Near-Real-Time Data Assimilation of the High Latitude Ionosphere

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The high latitude ionosphere provides a challenging environment for space weather forecasting due to its highly dynamic behaviour and the extreme sparsity of data. By design, climatological models cannot adequately capture the short-term variability of the ionosphere. To be able to provide the best possible understanding of the current state of the high-latitude ionosphere, augmenting traditional models with near-real-time data sources is necessary.

A number of instruments are able to provide data with less than two-hour latency, including Global Navigation Satellite System (GNSS) receivers, ionosondes, and satellite-borne altimeters and GNSS receivers. These instruments are both sparsely and unevenly distributed at high latitudes, which creates challenges for traditional assimilation approaches. The locations of ground-based GNSS receivers preclude tomography in much of the region, a condition which is worsened when assimilation is limited to those stations that provide near-real-time data.

To address these issues, we have developed a new, near-real-time data assimilation framework intended for the high latitude region. This framework is built on the Empirical Canadian High Arctic Ionospheric Model (E-CHAIM) and uses a Sequential Monte Carlo Particle Filter as the basis of the assimilation. By parameterizing the vertical profile as a semi-Epstein layer with height-varying thickness and using spherical cap harmonics for geographic variation, we can greatly reduce the dimensionality of the state space. This parameterization also allows us to easily spread information over regions with little or no available data, while ensuring that the resulting ionospheric profile is physically realistic.

We present results using both simulated GNSS and ionosonde observations in order to verify the validity of this technique. This data was simulated using a model ionosphere with a higher spatial and temporal variability than either our background model or assimilation can reproduce, in order to create an adequately challenging test environment. To accomplish this, the model ionosphere uses real vertical Total Electron Content (vTEC) measurements from Madrigal TEC maps in order to construct spatial and temporal variations on hundred- and thousand-kilometer scales that would otherwise be difficult to model when creating the simulated data.

In this test environment, we demonstrate an improvement in the reconstructed ionospheric profile, and in reconstructed vTEC, when compared to the base empirical model. In addition, we are able to resolve the simulated Differential Code Biases (DCBs) of the GNSS receivers, an essential capability in order to be able to use real GNSS data self-consistently. Early results using real data are also presented.