Daily ensemble forecasting from the Sun to 1 AU

Tony Arber, Keith Bennett, Andrew Angus - University of Warwick, UK
Bart van der Holst - University of Michigan, USA

Abstract: Ensemble predictions of SW at 1 AU using a 1D field-line tracing model for the solar corona to drive a 3D inner heliospheric model. This is part of the EU funded PAGER project. Using this combination of 1D coronal and 3D heliospheric models it is possible to run ensembles with 20 members every few hours. The ensemble members are sampled using a Latin hypercube across the range of known uncertainties in the key physics inputs. The optimal value from this ensemble is found through Gaussian Process regression. This overall method is therefore capable of predictive ensembles of SW for the steady SW every few hours. To compliment this a CME injection model is used. This is triggered by alerts from the CCMC DONKI service and injects a Gibson-Low flux rope CME into the simulations at 0.1 AU. The CME is selected from a pre-calculated database of Gibson-Low CME's generated by the SWMF framework.

Magnetogram GONG → DEF Code solves MHD up to 0.1 AU → Add SWMF CME Buffer at 0.1 AU → SWIFT code solves 3D MHD to 1 AU → Ensemble predictions For next 2-4 days

DEF code

Photosphere to 0.1 A.U.
Construct steady magnetic field
PFSS solution out to R_pfss ~ (1.5 - 3.5) radii
Schatten current sheet model R_sc = R_pfss to 0.1 AU
Solve 1D MHD along flux tubes which reach 0.1 AU
AWSoM Alfven wave (AW) turbulence model[1]
Save MHD solution at 0.1 AU into buffer

SWIFT code

0.1 AU to 2 AU
Solve 3D 2 temperature MHD in spherical geometry[2]
If a CCMC DONKI CME alert - add CME buffer to DEF buffer
CME buffer from database of Gibson-Low CMEs from SWMF
Currently only 5 latitude, fixed strength CME's
Output MHD variables at Earth trajectory

AWSoM model[1]

AW energy density propagates up/down 1D field-lines
Energy reflected off gradients in Alfven speed
Counter-propagating AW energy heats plasma
Average AW energy density added to thermal pressure

