SMART DA WITH JULES IN EMPIRE

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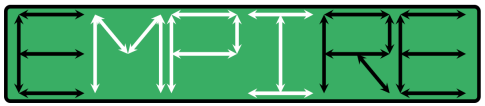
With thanks to: Phil Browne

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL



University of Reading

Why data assimilation?

The aim of the data assimilation is to combine the prior knowledge or model forecast with likelihood or available observations primarily to:

- obtain analysis which is more accurate than either forecast or observations alone;
- learn about the model, e.g. model error, parameter values;
- assess observation impact.

Why data assimilation?

Thus, given model forecast at time *m*:

$$\mathbf{x}^{(m)} = \mathcal{M}_m\left(\mathbf{x}^{(m-1)}\right) + \boldsymbol{\beta}^{(m)} \qquad (1)$$

and observations at time *m*:

$$\mathbf{y}^{(m)} = \mathcal{H}_m\left(\mathbf{x}^{(m)}\right) + \boldsymbol{\beta}_{Ro}^{(m)}, \qquad (2)$$

we aim to combine these two pieces of information.

There are three major ways of doing it:

- minimise a linear cost function - **variational DA**;
- linearly combine using Kalman gain & ens.- **ensemble DA**;
- solve Bayes theorem - **particle filters**.

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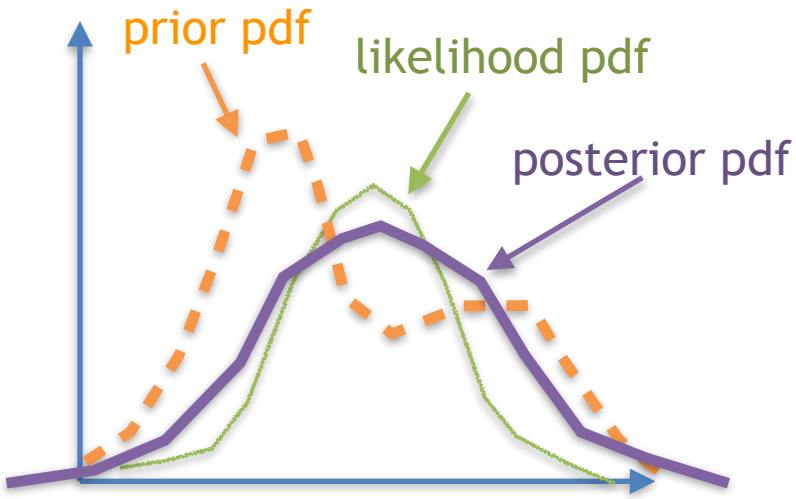
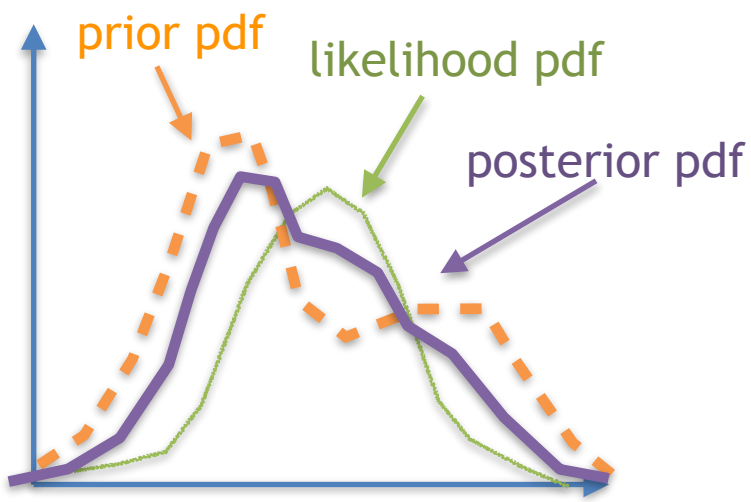
Stochastic DA methods

Ensemble data assimilation (EnDA)
- based on Kalman Filter equations
- uses Gaussian assumptions of errors
- needs knowledge of prior errors, P
- localisation needed for high-dimensional systems

