Forecasting at L1: Development of AWSoM/SWIFT

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The AWSoM [1] coronal model has been coupled to a two temperature MHD inner heliospheric model (SWIFT) to give predictions at L1. These models rely only on the MHD equations, GONG data and an Alfvén wave turbulence model. This turbulence model has a tuneable parameter, the stochastic exponent (h_s) That controls the partitioning of heating between ions and electrons. Another model tuneable parameters is the photospheric boundary Alfven wave Poynting flux per unit magnetic field (*S/B)*.
To constrain these parameters we use the Dakota uncertainty quantification (UQ) framework from SNL [2] to optimise them for steady state solutions for three Carrington rotation GONG datasets. We use the average L_1*-norm* for B-field, U_r and ion temperature to quantify accuracy of the AWSoM/SWIFT output at L1 compared to OMNI data.

Alfvén wave solar model (AWSoM)

$$\frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\mathbf{u}) = 0,$$
$$\frac{\partial\mathbf{B}}{\partial t} + \nabla\cdot(\mathbf{uB} - \mathbf{Bu}) = 0,$$
$$\frac{\partial(\rho\mathbf{u})}{\partial t} + \nabla\cdot\left(\rho\mathbf{uu} - \frac{\mathbf{BB}}{\mu_0}\right) + \nabla\left(P_i + P_e + \frac{B^2}{2\mu_0} + P_A\right) = -\frac{GM_\odot\rho\mathbf{R}}{R^3},$$

Two temperature MHD with radiative loss, conduction and heating from dissipation of Alfvén wave energies w_+ and w_-

$$\frac{\partial}{\partial t}\left(\frac{P}{\gamma-1} + \frac{\rho u^2}{2} + \frac{\mathbf{B}^2}{2\mu_0}\right) + \nabla\cdot\left\{\left(\frac{\rho u^2}{2} + \frac{\gamma P}{\gamma-1} + \frac{B^2}{\mu_0}\right)\mathbf{u} - \frac{\mathbf{B}(\mathbf{u}\cdot\mathbf{B})}{\mu_0}\right\} =$$
$$= -(\mathbf{u}\cdot\nabla)P_A + \nabla\cdot(\kappa\cdot\nabla T) - Q_{\rm rad} + \Gamma_- w_- + \Gamma_+ w_+ - \frac{GM_\odot\rho\mathbf{r}\cdot\mathbf{u}}{r^3},$$

Alfvén wave energies evolved in both directions along fields with reflection and dissipation

$$\frac{\partial w_\pm}{\partial t} + \nabla\cdot[(\mathbf{u}\pm\mathbf{V}_A)w_\pm] + \frac{w_\pm}{2}(\nabla\cdot\mathbf{u}) = \mp\mathcal{R}\sqrt{w_-w_+} - \Gamma_\pm w_\pm$$

$$\Gamma_\pm = \frac{2}{L_\perp}\sqrt{\frac{w_\mp}{\rho}}$$

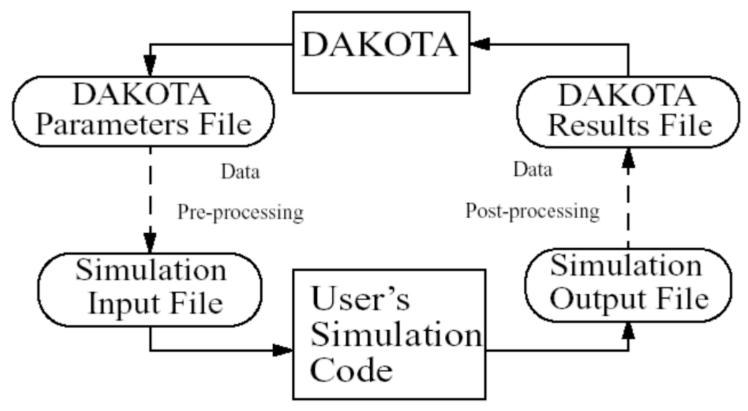
$$\mathcal{R} = \min\left\{\sqrt{(\mathbf{b}\cdot[\nabla\times\mathbf{u}])^2 + [(\mathbf{V}_A\cdot\nabla)\log V_A]^2}, \max(\Gamma_\pm)\right\}\times$$
$$\times\left[\max\left(1 - \frac{I_{\rm max}}{\sqrt{w_+/w_-}}, 0\right) - \max\left(1 - \frac{I_{\rm max}}{\sqrt{w_-/w_+}}, 0\right)\right],$$

