Interpretable Machine Learning for Ionosphere Forecasting with Uncertainty Quantification

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Abstract

The ionosphere, the ionized upper Earth´s atmosphere, affects the radio wave propagation and consequently, can degrade the performance and reliability of GNSS positioning. To minimize these degradations, ionospheric effects need to be precisely and timely corrected by providing information of the spatially and temporally variable Total Electron Content (TEC). This requires nonlinear modeling of the ionosphere and the associated space weather effects. Such nonlinear relationships can be approximated using Machine Learning (ML). However, ML models are often treated as black-box models. Interpreting ML results, and assessing their quality and reliability are important steps toward developing a “trustworthy” model.

This study presents novel ML approaches to forecast the vertical TEC (VTEC) utilizing state-of-the-art supervised learning techniques. Particular attention is paid to the GNSS-derived VTEC data, which are systematically analyzed, selected and pre-processed for optimal model learning, especially during space weather events. The uncertainty of the achieved results is quantified robustly, for example by ensemble modeling or by modifying the objective cost function accordingly. Also, the results are further interpreted by applying explainable AI methods. Our approach shows potential for forecasting VTEC in different ionosphere regions during quiet and storm periods, while providing the uncertainties and improving the interpretability of the results.