Particle filters (PF)
- based on Bayes theorem
- fully non-linear methods
- needs knowledge of model errors, Q but not prior errors
- curse of high-dimensionality





Data assimilation in JULES

- ADJULES (U Exeter): provides adjoint based optimisation for finding JULES parameters
- CARDAMOM (U Edinburgh): retrieves terrestrial carbon cycle variables using obs. and model
- PECAN (U Reading w/ Boston): predictive ecosystem analyser with JULES added in 2016/17
- JULES/EMPIRE (U Reading): uses MPI to communicate between JULES and EMPIRE

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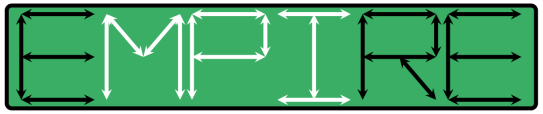
EMPIRE

EMPIRE - Employing **M**essage **P**assing **I**nterface for **R**esearching **E**nsembles



www.met.reading.ac.uk/~darc/empire

EMPIRE is: a system which easily connects any dynamical model to a DA method.

EMPIRE uses: MPI calls to setup communication and transfer data between the model and DA methods.

EMPIRE is: continuously developed at UoR

EMPIRE

Models connected to EMPIRE

Model Name	Description
HadCM3	Coupled ocean-atmosphere climate model
UM vn8.2	UK Met Office atmospheric forecast model configured as N512L70 global model
TELEMAC-2D	Unstructured finite element code, used for storm surge modelling
DALECv2	Land surface model
JULES	Operational land surface model
GOTM-ERSEM	Coupled hydrodynamic-biogeochemical model
NEMO	Ocean model
Liley-Bojak model	Neurofield model of electrocortical activity in the brain
Barotropic vorticity model	Simple 2D fluid dynamics model of barotropic flow on a torus
ECMWF IFS Single column model	A single column, coupled ocean-atmosphere model
MITgcm	Numerical model designed for study of the atmosphere, ocean, and climate
Enlil	A time-dependent 3D magnetohydrodynamics model of the heliosphere

EMPIRE

Currently available DA methods are:

- LETKF
- EWPF
- IEWPF
- SIR PF
- 4DEnVar
- 3DVar

Future:

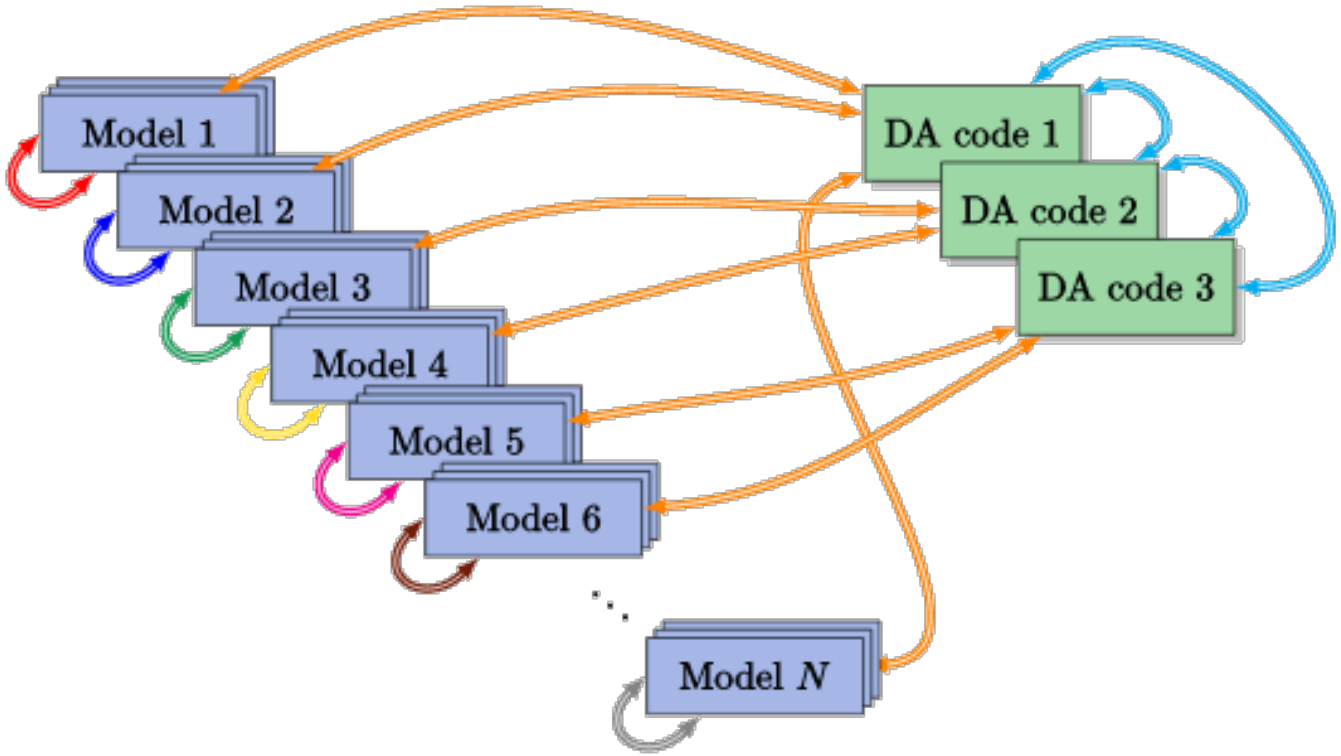
- More flavours of EnKF
- Variational methods

