International Beacon Satellite Symposium BSS-2016
Trieste, Italy

The USU-GAIM Data Assimilation Models for Ionospheric Specifications and Forecasts

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ABSTRACT

Physics-based data assimilation models have been used in meteorology and oceanography for several decades and are now becoming prevalent for specifications and forecasts of the ionosphere. This increased use of ionospheric data assimilation models coincides with the increase in data suitable for assimilation. At USU we have developed several different data assimilation models, including the Global Assimilation on Ionospheric Measurements Gauss-Markov (GAIM-GM) and Full Physics (GAIM-FP) models. Both models assimilate a variety of different data types, including ground-based GPS/TEC, occultation, bottomside electron density profiles from ionosondes, in-situ electron densities, and space-based UV radiance measurements and provide specifications and forecasts on a spatial grid that can be global, regional, or local. The GAIM-GM model is a simpler model that uses the physics-based Ionosphere Forecast Model (IFM) as a background model but uses a statistical process in the Kalman filter. This model is currently in operational use at the Air Force Weather Agency (AFWA) in Omaha, NE. The GAIM-FP model is a more sophisticated model that uses a physics-based ionosphere-plasmasphere model (IPM) and an Ensemble Kalman filter. The primary GAIM-FP output is in the form of 3-dimensional electron density distributions from 90 km to near geosynchronous altitude but also provides auxiliary information about the global distributions of the self-consistent ionospheric drivers (neutral winds and densities, electric fields). The GAIM-FP model has recently been updated and extended to include the ionospheric D-region and to incorporate bubble information obtained from the SSUSI instruments.

Key words: Data Assimilation, Ionosphere

Introduction

At Utah State University, two physics-based Kalman-filter data assimilation models for the Earth's ionosphere have been developed. These models are the Gauss-Markov Kalman Filter Model (GAIM-GM) and the Full Physics-Based Kalman Filter Model (GAIM-FP) [2, 3]. Both models are part of the Global Assimilation of Ionospheric Measurements (GAIM) project [2, 3, 4 ,5 ,6].

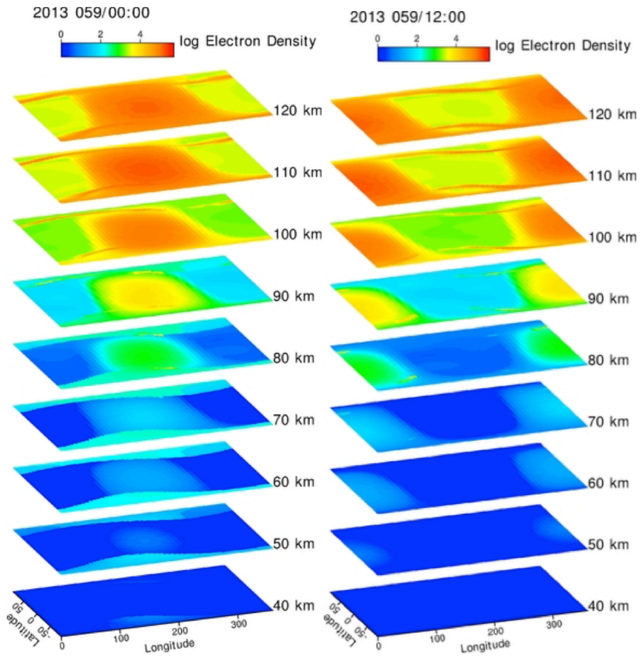

Figure 1. GAIM-FP electron densities in the D region and lower E region. The log of the electron density for day 2013/059 is shown from 40 km to 120 km altitude in 10 km altitude steps. The left panel corresponds to 00:00 UT and the right panel corresponds to 12:00, respectively.

