Project Details

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Project Title:
Deep Learning for Ensembles of High-Resolution and High-Cadence Transverse Velocity Maps as High-Level Data Products

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Summary:
Knowledge of flows in the solar photosphere is crucial for understanding many aspects of solar physics, from processes in the interior to coronal heating and eruptions. While velocities along the line-of-sight are a common data product derived from spectropolarimetric observations, transverse velocities are not. The aim of this proposal is to provide tools to compute transverse flows from observations and enable science relevant to the Living with a Star (LWS) program, including the study of energy transport from the photosphere to the atmosphere where it can be released in the form of space weather events, and the derivation of realistic boundary conditions for data-driven simulations of the atmosphere necessary for studying these events.

There are three main groups of methods to infer transverse flows from observations. Tracking methods (e.g., Local Correlation Tracking, Balltracking) measure optical flows typically from intensitygrams in the Quiet Sun and magnetograms in active regions. Physics-based methods use magnetograms and Dopplergrams and solve the magnetic induction equation (e.g., PDFI, DAVE4VM) to infer flows in typically active regions. Finally, the DeepVel & DeepVelU deep learning methods use magnetohydrodynamics (MHD) simulations and a combination of intensitygrams, magnetograms, and Dopplergrams of Quiet Sun or a active region to infer depth-dependent transverse velocities. Through supervised learning, the neural network emulates flows, and by extension the full set of MHD equations, from the training simulation. Recently, we trained DeepVel using simulation data with spatial resolutions and cadences comparable to instruments like SDO/HMI, DST/IBIS, SUNRISE/IMaX, and DKIST/VBI. Our tests using model data have yielded promising results (Tremblay et al., 2021). For example, using DeepVel, we were able to recover flows in the Quiet Sun at subgranular spatial and temporal scales where optical flows decorrelate from physical flows. While these results are encouraging, there remain improvements before DeepVel can confidently be applied to observations. Although simulations have become increasingly realistic, the validity of model-dependent flows inferred through deep learning needs to be addressed thoroughly.

With this proposal, we plan to: (1) Prepare instrument-specific versions of DeepVel trained on an ensemble of state-of-the-art radiative-MHD simulations of granulation, pores, and sunspots to be gathered from the community; (2) Use combinations of inputs (intensitygrams, magnetograms, Dopplergrams) and provide physical interpretations of the results; (3) Improve preprocessing (spatial sampling, PSF convolution, etc.) to project from the model space to the observations space; (4) Assess realism of flows inferred through deep learning by comparing to tracking methods (e.g., FLCT, Balltracking) in weak-field regions and physics-based methods (e.g., PDFI) in strong-field regions; (5) Estimate errors; (6) Experiment with neural network architectures and training, like the development of a physics-informed neural network to generate flows constrained by the induction equation in strong-field regions and by a continuity or transport equation in weak-field regions.

The aim of this proposal is to provide the community with tools to generate realistic transverse velocity maps. We will make the codes available on Github with Jupyter notebook tutorials by 11/01/23. The proposed tools will enhance the scientific output from heliophysics missions (e.g., SDO, Hinode) and target the transport of plasma and magnetic energy, thus addressing LWS objective #1, quantify the physics, dynamics, and behavior of the Sun-Earth system over the 11-year solar cycle", and key goal #4 of the 2013-2022 Heliophysics Decadal Survey Advances in understanding of solar and space physics require the capability to characterize fundamental physical processes that govern how energy and matter are transported."

Publication References:

no references