Abstract

The research area called "space weather" lies at the intersection of space physics and its effects on society and technology. Earth's magnetic field forms a protective bubble, called the magnetosphere, embedded in the magnetized plasma of the solar wind. Energy and momentum are transferred from the solar wind to the magnetosphere, driving geomagnetic activity. Current systems in the magnetosphere can close through Earth's partially-ionized upper atmosphere - the ionosphere - and these ionospheric currents, in turn, drive changes in the magnetic field measured on the ground. Time-varying changes in the magnetic field interact with the Earth's crust and upper mantle, inducing an electric field at the surface of the Earth. This geoelectric field presents a hazard for any long, grounded conductors, such as power lines. To address the needs of users, such as the electric power industry, routine forecasts of key quantities need to be made. As with terrestrial weather, the state-of-the-art is numerical prediction of user-relevant quantities. Although probabilistic forecasts are issued for some space weather phenomenologies, most numerical magnetospheric prediction systems currently yield deterministic forecasts. For more useful forecasts, as well as scenario definition for benchmarking purposes, we need to go beyond deterministic forecasts and report likely outcomes or probabilities of different results. Errors in numerical predictions typically arise through inaccurate specification of initial conditions or boundary conditions, as well as model uncertainties that arise because the model only approximates the system it simulates. Earth's magnetosphere is primarily an externally-driven system and so is extremely sensitive to the upstream boundary condition applied by the solar wind, and the interplanetary magnetic field it carries. A key challenge in space weather, for both prediction and model validation, is the sparse sampling of the system. Numerical models for space weather are typically driven by measurements of the upstream solar wind at a single point. I will introduce recent work that aims to take account of uncertain knowledge of the solar wind state as it impacts the magnetosphere, and how this can be applied to allow perturbed boundary condition ensemble modeling for space weather. This has recently been demonstrated using the operational configuration on the Space Weather Modeling Framework, and I will showcase the improvements this brings to predictions of geomagnetic indices, geomagnetic disturbances, and the resulting geoelectric field. This ensemble method also allows us to identify intervals of activity that cannot be explained by uncertainty in the solar wind driver, highlighting areas for further model development.