Inference of Hidden States by Coupled Thermosphere-Ionosphere Data Assimilation: Applications to Observability and Predictability of Neutral Mass Density

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The ionosphere and thermosphere are a tightly coupled system, thus the predictability and observability of one subsystem affects that of the other. In contrast to the ionosphere, which is relatively well-monitored by diverse instrumentation techniques including ionosondes, coherent and incoherent radars, Global Navigation Satellite System (GNSS) radio occultation, and a network of GNSS ground-based receivers, monitoring of the thermosphere's state is limited. This asymmetric observing capability of the upper atmosphere impedes our ability to predict the dynamic behaviors of this coupled system as a whole. This paper demonstrates how state-of-the-art dynamical data assimilation approaches facilitate inference of hidden thermospheric states from abundant ionospheric observations, by systematically incorporating coupling between neutral and plasma species into the process of data assimilation as well as forecasting. Previously, it has been shown that the observability and predictability of the ionosphere can be extended considerably by estimating neutral compositions and winds from ionospheric observations in a coupled thermosphere-ionosphere data assimilation system. The notion of observability is here used to characterize how well the internal states can be inferred from observations. Observing system simulation experiments and observing system experiments suggest that neutral temperature can also be well-inferred from abundant GNSS radio occultation ionospheric observations. A comparison to independent CHAMP mass density measurements shows that assimilation experiments of actual COSMIC electron density profiles into the NCAR Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) can reduce the bias existing in the TIEGCM control simulation up to 50%. Ensemble forecast simulations furthermore suggest that initialization of TIEGCM by the coupled thermosphere-ionosphere data assimilation significantly improves the thermospheric mass density forecasting, with its impact lasting longer than 3 days under geomagnetic quiet conditions. Given the ever-expanding GNSS infrastructure, this is indeed a promising prospect for the thermospheric mass density specification and forecasting.