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Editorial: Uncertainty quantification and model validation in space weather modeling

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Editorial on the Research Topic
Uncertainty quantification and model validation in space weather modeling

Space weather models over the last several decades have become an important part of studying the near-Earth space environment, and also a critical step in developing the ability to forecast space weather. Several competing models have been developed, so comparing and validating their results is essential e.g., (Pulkkinen et al., 2013). However, there are uncertainties in the solar wind input to the models, boundary conditions, and measurements against which the model outputs are validated. Quantifying these uncertainties is also critical to comparing the model performances. Recent studies have shown that these uncertainties can create biases that mimic physical effects and can be large for extreme space weather events e.g., (Sivadas and Sibeck, 2022; Lockwood, 2022). The Committee on a Decadal Survey for Solar and Space Physics (Heliophysics) 2024–2033 (National Academies of Sciences, Engineering, and Medicine, 2024) has acknowledged the importance of quantifying these uncertainties, resulting from community feedback such as (Pogorelov et al., 2024; Matteo and Sivadas, 2022; Burkholder et al., 2023).

Therefore, this Research Topic aims to quantify and compare the uncertainties in different space weather models, including empirical, physics-based, and machine learning models. Five papers on quantifying and comparing uncertainties in space weather models are published in this Research Topic. Synopses of the five papers are as follows.

Florczak et al. compared the outputs of three global MHD models: Space Weather Modeling Framework (SWMF), Open Geospace General Circulation Model (Open GGCM), and Lyon-Fedder-Mobarry (LFM) combined with the Rice Convection Model (RCM) for two severe space weather events. The simulated ground magnetic perturbations for the two storms investigated are higher than observations for all models. This overestimation concerning the observations further increases with the inclusion of the

RCM model. No particular model appeared to be better than the others, indicating that uncertainties in the solar wind inputs or approximations required in MHD modeling might be the source of the discrepancies.

Bagheri and Lopez compared the joule heating output of one of the global MHD models, SWMF, during two geomagnetic storms, with three empirical models of joule heating. They showed that the model consistently predicted lower joule heating values than the empirical models, which they attribute to insufficient conductance estimates from the Ridley conductance model used in the SWMF simulations. They also note that increased correlation of SWMF Birkeland current estimates with AMPERE data results in increased correlation with joule heating estimates, implying the correlation with Birkeland current observations can be used as a gauge of the accuracy of SWMF joule heating estimates.

(O'Brien et al.) developed a neural network model (PRIME) to predict solar wind parameters near the Earth by training the model on MMS-1 measurements and L1 spacecraft. The resulting model provides an improved continuous rank probability score (CPRS) compared to the present solar wind propagation algorithm using the minimum variance analysis. Furthermore, PRIME also offers corresponding uncertainties for its predictions.

(Hathaway et al.) conducted a detailed metric survey on a space weather event in April 2010 by comparing AMPERE measurements of field-aligned current (FAC) characteristics with those of the output FAC from the SWMF model coupled with three ionosphere electrodynamic models: MAGNetosphere-Ionosphere-Thermosphere (MAGNIT), Ridley Legacy Model (RLM), and Conductance Model for Extreme Events (CMEE). The study found that MAGNIT coupled with SWMF exhibits marginally improved predictions throughout the storm. The metrics from the model-data comparison can be used to optimize model performance further.

(Zhan) investigates interhemispheric asymmetries in the uncertainties of the Whole Atmospheric Model with Ionosphere-Plasmasphere Electrodynamics (WAM-IPE). The estimated uncertainties in electron density, plasma drifts, and neutral winds during magnetically quiet periods exhibit a clear north-south asymmetry in the mid-to-high latitude regions. Uncertainties appear to be larger in the southern hemisphere, probably due to the difference in ion-neutral coupling between the hemispheres or the difference in the offset between the magnetic and geographic poles.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declare that no Generative AI was used in the creation of this manuscript.

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