Stochastic exponent (h_s) controls partitioning of energy between ions and electrons

$$\Gamma_{i\perp} = 0.18\varepsilon_i\Omega_i \exp\left(-\frac{h_S}{\varepsilon_i}\right)$$

DAKOTA

The Dakota toolkit provides an interface between simulation codes and iterative analysis methods.[2]

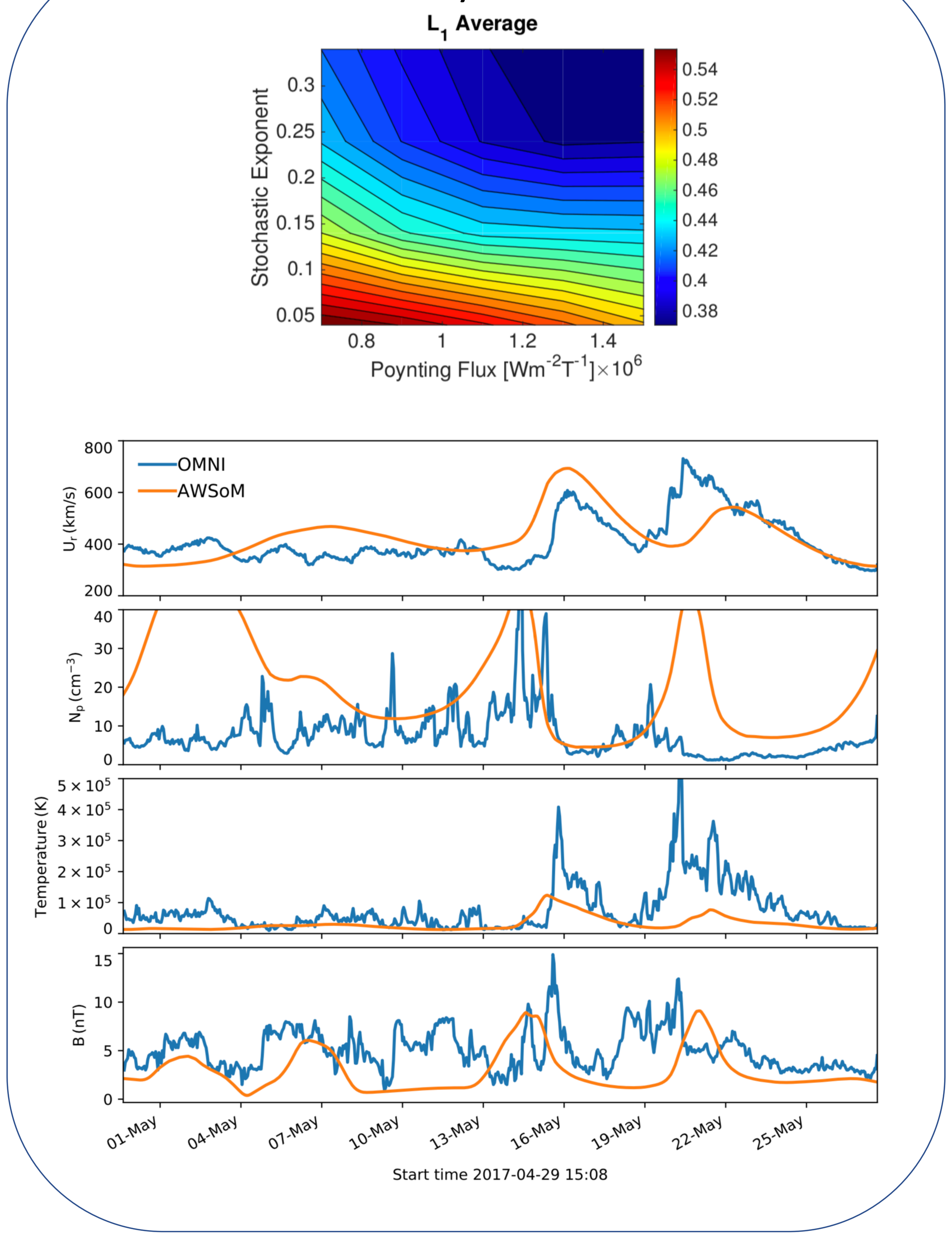


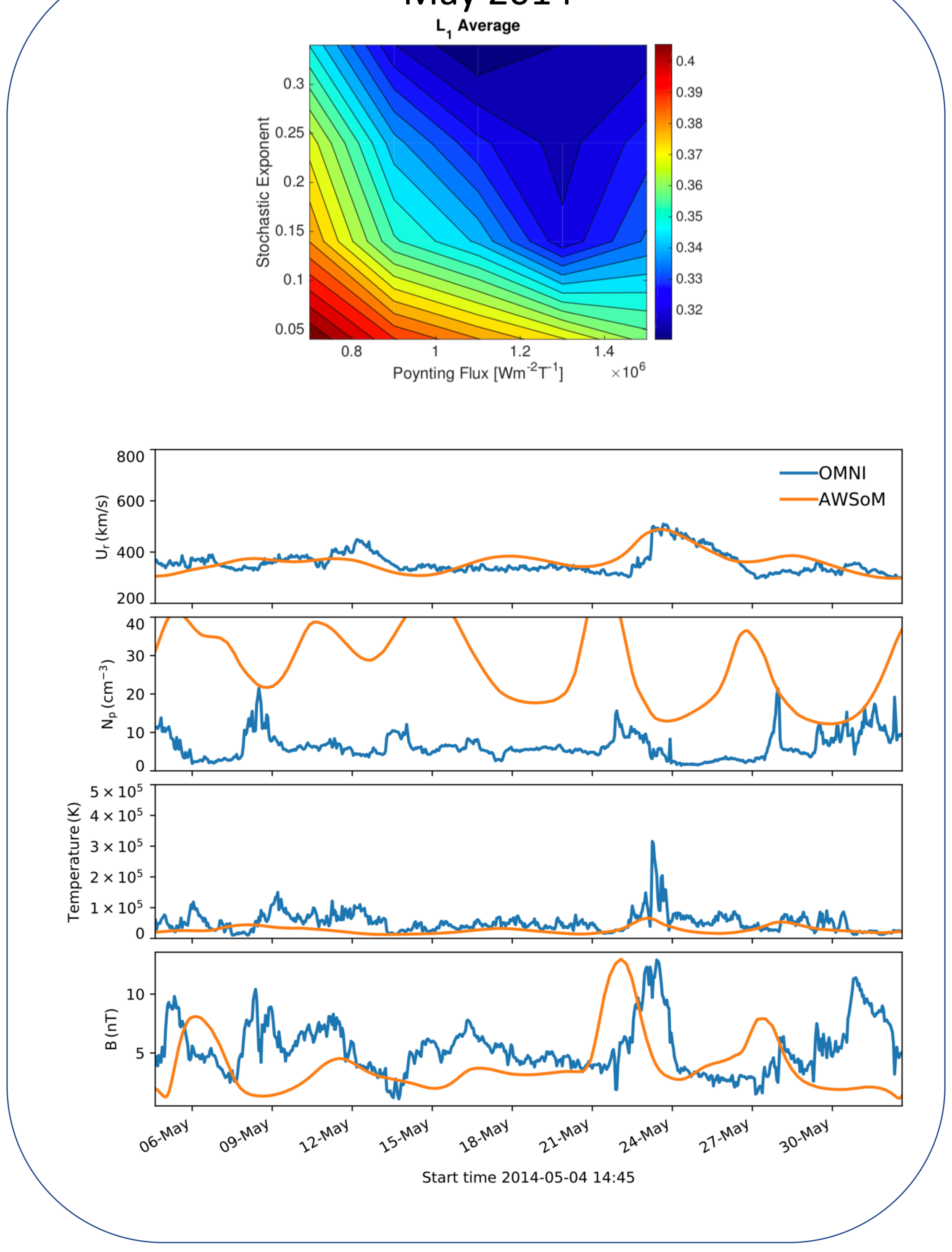
Contains algorithms for optimization, uncertainty quantification (UQ), parameter studies, calibration, and sensitivity/variance analysis.

