Project Details

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Topic: Magnetic Origins of the Corona and Inner Heliosphere

Project Title:
The Influence of Structure and Turbulence on Coronal and Heliospheric Dynamics - Improved Magnetohydrodynamic Modeling with Data-driven Subgrid-scale Effects

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Summary:
The solar wind is a complex and dynamic system that involves interactions across multiple physical and temporal scales. Global magnetohydrodynamic (MHD) simulations coupled to subgrid-scale turbulence models incorporate such cross-scale couplings, and are a valuable tool for providing context for in situ observations and for studying a variety of problems that involve the interplay between large-scale structure and turbulence. A crucial input to these models is provided by solar photospheric magnetograms. However, models, which typically have relatively coarse resolution, are unable to utilize the full information available in high-resolution (hi-res) magnetograms. Here we propose a novel approach for extracting high-wavenumber" information from these magnetograms and incorporating these data in our simulations. This will expand the physics contained within the model and help us better understand the magnetic field's influence on coronal and heliospheric structure and dynamics.

In particular, we propose the following focused research tasks -
1) Use a novel approach to estimate magnetic turbulence levels at the photosphere, by applying filtering methods on hi-res magnetograms to compute small-scale fluctuations.
2) Use these turbulence levels as data-driven, spatially-varying input for our model, which will produce distributions of large-scale fields and turbulence parameters through the inner heliosphere, thus enabling investigation of effects of photospheric turbulent variations on acceleration, heating, and dynamics of the inner-heliospheric plasma. Simulation results will be compared with in situ observations, to test model performance and provide 3D context for observations.
3) Apply the model to study magnetic field-line random walk (FLRW), and its effect on magnetic connectivity between solar sources and heliospheric observation points. Statistical approaches will be used to study FLRW, and evaluate related effects on field-line path-lengths and meandering in longitude/latitude. Implications for energetic particle transport will be considered.
4) Apply the model to study azimuthal flows in the young solar wind, including investigation of the effect of turbulence on angular momentum loss of the Sun, and on the morphology of the Alfven surface. This problem is of particular contemporary relevance in light of recent observations [1] of unexpectedly strong azimuthal flows by Parker Solar Probe (PSP).

By linking a novel analysis of photospheric turbulence to the dynamics of the extended solar atmosphere, and by applying our model to the focused problems listed above, we aim to arrive at an improved understanding of the magnetic field's influence on the heliosphere, as well as the radial evolution of magnetic connectivity.

Methodology: We will use (and improve) well-tested 3D MHD simulations of coronal and solar wind that include turbulence modeling [2]. Effects of long-term solar variability will be incorporated by varying source dipole tilts and by using magnetograms (e.g., ADAPT, HMI) from different epochs. In situ observations from several missions, including PSP and Solar Orbiter, will be compared with the model. Standard diffusion-theory approaches will be used to study FLRW.

Relevance to FST: The proposed research will support FST#4 by achieving an improved understanding of the structure, evolution, and influence of the magnetic field from the solar photosphere to the inner heliosphere, focusing in particular on the interplay between turbulence and large-scale dynamics. 3D distributions of large-scale flow and turbulence parameters from our model can potentially be used to provide global context for more local investigations by other teams.

[1] Kasper et al., Nature, 576 (2019); [2] Usmanov et al., ApJ, 865:25 (2018)

Publication References:

no references