the prereversal enhancement in ion drift. The ability to capture the enhanced upward ion drift is significant because it can lead to equatorial spread *F*, plasma bubbles, and scintillation, which in turn, result in HF communication outages and degradation of GPS navigational systems.

An example of a regional run of the GAIM-Full Physics (FP) model is shown in Figure 2. For this midlatitude run, data from five ionosondes and numerous ground GPS/total electron content (TEC) receivers were assimilated for day 82 in 2004. Figure 2 shows the GPS/TEC measurements at 17:00 UT (left), the vertical TEC from the GAIM-FP model (middle), and the corresponding meridional neutral wind at 300 km from the GAIM-FP model (right). The data significantly modified the background physics-based Ionosphere-Plasmasphere Model (IPM) result, and the deduced neutral wind is very different from the empirical neutral wind model used in the IPM. The neutral wind has an important effect on the peak *F* region electron density (N_mF_2) and the ability to provide reliable specifications and forecasts of N_mF_2 leads to improved predictions of the maximum frequency that can be used by emergency responders during natural disasters. In this regard, it should be noted that the tsunami that hit Japan on 11 March 2011 destroyed cell towers and HF communications then became very important.

In a recent run of the Ionospheric Dynamics and ElectroDynamics-Data Assimilation (IDED-DA) model, $\Delta\mathbf{B}$ from 92 ground magnetometers, cross-track drift velocities from four DMSP satellites, and line-of-sight velocities from nine Super Dual Auroral Radar Network (SuperDARN) radars were simultaneously assimilated into the IDED-DA model for a multiday period in 2000. Figure 3 shows a snapshot at 12:00 UT on day 43 of some of the ionosphere and electrodynamics parameters obtained from the run.

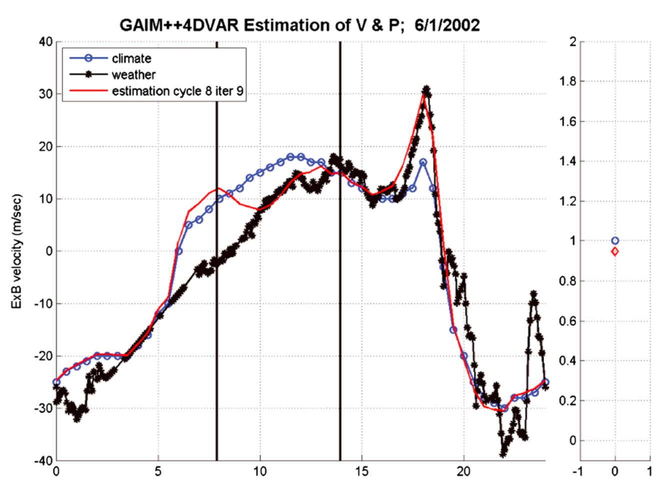

Figure 1. GAIM – 4DVAR reconstruction and driver determination [*Pi et al.*, 2009].

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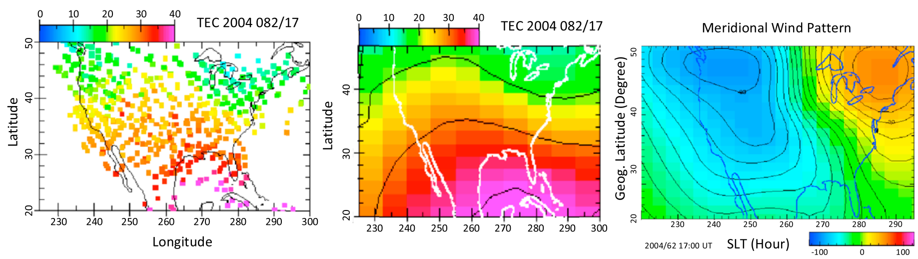

Figure 2. Snapshots of TEC measurements (left), GAIM-FP reconstruction (middle), and GAIM-FP neutral wind at 300 km (right) for 17:00 UT, day 82, 2004.

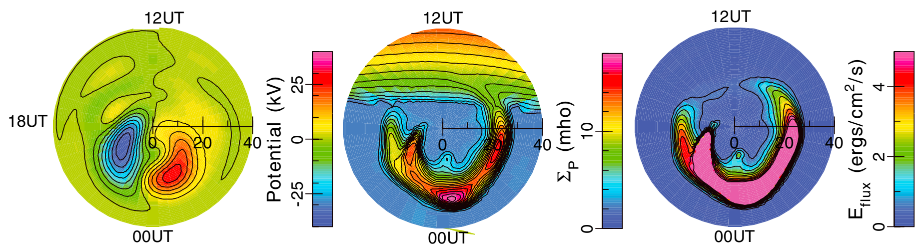

Figure 3. Snapshot of electric potential (left), height-integrated Pedersen conductance (middle), and precipitating electron energy flux (right) from a run of the IDED-DA model for the northern polar region. Storm period 2000/43 12:00 UT.

3. Data Sources

Data are a critical element of a data assimilation model, and the more data that are available the better, but it is also important to have different types of data (Table 2). Note that the instruments/measurements listed in Table 2 provide data for all of the important neutral and plasma parameters and cover a large part of the globe. However, at present, not all of the individual models are capable of assimilating all major global data sets, but the individual ionosphere data assimilation models will be enhanced to assimilate the five major global data types (GPS-TEC, occultation, in situ N_e, ionosonde, limb, and disk UV).

4. Ensemble Modeling With Different Data Assimilation Models

The Multimodel Ensemble Prediction System (MEPS) will be invaluable for specifications, forecasts, and science. Our team's science focus is to elucidate the fundamental physical, chemical, and coupling processes that operate in the I-T-E system for a range of *actual*, *global-scale*, *space weather events* that include plasma and neutral structures generated, for example, during storms and substorms. However, MEPS will be delivered to the Community Coordinated Modeling Center and this will provide the science community with an opportunity to study a wide range of unresolved science problems. Finally, MEPS will provide an innovative approach to space weather specifications and forecasts.

Table 2. Data Sources That Our MEPS Data Assimilation Models Will Assimilate

Ionosphere	Electrodynamics	Thermosphere
Ground-based GPS-TEC	Ground magnetometers	Satellite UV emissions
Satellite-based GPS occultation	DMSP cross-track velocities	In situ neutral densities and winds
Ionosonde and digisonde	SuperDARN line-of-sight velocities	Satellite accelerometer and drag
In situ N_e	Iridium magnetometers	FPI winds
911 Å, 1356 Å, limb, disk (UV)	ACE interplanetary magnetic field, *Dst*	ISR neutral parameters
Solar UV, EUV	Solar UV, EUV	Solar UV, EUV

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