4th URSI AT-RASC, Gran Canaria, 19-24 May 2024

Short-term Regional Ionosphere Imaging at Mid- and High-latitudes: A four-dimensional Ensemble-based Variational Approach

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At 4DSpace, we have developed and rigorously evaluated a robust short-term ionosphere electron density forecasting flavour based on a Strong Constraint Four-Dimensional Ensemble-Based Variational (SC4DEnVar) formulation. The scheme initializes from IRI-2016 and utilizes Gauss Markov filtering to forward propagate electron densities (30-min) while ensuring their adherence to a log-normal distribution for the requisite positive definiteness of ionospheric density. Preliminary assimilation is only with ubiquitous Global Navigation Satellite System (GNSS) observables from ground-based receivers. The focus is on moderately quiet mid-latitudes and high-latitudes-where non-linearities, often absent in models like IRI, are prevalent. We verify the reconstructions with independent data from ground-based ionosondes, SWARM satellites and satellite radio occultations (RO). We verify the 3D reconstructions with independent data from ground-based ionosondes, SWARM satellites and satellite radio occultations (RO). Results indicate that improvements are fairly adequate during the quiet period-notably, SC4DEnVar effectively incorporates new information, such as the time expansion of the tongue of ionization, previously absent in the background model. Through verification with ionosonde data, equator-wards, the scheme reconstructs show plasma rises associated with intensified eastward prompt penetration electric fields induced on the day side, as predicted in theory. Further, the SC4DEnVar scheme is found adequate for tracking the hmF2 variations. Using SWARM and RO data, we find SC4DEnVar to significantly improve the 3D-electron density picture, specifically in the F-region, remote areas and during severe conditions. Close to the poles, SC4DEnVar performance degrades as the uncertainty in the prognostic model increases. Nonetheless, SC4DEnVar reconstructions are better than stand-alone empirical models such as IRI. Therefore, in addition to computational efficiency and maintainability, these results support SC4DEnVar as a candidate for precise short-time regional forecasting.