Continued Development and Validation of the USU GAIM Models

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LONG-TERM GOALS

The primary goal of the project is to continue the development and validation of the USU GAIM models. A secondary goal is to provide support for the Air Force Weather Agency (AFWA) and other DoD organizations in connection with the operational GAIM model.

OBJECTIVES

We developed two physics-based data assimilation models of the ionosphere under a program called Global Assimilation of Ionospheric Measurements (GAIM). One of the data assimilation models is now in operational use at the Air Force Weather Agency (AFWA) in Omaha, Nebraska. This Gauss-Markov data assimilation model (GAIM-GM) uses a physics-based model of the ionosphere (IFM) and a Kalman filter as a basis for assimilating a diverse set of real-time (or near real-time) measurements. The second data assimilation model uses a physics-based ionosphere-plasmasphere model (IPM) and an ensemble Kalman filter as a basis for assimilating the measurements. This full physics model (GAIM-FP), which covers the altitude range of from 90 to 30,000 km, is more sophisticated than the GAIM-GM model, and hence, should provide more reliable specifications in data poor regions and during severe weather disturbances. The GAIM-FP model is scheduled for operational use in 2012. Currently, both GAIM models are capable of assimilating bottom-side N_e profiles from a variable number of ionosondes, slant TEC from a variable number of ground GPS/TEC stations, in situ N_e from four DMSP satellites, occultation data, and line-of-sight UV emissions measured by satellites. The goal of this project is to continue the development and validation of the USU GAIM models, and the objectives are (1) Test assimilation strategies for the SSULI UV data in an effort to mitigate the noise problem; (2) Assimilate GUVI and/or SSUSI UV data, which might be new data sources available at the Air Force Weather Agency (AFWA); (3) Assimilate data from the 6 COSMIC satellites; (4) Continue the validation of the GAIM-GM model in collaboration with the Air Force Research Laboratory; and (5) Continue testing and perfecting the driver determining algorithms in the GAIM-FP model. Also, new versions of the GAIM models will be delivered to AFWA as the models are upgraded and new data are assimilated. AFWA has scheduled GAIM deliveries up through 2012.

APPROACH

The Gauss-Markov data assimilation model (GAIM-GM) was developed as part of the MURI effort (*Schunk et al., 2004a, 2005a; Scherliess et al., 2004, 2005, 2006*). It is a data assimilation model of the ionosphere that is based on the Ionosphere Forecast Model (IFM) (*Schunk*, 1988; *Sojka*, 1989; *Schunk*

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14. ABSTRACT
The primary goal of the project is to continue the development and validation of the USU GAIM models. A secondary goal is to provide support for the Air Force Weather Agency (AFWA) and other DoD organizations in connection with the operational GAIM model.

15. SUBJECT TERMS

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et al., 1997), which covers the E-region, F-region, and topside ionosphere up to 1400 km, and takes account of six ions (NO^+, N_2^+, O_2^+, O^+, He^+, H^+). In the Gauss-Markov Kalman filter, the ionosphere densities obtained from the IFM constitute the background ionosphere density field on which perturbations are superimposed based on the available data and their errors. To reduce the computational requirements, these perturbations and the associated errors evolve over time with a statistical model (Gauss-Markov process). As a result, the Gauss-Markov Kalman filter can be executed on a dual CPU workstation. Like all assimilation techniques, the GM model uses the errors on the observations and model in the analysis, and computes the errors in the match. This model also has both regional and global modes, and has latitude, longitude, and temporal resolutions that are adjustable. To date, we have conducted numerous simulations with several different data types. We have assimilated GPS/TEC from up to 1000 ground receivers, in situ N_e from 4 DMSP satellites, bottomside N_e profiles from 30 digisondes, occultation data from 3 satellites (IOX, CHAMP, SAC-C), and UV emission data (*Scherliess et al., 2005a; Sojka et al., 2007; Thompson et al., 2006*).

The full physics-based data assimilation model (GAIM-FP) rigorously evolves the ionosphere and plasmasphere electron density field and its associated errors using the full physical model (*Schunk et al.*, 2004b, 2005b*; Scherliess et al*., 2004, 2005). Advantages of this rigorous approach are expected to be most significant in data-sparse regions and during times of "severe weather." The model is based on a new physics-based model that is composed of an Ionosphere-Plasmasphere Model (IPM) that covers low and mid-latitudes and an Ionosphere-Polar Wind Model (IPWM) that covers high latitudes. These new physics-based models are state-of-the-art and include six ion species (NO^+, O_2^+, N_2^+, O^+, He^+, H^+), ion and electron temperatures, and plasma drifts parallel and perpendicular to the geomagnetic field. These models use the International Geomagnetic Reference Field, which accurately describes the relative positions of the geographic and geomagnetic equators and the declination of the magnetic field lines. The physics-based models cover the altitude range from 90 to 30,000 km, which includes the E-region, F-region, topside ionosphere, plasmasphere, and polar wind. The different data sources are assimilated via an ensemble Kalman filter technique and quality control algorithms are provided as an integral part of the Kalman filter model. The GAIM-FP model provides 3-dimensional ion and electron density distributions as a function of time. In addition, the GAIM-FP model provides *self-consistent* distributions for the *global drivers* (neutral winds and densities and equatorial electric fields), and in its specification mode it provides *quantitative estimates of the accuracy of the reconstructed plasma densities*.

