

Reconstruction of meridional flow by data assimilation

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Ensemble Kalman filter data assimilation in a Babcock-Leighton solar dynamo model: An observation system simulation experiment for reconstructing meridional flow speed Geophysical Research Letters

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Solar magnetic activity:

400 Years of Sunspot Observations



Popular perception:





Double CMEs on July 2012, moving with speed more than 3000 km-pers; fortunately not directed at the earth. CME-CME interactions gave rise to about 2000 km-per-s solar wind speed with about 100 nT magnetic field at 1AU (Liu et al, Nature Communications, 2014)!

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(numerical) weather forecast:

- We have a model (including velocity, pressure, humidity, etc)
- We have observations at specific points at specific times.
- We have to tune unknown parameters to be "best" of our abilities; and then forecast the future...



Lewis F. Richardson (source Wikipedia)

Kalman Filter

- But long-term weather forecast is doomed (Edward N. Lorenz).
- Yet, there is hope (Rudolf E Kalman).





Definition of problem:

- * Chaotic dynamical system.
- Badly-known initial condition.
- Badly-known parameters.
- Observations at irregular intervals in time and unevenly distributed in space which must be "assimilated" into the evolution of the dynamical system.
- * Can we at least make a short-time forecast?
- * How "short" and how "accurate" ?

EnKF scheme:

- An "assimilated" state is a linear superposition of the "observed" state and the "evolved" state (background, forecast) such that the error is minimized in the least-square sense.
- Estimate the error by an ensemble approach.

$$y = H\psi + \varepsilon$$

 $\psi_{\mathrm{ini}} = \psi_0 + \epsilon_0$

$$\psi^{\mathrm{a}} = \psi^{\mathrm{b}} + rac{PH^{\mathrm{T}}}{HPH^{\mathrm{T}} + C} \left(y - H\psi^{\mathrm{b}}
ight)$$

$$\mathsf{P}_{ij} = \langle \left(\psi^{b}_{i} - \langle \psi^{b}_{i} \rangle \right) \left(\psi^{b}_{j} - \langle \psi^{b}_{j} \rangle \right) \rangle$$

Data Assimilation Research Testbed (DART) :



Welcome to the Data Assimilation Research Testbed - DART

DART is a community facility for ensemble DA developed and maintained by the Data Assimilation Research Section (DAReS) at the National Center for Atmospheric Research (NCAR). DART provides modelers, observational scientists, and geophysicists with powerful, flexible DA tools that are easy to implement and use and can be customized to support efficient operational DA applications. DART is a software environment that makes it easy to explore a variety of data assimiliation methods and observations with different numerical models and is designed to

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Flux-transport dynamos

- Model parameters: Babcock-Leighton term, meridional circulation, diffisivisties, ...
- Observations: Magnetic field at specific points on the top boundary (uniformly distributed). These are synthetically generated by a run of the model itself.
- How well can the EnKF scheme estimate the meridional circulation ?



Estimating meridional circulations



Summary

- Time-variation of meridional flow speed can be reconstructed by using 192 ensemble members and 180 observation each with 1% error.
- RMS error in reconstruction decreases as (a) error in observation decreases, (b) number of ensemble members increases (c) number of observations increases.

More copies ...



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If our guess is wrong:



where should we observe ?



 Surface poloidal magnetic field near 10 degree latitude gives the best estimate. This result is quite robust.

Earthquakes and CMEs



 Self-organized criticality and sandpile models.