Some of the data that have previously been assimilated by these models include phase-leveled ground-based Global Positioning Satellite (GPS) slant total electron content (TEC); bottomside electron density profiles from ionosonde/digisonde in Standard Archiving Output (SAO) data files; radio occultation (RO) slant total electron content data from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) Precision Omni-directional Dipole (POD) antennas; topside ionospheric plasma electron density measurements from the Defense Meteorological Satellite Program (DMSP) in situ sensors; and DMSP Special Sensor Ultraviolet Spectrographic Imager (SSUSI) and Special Sensor Ultraviolet Limb Imager (SSULI) nighttime UV radiances.

Recently, information about the location and extend of ionospheric bubbles has been incorporated into the GAIM models. Furthermore, GAIM-FP has been updated to include a Data Driven D-region (DDDR) model [1].

D-Region Extension

Recently, GAIM-FP has been extended to include a Data-Driven D-region model (DDDR) [1] that extends the lower boundary of the model down to 34 km altitude. Within the DDDR, the solar x-rays are modeled as hard x-rays (0.1 Å < l < 10 Å) and soft x-rays (10 Å < l, 100 Å). The x-ray ionization creates energetic secondary electrons or Compton photons that have sufficient energy for further ionization. The DDDR also includes Lyman Alpha ionization of Nitric Oxide as an important source of D-Region ionization. The DDDR nighttime ionization is created from geocorona resonant emissions, interplanetary gas scatter (He II, He I, Lyman Alpha) and starlight. At high latitudes, DDDR includes ionization due to energetic electrons and Solar Proton Events using the GOES energetic proton flux observations. Figure 1 shows an example of the GAIM-FP electron density in the D region and lower E region for day 2013/059 from 40 km to 120 km altitude in 10 km altitude steps. The left panel corresponds to 00:00 UT and the right panel corresponds to 12:00, respectively.

Bubble Incorporation

Although neither GAIM-GM, nor GAIM-FP includes the physical processes that drive ionospheric plasma instabilities and bubbles, information about the location and extend of ionospheric bubbles has recently been incorporated into the GAIM models. The bubble

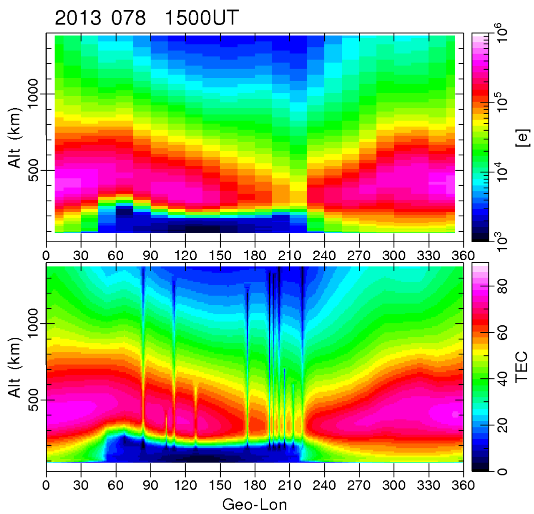

Figure 2. GAIM-GM results in top panel. Interpolated & bubble results in bottom panel. Both are a longitude slice at the geographic equator.

information is obtained from the HiRes SSUSI 3-D ionosphere product and consists of the plasma-depletion centroid location (longitude, latitude, altitude) and the median depth of the plasma depletion. Figure 2 shows an example of the GAIM-GM electron densities at 1500 UT for day 078/2013. The top panel shows a longitude/altitude slice through the 3-d electron density field as provided by GAIM-GM at the geographic equator. The bottom panel shows the interpolated density field together with the superposed plasma depletions. These interpolated output files with superposed plasma bubbles can be useful, for example, for sensitive mathematical procedures, such as ray-tracing programs.

Summary and Conclusions

Two ionospheric data assimilation models with different sophistication and complexity have been developed at USU. Both models assimilate measurements from various ionospheric observing systems and allow for data latencies of up to 3 hours. Recently, the GAIM-FP model has been updated to include ionospheric bubble information and a data-driven D-region model. The D-region model extents the altitude range of GAIM-FP down to 34 km altitude.

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Acknowledgements: This work was supported in part by NSF grant AGS-1329544.