These GAIM data assimilation models are being used to accomplish the goals and objectives outlined above.

WORK COMPLETED

During the second year of the project, we addressed several of the proposed tasks:

(1) The latest version (2.4.3) of the GAIM-GM model is running at NRL, AFRL and AFWA. This version included a bug fix in the background NmF2 output file and an improved background ionosphere construction to eliminate difficulties when the IFM density is very low (typically at night at low latitudes). These improvements yield much better hmF2 values in the affected areas. Also, a computationally efficient hot-start capability (requested by AFWA); construction of an independent latent data acceptance window for SSIES data; and matrix optimizations suggested by Northrop Grumman were included.

(2) We continued the testing and validation of the GAIM-FP model. The advantage of the Full Physics model is that the self-consistent drivers of the ionosphere are calculated along with the ionospheric reconstruction. First, we obtained neutral winds at mid latitudes and then we obtained electric fields at low latitudes. More recently, we obtained both neutral winds and electric fields throughout the low-mid latitude domain, and validation with data that was not assimilated indicated the GAIM-FP model is working correctly. This validation work will continue for the duration of this project.

(3) The GAIM-FP data assimilation model now routinely incorporates ground GPS TEC data, bottom-side electron density profiles from ionosondes and COSMIC occultation data.

(4) We have been working extensively with the SSUSI UV limb and disk data. To date, we have delivered the GAIM-GM model, and data reduction and quality checking algorithms capable of using SSUSI disk and limb data from F16 and F17. Further work is required to finalize the F17 capability before this is transitioned to operations. We have developed utilities to reduce and assimilate the GUVI data as well.

(5) SSULI data from F16 and F17 appear to be contaminated by noise owing to the instrument design and placement. This has precluded using the data for any research and development at USU.

(6) TIP data have been used extensively to compare against the USU GM model results. However, the data are contaminated by a red light leak, and is therefore biased too high in certain regions. In particular, city lights and reflected moonlight cause difficulties. While there has been some work at NRL to mitigate these effects, the data have not been corrected to a level that makes assimilation of the data by the GM warranted at this point.

(7) As part of the validation effort, we conducted simulations to determine the effect that upward propagating waves from the lower atmosphere have on the ionosphere-thermosphere system.

(8) We continue to support Northrop Grumman, AFWA, NRL, and AFRL in their validation and implementation efforts.

(9) Several GAIM papers and talks were presented at scientific meetings, including the Community Coordinated Modeling Center (CCMC) workshop in November 2007, the Fall AGU Meeting in December 2007, the American Meteorological Society (AMS) Meeting in January 2008, the Space Weather Workshop in April 2008, the Ionospheric Effects Symposium (IES) in May 2008, the NSF CEDAR meeting in June 2008, and the international COSPAR symposium in Montreal, Canada in July 2008.

(10) We attended GAIM Summit Meetings at AFWA in March and August 2008.

RESULTS

The GAIM-FP model was recently used to determine the ionospheric electron density and drivers in the middle-low latitude domain. The goal was to obtain a 3-dimensional electron density reconstruction and the neutral wind and electric field that were responsible for the electron density configuration. The simulation covered a several day period in March/April 2004, during which the magnetic activity was low. Slant TEC measurements from a worldwide distribution of 162 GPS ground receivers were assimilated into the GAIM-FP model. Digisonde electron density profiles were also available for this period, but they were not assimilated. Instead, they were used for validation purposes. Figure 1 shows a snapshot of the vertical TEC distribution on day 80 at 11:00 UT, 2004. In the top panel the slant TEC was converted to vertical TEC with an angle factor and plotted at 350 km in order to show the measurements. The bottom panel shows the corresponding global TEC distribution obtained from the GAIM-FP data assimilation model. A comparison of the reconstructed electron density profiles with the digisonde profiles indicated that the GAIM-FP model successfully reproduced the ionospheric conditions at that time. The deduced meridional neutral wind was also shown to be consistent with the TEC distribution calculated by the GAIM-FP model.

