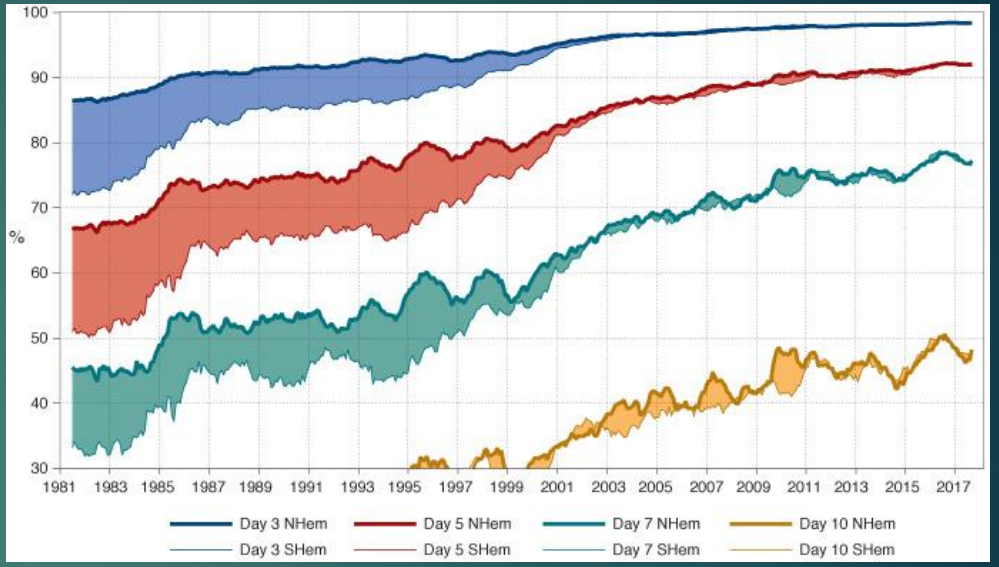
Data Assimilation in the Solar Wind

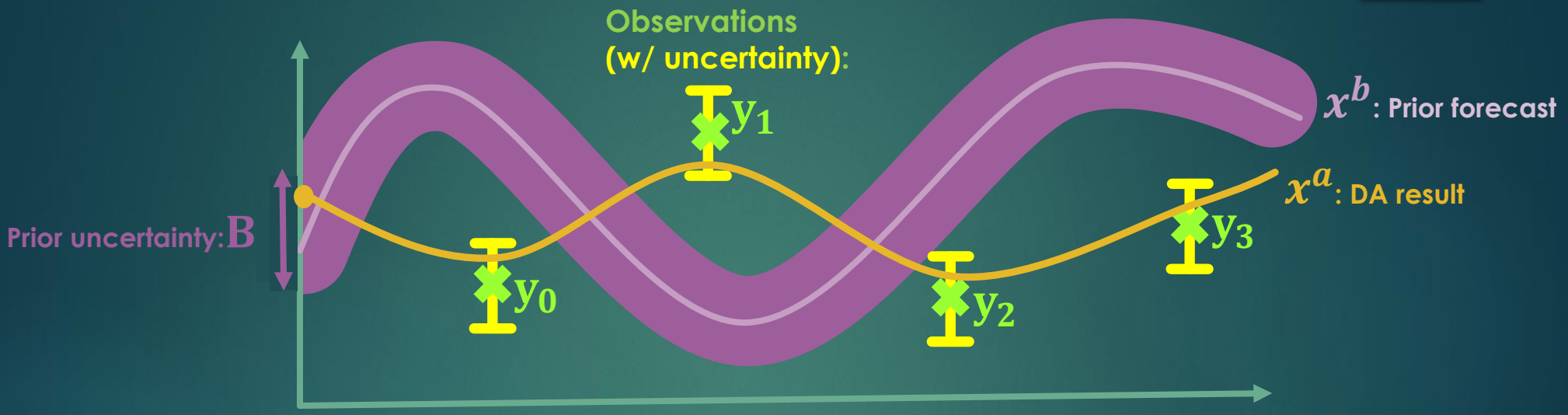
Matthew Lang, Mathew Owens, Amos Lawless, Ross Bannister, Siegfried Gonzi

