Quantifying CME arrival time uncertainty with mega ensembles

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Near-Earth solar wind conditions, including disturbances generated by coronal mass ejections (CMEs), are routinely forecast using 3-dimensional, numerical magnetohydrodynamic (MHD) models of the heliosphere. The resulting forecast errors are largely the result of uncertainty in the near-Sun boundary conditions, rather than heliospheric model physics or numerics. Thus ensembles of heliospheric model runs with perturbed initial conditions are used to estimate forecast uncertainty. MHD heliospheric models are relatively cheap in computational terms, requiring tens of minutes to an hour to simulate CME propagation from the Sun to Earth. Thus such ensembles can be run operationally. However, ensemble size is typically limited to $10^1$-$10^2$, which may be inadequate to sample the relevant high-dimensional parameter space. Here, we describe a simplified solar wind model that can estimate CME arrival time in approximately 0.01 seconds on a modest desktop computer and thus enables significantly larger ensembles. It is a 1-dimensional, incompressible, hydrodynamic model, which has previously been used for the steady-state solar wind, but is here used in time-dependent form. This approach is shown to adequately emulate the MHD solutions to the same boundary conditions for both steady-state solar wind and CME-like disturbances. We suggest it could serve as a “surrogate” model for the full 3-dimensional MHD models. For example, ensembles of $10^5$-$10^6$ members can be used to identify regions of parameter space for more detailed investigation by the MHD models. Similarly, the simplicity of the model means it can be rewritten as an adjoint model, enabling variational data assimilation with MHD models without the need to alter their code. Model code is available as an Open Source download in the Python language.