An ensemble Kalman filter algorithm for ionospheric characterization and forecasting

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The characterization and forecasting of ionospheric electron density is an important area of research due to the ionosphere's impact on positioning, navigation, and communication systems. A number of detailed, physics-based models of the ionosphere exist, but their ability to reproduce observational data strongly depends on the accuracy of their drivers. Data assimilative methods can be used to infer appropriate model driver values from ionospheric data such as slant TEC and ionosonde measurements.

In this work, we demonstrate a two-step process for assimilating ionospheric data into the Thermosphere Ionosphere Electrodynamic General Circulation Model (TIE-GCM). In the first step, GNSS slant TEC data is assimilated into a background electron density field using the TRIPL-DA data-assimilation software, which uses a 3D-VAR data-assimilation algorithm to produce "nowcasts" of the ionospheric electron density. In the second step, electron density vertical profiles are taken from the data-rich regions of the "nowcast" field and assimilated into an ensemble of TIE-GCM model states using an ensemble Kalman filter algorithm. Our current implementation uses the ensemble adjustment Kalman filter (EAKF) [Anderson, 2003] variant of the ensemble Kalman filter.

As a proof of concept, results have been gathered from several Observing System Simulation Experiments (OSSEs) in which vertical profile "data" were sampled from a TIE-GCM model run starting at March 21, 2014 and moving through April 12, 2014, driven by historical values of K_p and $F_{10.7}$. A synthetic data set of vertical profiles was created by selecting vertical profiles from TIE-GCM grid points containing three or more GNSS stations (meant to represent data-rich areas). A number of experiments were performed to investigate 1) the relative effect on both forecasting and characterization of including specific state variables in the EnKF state vector and 2) the importance of updating external drivers along with the state variables at each assimilation step (for TIE-GCM, these drivers are the solar 10.7cm radio flux ($F_{10.7}$), cross-tail potential drop (CP), and auroral hemispheric power (HP)). Our results suggest that 1) thermospheric variables such as neutral densities and neutral temperatures are very important to include, in addition to ionspheric variables, for accurate characterization of the electron density field and 2) updating external drivers at each assimilation step is crucial for producing accurate, long-term forecasts.

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