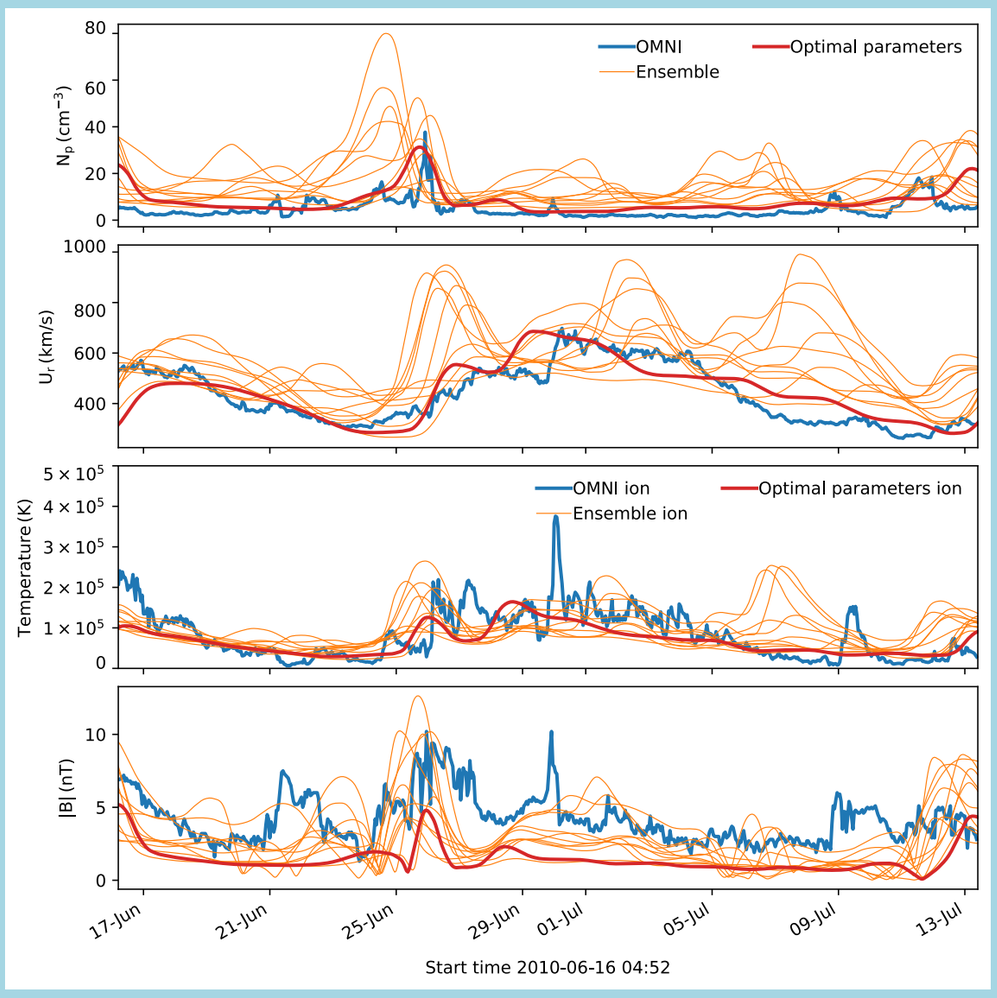
Range of input parameter

Poynting flux (per unit B) at photosphere	**S/B** ~ 0.8-1.2 x 10^6 $Wm^{-2}T$
Scaling of GONG data	**B_scale** ~ 1 - 3.5
Height of PFSS surface	**R_pfss** ~ 1.5 - 3.5 Solar radii

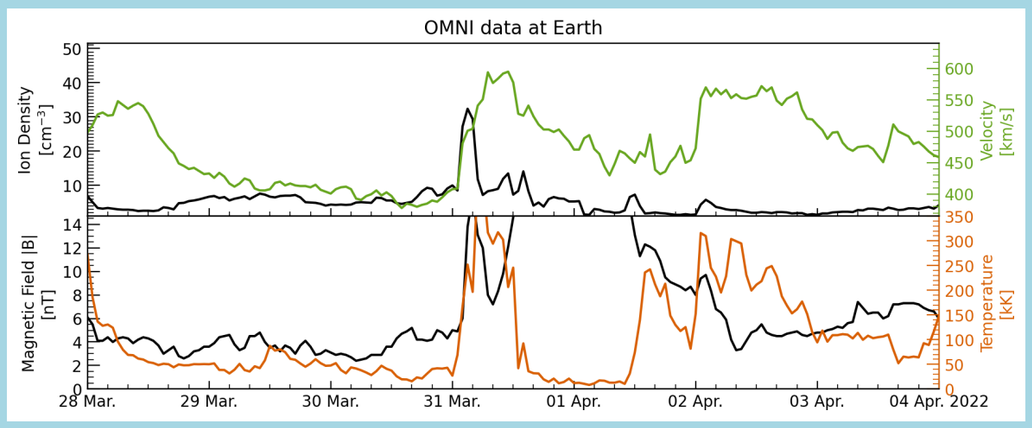
Ensemble + GP regression

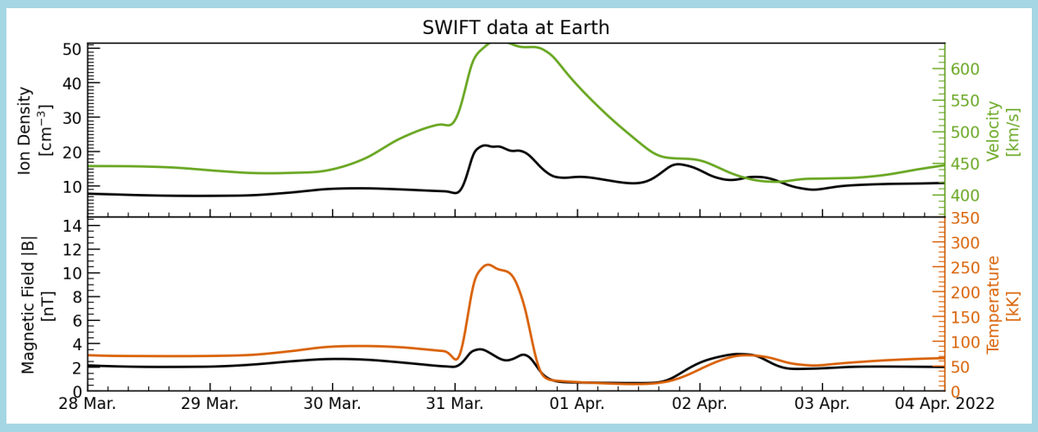
Theory/observationally constrain limits on S/B, R_pfss, B_scale
Sample using Latin hypercube ~ 10 - 20 samples
Quantity of interest L2-norm of SW speed cf. OMNI
Gaussian Process regression to find optimal parameters
Assume parameters persist between GONG/OMNI CR maps

Typical quiet Sun ensemble



Example CME injection





Note: Only single strength CMEs currently in SWMF database so no control over B-field strength. CME speed at 0.1 AU scaled to match DONKI alert.

Conclusions

Real-time ensemble SW predictions with CME injection based on physics constrained coronal model. Full ensemble can be run every few hours on a 32-core workstation.

References
1. B. Van der Holst et al. Astrophys. J., 728:81 (2014)
2. T. D. Arber et al. J. Comp. Phys., 171 (2001) 151-181
https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/tda/esww2022/

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