- Why should you care?
  - Variations in the solar wind lead to many adverse effects
    - Radio communication failures, Astronauts/polar aircrew health effects, satellite failures etc.
  - Data Assimilation (DA) is a vital component of numerical weather prediction that has gone hand-in-hand with improvements in forecasting skill
- A new DA scheme based upon the new and innovative HUXt solar wind speed model is presented here



- ECMWF's 500hPa geopotential height anomaly correlation, a measure of skill, for the Northern and Southern Hemisphere for forecasts of different lead times
- It can be clearly seen in the late-1990's/early 2000'd when the DA method was updated and satellite observations were included in the assimilation.
  - The forecast model as skills increase and the gap in the Northern and Southern Hemisphere skill closes rapidly

What is Data Assimilation?



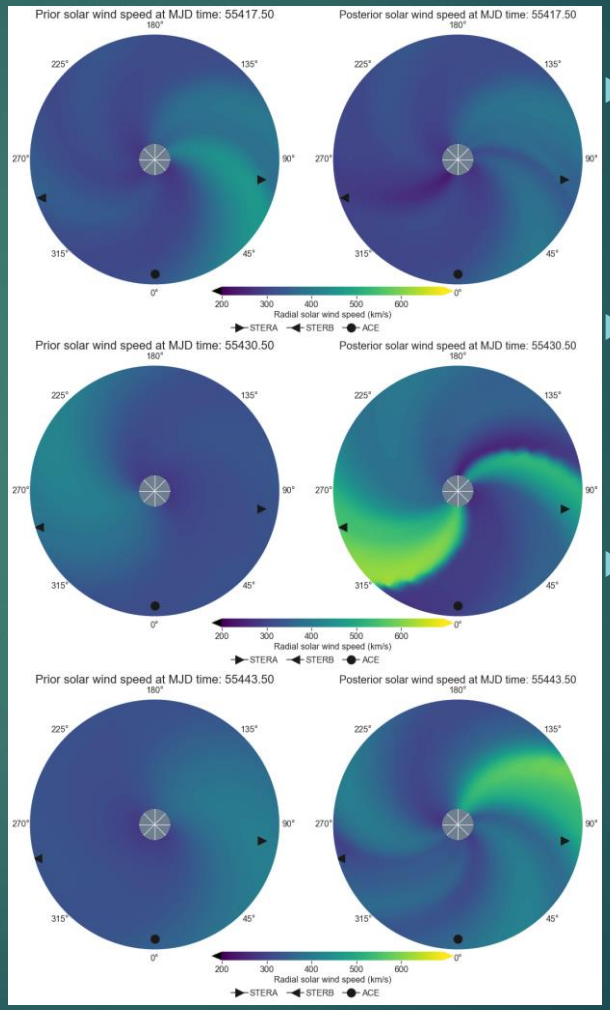
- Data assimilation is the optimal merging of observations with model forecasts to produce improved estimates of the truth, along with their associated uncertainties.
- To produce these improved estimates, a weighted cost function is minimised, based upon the prior errors and the observation errors (both are assumed to be Gaussian).

$$\mathbf{J}(\mathbf{x_0}) = \left(\mathbf{x_0} - \mathbf{x^b}\right)^{\mathrm{T}} \mathbf{B}^{-1} \left(\mathbf{x_0} - \mathbf{x^b}\right) + \sum_{i=0}^{N_y} \left(\mathbf{y_i} - \boldsymbol{H_i}(\mathbf{x_0})\right)^{\mathrm{T}} \mathbf{R_i^{-1}} \left(\mathbf{y_i} - \boldsymbol{H_i}(\mathbf{x_0})\right)$$

  - where H_i is known as the observation operator (essentially, it gives what the model thinks the observation should be) and R_i is the each observation's uncertainty
- The resultant analysis from DA is called the posterior state.

