Ionospheric-Thermospheric State Estimation With Neutral Wind Data Assimilation

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Assimilation of radio sounding measurements --- Global Navigation Satellite System (GNSS) data, ionosondes, beacon satellites, and more --- of the ionosphere has been ongoing for over a decade, and has enabled ionospheric plasma mapping at global scales and at unprecedented resolution. Data assimilative technology has allowed us to sense and map the redistribution of plasma in response to stormtime forcing, in the form of storm-enhanced densities (SED), plumes of plasma feeding into the plasmasphere, bubbles, depletions and troughs. However, the drivers behind these formations have had to be measured in situ or indirectly, and with greater sparsity than measurements such as total electron content (TEC) from GNSS.

Previous work used GNSS-based assimilation of time-varying plasma distribution from Ionospheric Data Assimilation 4-Dimensional (IDA4D), to try to deduce the important electrodynamic and convective processes during stormtime. The algorithm developed, Estimating Model Parameters from Ionospheric Reverse Engineering (EMPIRE), formed the ion continuity equation as an overdetermined linear system in which the measurements are the time-varying plasma densities, and the states to be estimated low-order basis expansions of the electric potential and neutral wind field. The interaction of neutral winds with plasma is an important dynamic in the mid-latitude ionosphere, particularly during stormtime. Electrodynamics dominate at low and high-latitudes but winds and transport processes are thought to be key drivers of mid-latitude stormtime behavior. In particular at nighttime, thermospheric winds may contribute to redistribution of plasma in significant ways.

In this work we present our results expanding EMPIRE to additionally assimilate thermospheric neutral wind measurements made from Fabry-Perot interferometers (FPI). The EMPIRE algorithm has been updated to Kalman filter each of the states (production, loss, neutral winds, electric fields) with a background model updated by the measurements. In addition the ion continuity equation matrix is now augmented with measurements themselves of the line-of-sight winds made by a mid-latitude FPI sensing the redline and greenline thermospheric nighttime emissions over the Midwestern United States.

We compare our estimated three-dimensional drifts with DMSP satellite in situ measurements of plasma motion. These are compared without and with FPI neutral wind ingestion. The Kalman filtering of FPI data yields neutral wind estimates that more closely follow the measurements. This also has the effect of indirectly altering the estimates of other states, such as electric potential, and allows us to compare the relative importance of these two plasma transport drivers during nightside stormtime plasma density redistribution.