APPLICATION OF DATA ASSIMILATION TECHNIQUES FOR SPACE WEATHER

Tim Fuller-Rowell
Space Environment Center
325 Broadway
Boulder, CO 80305

ABSTRACT

The potential of data assimilation for operational numerical weather forecasting has been appreciated for many years. For space weather it is a new path that we are just beginning to explore. With the emergence of satellite constellations and the networks of ground based observations, sufficient data sources are now available to make the application of data assimilation techniques a viable option. The first space weather product to be launched by SEC utilizing data assimilation will be launched later this year. This is the first step along a path that will likely lead to major improvement in space weather forecasting, paralleling the advances achieved in meteorological weather forecasting.

1.INTRODUCTION

Advances in forecasting tropospheric weather over the last two decades have been built on three pillars: improvements in capturing physical processes in numerical models, a huge increase in the availability of data primarily from new satellite observations, and the ability to combine the two using optimal data assimilation techniques. Physical model of the upper atmosphere both for the ionosphere (Schunk and Sojka, 1996; Richards and Torr, 1996; Bailey and Balan, 1996) and for the coupled thermosphere ionosphere system (Roble, 1996; Fuller-Rowell et al., 1996a) have matured over the years and can now simulate many of the observed features. These models are able to match the global features in comprehensive empirical models such as the International Reference Ionosphere (IRI; Bilitza, 2001) and the Mass Spectrometer and Incoherent Scatter (MSIS; Hedin et al., 1987) neutral atmosphere model. In addition, the physical models have the added advantage of being able to follow time-dependent changes and can be used to interpret observations by analysis of the physical processes embedded in the model. For a given season, and level of solar and geomagnetic activity, the physical models are able to describe the global distribution of ion and neutral parameters to about the same level of accuracy as the empirical models. The advances will come by combining the knowledge of the physics contained in the numerical models with the rapidly increasing data source.

The volume of real-time observational data for the upper atmosphere has been limited in the past to a few ground-based ionosondes and incoherent scatter radar facilities, and perhaps one or two in-situ measurements from polar orbiting spacecraft. Now, data is available from an ever-increasing global network of dual-frequency GPS receivers providing slant path electron content, routine imaging from a variety of polar and equatorial spacecraft, and from constellations of satellites providing a dense global distribution of occultation measurements. The maturity of the models and the promise of increased data resources have spawned the application of data assimilation techniques in the space physics community. One of the major thrusts proceeded under the MURI Global Assimilation of Ionospheric Measurements (GAIM) initiative (Scherliess et al. 2004). By applying these new techniques to specification and forecast of the ionosphere and neutral upper atmosphere, the accuracy of the predictions will begin to parallel the breakthroughs in meteorological weather forecasting.

2.CURRENT ACTIVITIES

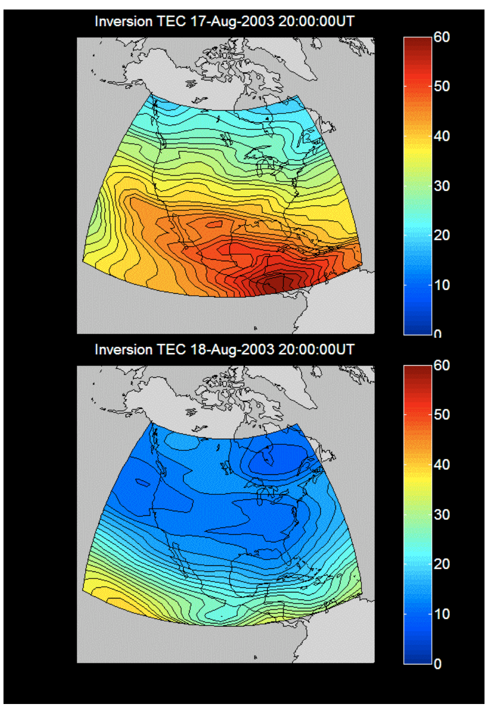
Space Environment Center (SEC) is a 24x7 operational center and in FY05 will transfer to the National Weather Service (NWS) to be a full National Center for Environmental Prediction (NCEP) partner. SEC's mission is to characterize the space environment in real-time and provide alerts and warnings to customers, in much the same way as NWS provides tropospheric weather forecasts. SEC is now making the first steps in adopting data assimilation techniques for space weather. Through a collaboration between the National Geodetic Survey (NGS), the University of Colorado's Cooperative Institute for Research in Environmental Sciences (CIRES), and SEC, a regional ionospheric data assimilation model has been developed to specify the total electron content over the Continental United States (CONUS). This first venture does not yet utilize the sophisticated physical models within the assimilation process, but it does capitalize on the recent increase in data availability. The model relies on the real-time network of ground-based, dual-frequency, GPS receivers operated by the US Coast Guard for the National Differential GPS Service (NDGPS). The NDGPS system has twin GPS receivers currently operating at approximately 100 stations across the CONUS. These data are also part of the Continuously Operation Reference Station (CORS) network of over 400 stations that are used by NGS for geodetic application. These data are now streamed into SEC within seconds of acquisition.

The availability of the GPS data in real-time and recent model development has resulted in the first space weather assimilative model suitable for transition to SEC Space Weather Operations (SWO). With the reliable feed of GPS data, the model is capable of accurate real-time specification of vertical and slant-path total electron content (TEC) over the Continental US (CONUS). The product (US-TEC) is of potential value for improved single frequency GPS positioning and more rapid dual-frequency centimeter accuracy positioning.

The figure below illustrates the response of the ionosphere over the CONUS during a geomagnetic storm in August 2003, as captured by the assimilative model. The top panel shows the normal development of the peak total electron content during the day reaching values over 50 TEC units on August 17 (1 TEC = 10^{16} electrons m^{-2}). On the storm day on August 18th, in the lower panel, the geomagnetic storm wiped out the normal development of the dayside peak, leaving a trough in electron density.

Validation of the model indicates that the data assimilation techniques will be able to specify these storm-time depletions with much greater accuracy than the empirical models.

The US-TEC product is currently being validated for reliability and accuracy, and is expected to transition as a test operational product in the fall of 2004. This venture into space weather assimilative models is a first step, and is laying the foundations for future products of this kind. The next steps will extend the coverage to global, include a wider spectrum of input data, and adopt physical models for the propagation of the state, which will enable the assimilative models to forecasts the space weather system.



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