Application of DA to the solar wind

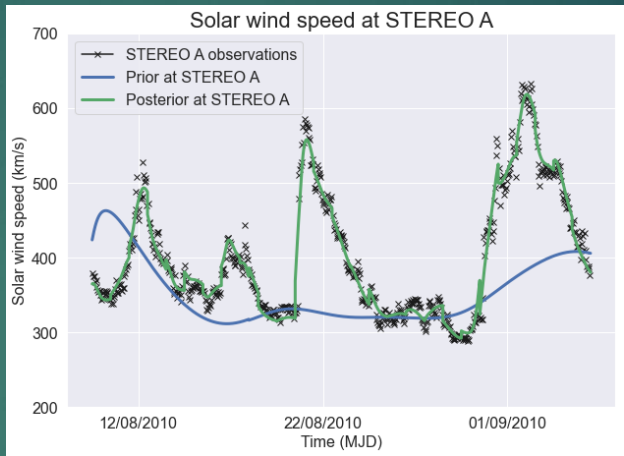
- The HUXt model, a lightweight solar wind speed model, is used to generate a prior forecast for a 27-day period (09/08/2010 - 04/09/2010).
- Our DA scheme starts from the same initial conditions and assimilates STEREO A and B data in 27 consequent 1-day ‘chunks’ to produce an analysis (which we call the posterior)
- During these experiments, STEREO A is 80° ahead of Earth and STEREO B is 72° behind Earth
- The posterior is then compared to independent ACE observations to quantify the improvements made by the DA.

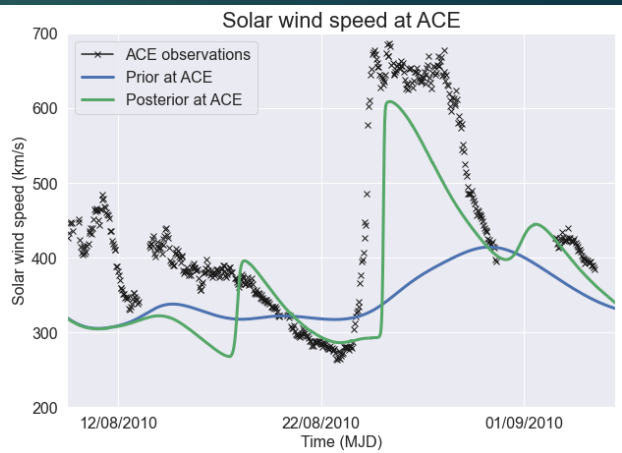


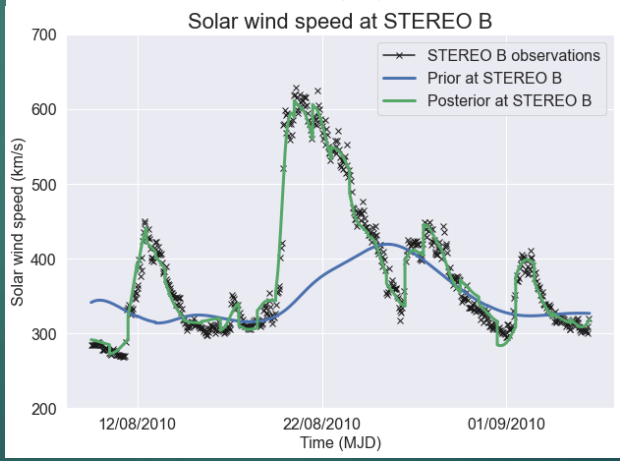
- The prior (no DA) and posterior (with DA) for 09/08/2010 (top), 22/08/2010 (middle) and 04/09/2010 (bottom)
- DA updates in the posterior are mostly near the obs. and then rotate around to rest of of heliosphere
- DA gives an updated solar wind field, with more structure, which gives a better medium to propagate modelled CMEs through, potentially improving CME arrival time forecasts

DA results

- STEREO A and B observations are assimilated and the results verified against ACE.
- Prior state predicts a very steady solar wind over solar rotation
- Observations indicate that the solar wind speed is much higher than prior with several fast wind bands.
- The posterior recreates many of these fast wind bands.
- DA leads to a 28% reduction in the RMSE in near-Earth space, over the solar rotation.
- At ACE, prior and posterior are the same for the first ~4 days as the DA updates rotate from STEREO B to ACE
- These results shows that data assimilation can lead to huge improvements in solar wind estimates.







Assimilated observations

Verification observations

	Prior RMSE (km/s)	Posterior RMSE (km/s)	RMSE Red. (%)
STEREO A	92.10	14.91	83.81
STEREO B	87.17	14.29	83.61
ACE	141.37	101.57	28.16