EMPIRE

Benefits of using EMPIRE are obvious for both model developer and research communities:

- Easy to test your model with various DA methods;
- Easy to test your DA method with various models;
- No need to hack the model code to add DA;
- Quick way to decide which DA method will perform best for a given model;
- Little time spent on coupling a given model to EMPIRE; No need to change a given model flow and working;
- No need to spend time coding DA methods.

EMPIRE


Model 1
Model 2
Model 3
Model 4
Model 5
Model 6
Model N
DA code 1
DA code 2
DA code 3

EMPIRE

User needs to provide following operators to EMPIRE:

- H, H^T
- $R^{1/2}$, R^{-1}, $R^{-1/2}$
- Q, $Q^{1/2}$
- Distance between element of state vector and observation $(HQH^T+R)^{-1}$

EWPF, LETKF, twin experiment observation generation

EMPIRE

To couple EMPIRE to JULES we added ONE EMPIRE module into the code - empire_module, which includes subroutines to:

- Create MPI communication between JULES and EMPIRE
- Pack and unpack JULES state variables into 1D state vector for use in EMPIRE
- Send and receive data between JULES and EMPIRE
- Clean up MPI communication at the end of the run.

EMPIRE

Changes in JULES:

- the only modified routine in JULES is jules.F90
- preprocess using key EMPIRE (e.g. #if defined(EMPIRE)) - added in FCM code if used
- Routines called in jules.F90 are:
  - before time step loop: *mpi_init(error) & empire_initialise_state()*
  - in the time step loop: *empire()*
  - at the end of the run: *empire_cleanup()*