IMPACT/APPLICATIONS

The USU GAIM-GM and GAIM-FP data assimilation models provide ionosphere specifications and forecasts on both global and regional grids. These specifications and forecasts are useful for DoD and civilian command and control operations, including HF communication links, geo-locations, over-the-horizon (OTH) radars, surveillance, and navigation systems that use GPS signals.

TRANSITIONS

The latest version (2.4.3) of the operational GAIM-GM model is running at NRL, AFRL, AFWA, and the CCMC.

RELATED PROJECTS

This project resulted from a basic research DoD MURI program called Global Assimilation of Ionospheric Measurements (GAIM). A research grade version of our GAIM-GM data assimilation model was developed under the MURI program.

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HONORS/AWARDS/PRIZES

R. W. Schunk was inducted into the International Academy of Astronautics

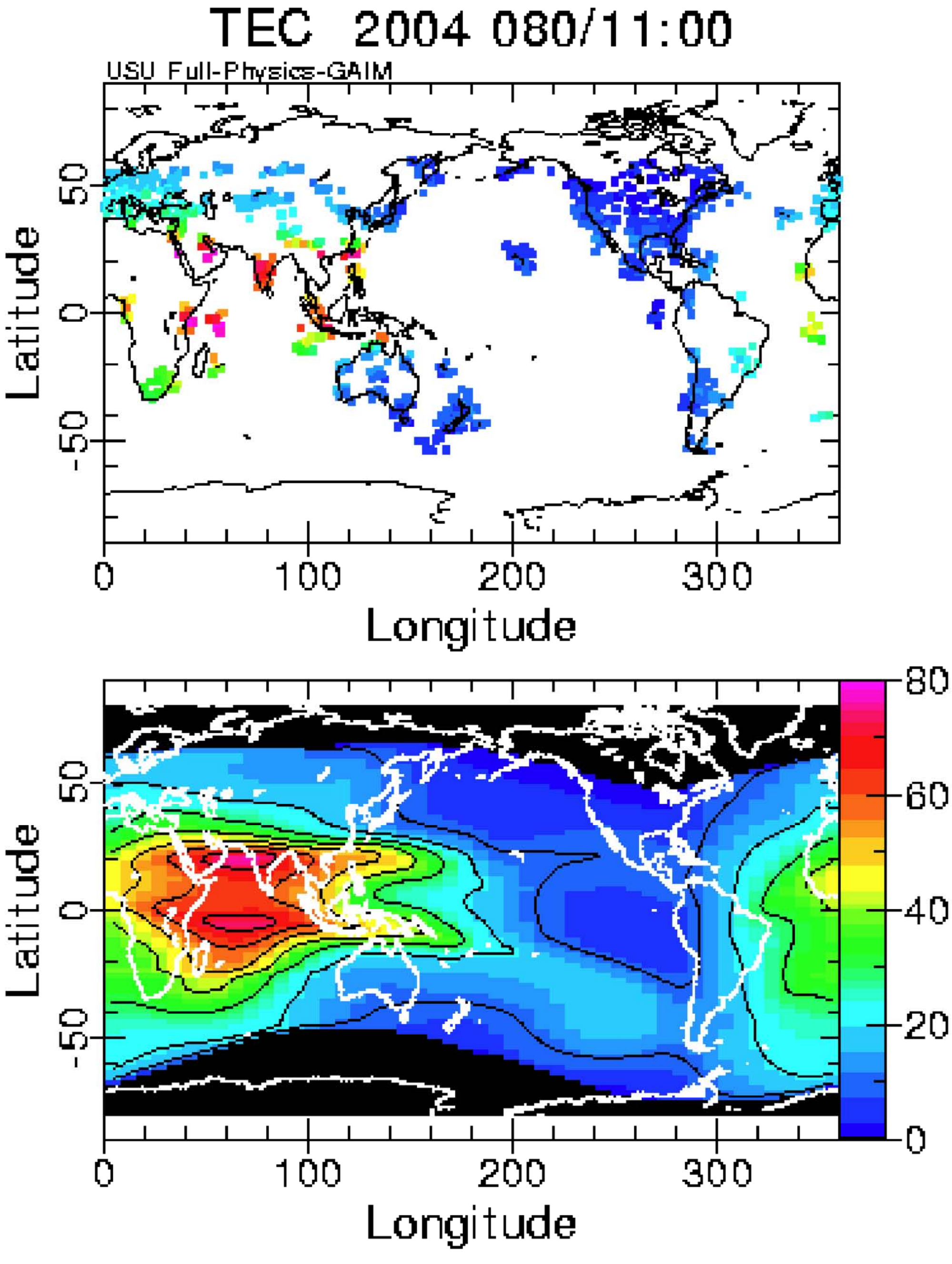

Figure 1. Distributions of vertical TEC obtained from GPS measurements (top) and the GAIM-FP model (bottom). The units are 10^{16} el/m^2.