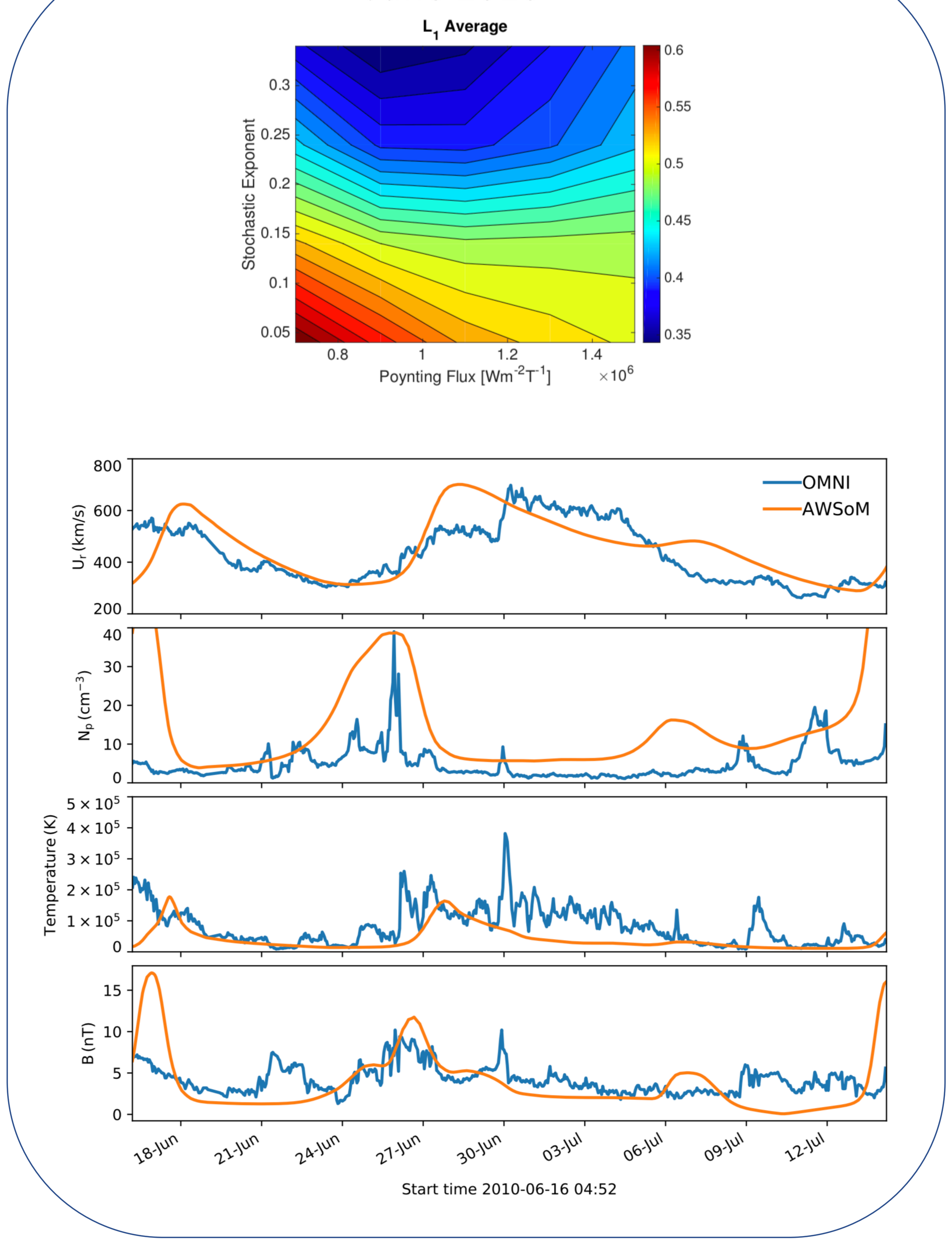
We perform a Sensitivity Analysis (SA) of AWSoM/SWIFT on the three free parameters, quantifying accuracy of solar wind predictions using the L_1*-norm* compared to OMNI data.

$$||L_i|| = \left\{\frac{1}{n}\sum^{n}[\boldsymbol{u}_{sim} - \boldsymbol{u}_{OMNI}]^i\right\}^{\frac{1}{i}}$$

Best fit *L1* results for three Carrington rotations







- Little variation in best fit for the stochastic exponent which controls the fraction of Alfvén turbulent heating into the ions. This is constant at 0.34 a value larger than used in previous AWSoM simulations [1].
- The Poynting flux per unit magnetic field (in W m^{-2} T^{-1}) corresponding to the best fit varies 0.9e6 (2010), 1.1e6 (2014) and 1.5e6 (2017) implying different levels of Alfven wave activity and the need for an algorithm to track variations in (S/B).
- Across all three Carrington rotations the fit to observed U_r, T_i and B is noticeably better than that for number density.
- Variation of cross field correlation length, which controls the Alfvén turbulent energy dissipation rate, has not yet been studied.

Simulations setup

Start from a GONG synoptic map. Lower boundary at upper chromospheric density and temperature. Run AWSoM to steady state. Use data at 21.5 radii to drive inner heliospheric model SWIFT to equilibrium.

Summary

Dakota SA of AWSoM/SWIFT has optimised the free parameters in the Alfvén turbulence model and improved L1 predictions. Time-dependent simulations are now Running based on daily GONG updates. Each AWSoM run requires ~14 hours on 128 cores. Poynting flux per unit B-field best fit varies with time while equipartition of Alfvén between ions and electrons is constant.

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References
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[2] Adams, Brian M., et al., Sandia National Laboratories, Tech. Rep. SAND2010-2183 (2009). https://dakota.sandia.gov