EMPIRE

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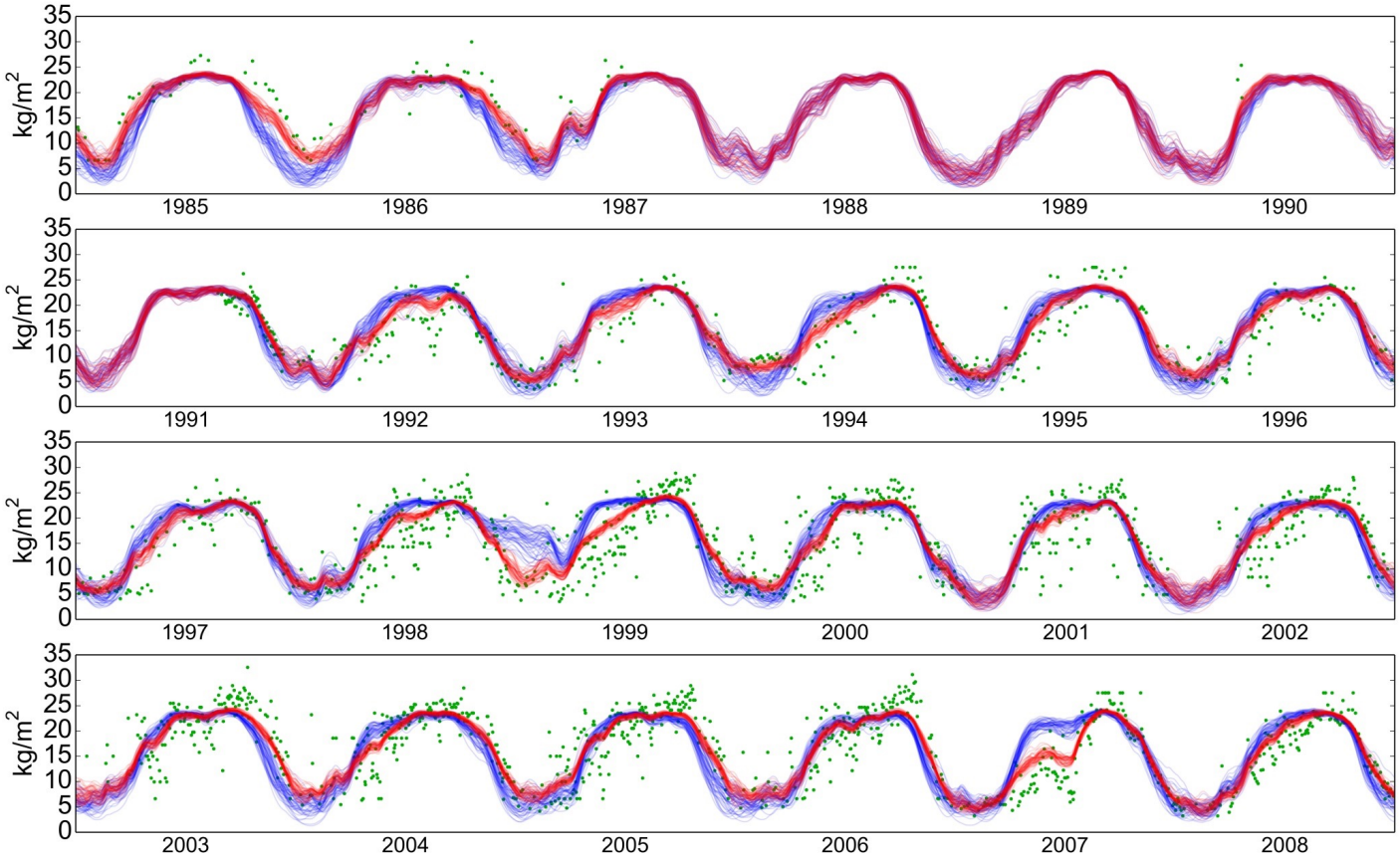
Preparing patch to automate the process!!!

