A novel full MHD forecasting model chain from Sun to Earth: COCONUT+ Icarus

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Space weather events can affect Earth. In order to mitigate damage, space weather modelling tools have been implemented. In this study, the full MHD chain is presented, starting from the Sun, with a 3D MHD data-driven coronal model COCONUT up to 0.1 AU, where the code is coupled to Icarus, an ideal 3D MHD heliospheric modelling tool.

COCONUT (Perri, Leitner et al. 2022, COolfluid COrona Unstructured) is a data-driven coronal model that was recently developed at the Centre for Mathematical Plasma Astrophysics, KU Leuven. It is a global 3-D MHD model based on the COOLFluiD code (Yalim et al. 2011, Lani et al. 2014). The advantage of the COCONUT model lies in its efficient, optimised implementation. It uses a time-implicit backward Euler scheme and unstructured computational grid, which avoids singularities near the poles and enables using high CFL numbers to rapidly converge to steady state for realistic simulations on modern HPC systems. In order to obtain realistic solar wind conditions at 0.1AU, the source terms have been implemented in the MHD equations, namely, the approximated coronal heating function, radiative losses and the thermal conduction. The output of the COCONUT coronal model is used as input boundary conditions for plasma variables in the heliospheric model Icarus.

Icarus (Verbeke et al. 2022, Baratashvili et al. 2022) is a new heliospheric wind and CME evolution model that is implemented within the framework of MPI-AMRVAC (Xia et al., 2018) and introduces new capabilities for better and faster space weather forecasts. Advanced numerical techniques, such as solution adaptive mesh refinement (AMR) and radial grid stretching, are implemented. These techniques result in optimised computer memory usage and a significant execution speed-up, which is crucial for forecasting purposes.

The modelled 3D data in the solar corona and heliosphere are presented for assessing the model capabilities. The density profiles near the Sun are compared to tomography data. The time-series profiles of different variables at Earth are compared to observational data. As a result, the COCONUT+Icarus model chain represents the full MHD model covering the domain from Sun to Earth, which allows more in depth studies and understanding of different physics phenomena, e.g.
shock formation, erosion, and deformation, compared to empirical or semi-empirical models.