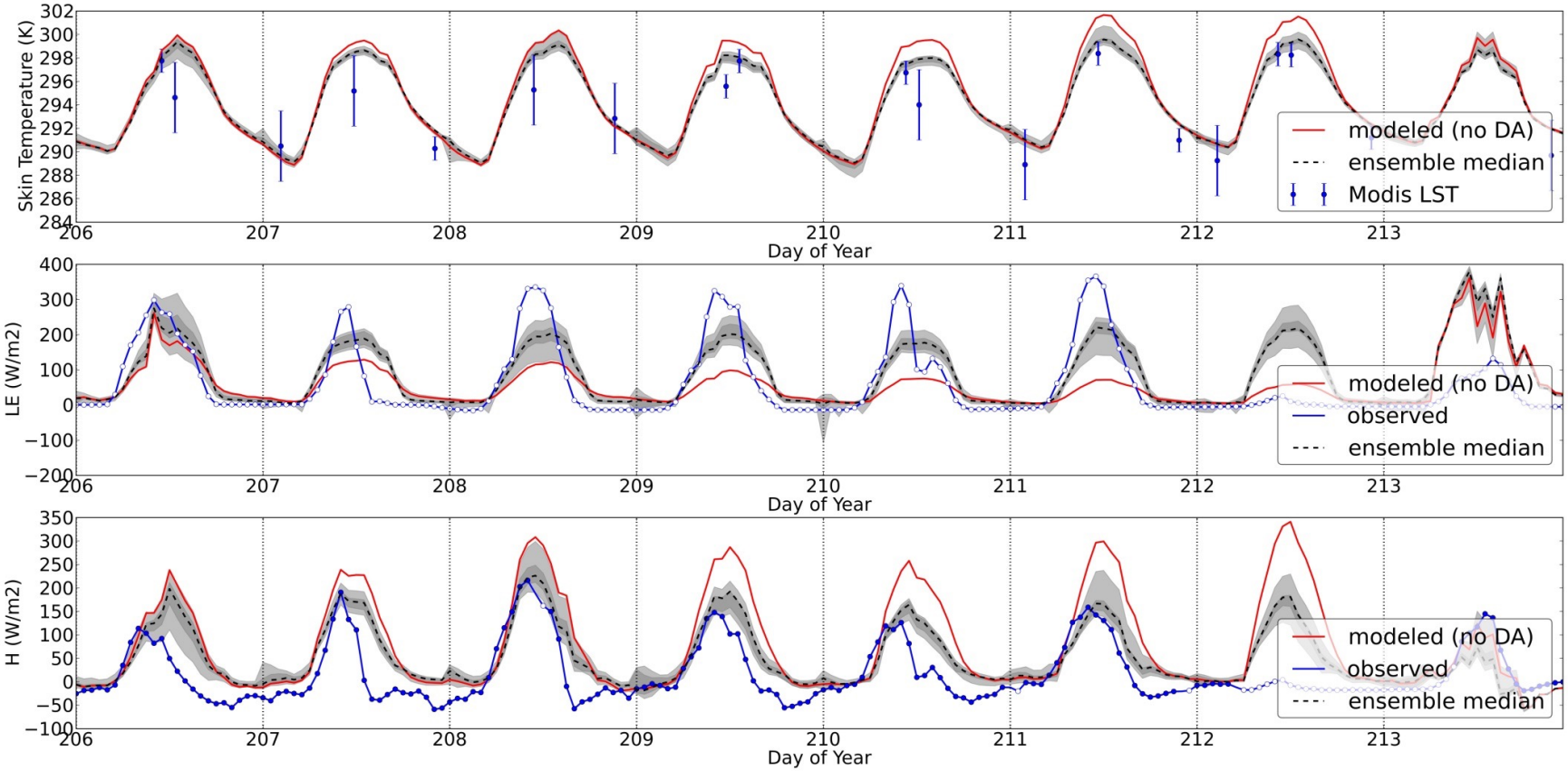
Preliminary results

Assimilation 30 years of ESA SM data (plus stochastic forcing from TAMSAT)



N = 50
Site = Gana
DA = ETKF
obs = top soil moist.
blue = no DA
red = DA

Assimilating MODIS LST & albedo



Summary

- Work has just started
- JULES has been coupled with EMPIRE
- Positive impact of DA in preliminary results

Future:

- Provide patches to users to couple their JULES code to EMPIRE (over next few months)
- Provide some basic operators for the user
- Research work in DA and JULES
- Ongoing work on EMPIRE with more DA methods added (not me)

Questions?

SANGOMA website: www.data-assimilation.net

EMPIRE website: www.met.reading.ac.uk/~darc/empire

Eager to learn how community

is interested to use DA in JULES

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