Land data assimilation: a tool for improving land surface models and observations

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Introduction:

In Numerical Weather Prediction (NWP), the routine confrontation of short-range weather forecasts with observations, facilitated by the analyses-prediction-comparison cycles built into the data assimilation (DA) method, has identified numerous shortcomings in the forecast model, leading to steady improvements in model performance over the years. More recently, this approach has started to be applied to testing parametrizations in climate General Circulation Models (Phillips 2004), and to the evaluation of chemical models (Lahoz et al. 2007). All these applications are based on the concept of ***confronting models with observations***.

At NILU (Norwegian Air Research Institute), we are applying this concept to develop a land DA capability, initially focussing on land soil temperature (LST) and soil moisture, later moving to snow, to provide analyses and forecasts and to improve the observations and the models (both land surface models and models containing the former).

The NILU set-up will be based on the following elements:

1. DA scheme: variants of the Ensemble Kalman Fiilter (ENKF) – see Evensen (2003);

2. Land surface model: models available at NILU include JULES (Blyth et al. 2006) and SURFEX (ALADIN newsletter, no. 32).

NILU will initially focus on assimilating LST fron MSG-SEVIRI, and preparing for LST measurements from ESA's Sentinel-3 mission.

This work will be done in collaboration with several groups, including: Met No (the Norwegian Met Office) and Paul Houser (GMU, USA).

As well as various research activities, it is hoped that this work will lead to improved use of land surface data at Met No and, thus, improved forecasting capability.

Ensemble Kalman Filter:

Two new state-of-the-art versions of the EnKF recently proposed by Sakov and Oke are being considered at NILU: (i) A new ***Ensemble Square Root Filter*** (ESRF) (Sakov and Oke, 2007a); (ii) A new ***Deterministic Ensemble Kalman Filter*** (DEnKF) (Sakov and Oke, 2007b).

The ESRF uses a product of a symmetric mean-preserving transform matrix with an optional mean-preserving orthonormal random rotation. This ensures the KF equations are accurately solved for the ensemble mean and variance-covariance matrix. The mean-preserving random rotations also prevent build-up of ensemble outliers in ESRF-based DA systems, in particular for non-linear models (particularly relevant for land DA). No perturbations of observations are necessary in this version of the filter. Sakov and Oke show the new ESRF method is superior to other non-mean preserving ESRFs and the more traditional EnKF, using perturbed observations.

The DEnKF is a simple modification of the traditional EnKF; it uses a linear approximation to the ESRF update matrix. This linear approximation has the property that it automatically increases the spread of the ensemble in cases where the observation-based analysis correction of the ensemble is large; conversely, increase in spread is much smaller when the analysis correction is small. This prevents collapse of the ensemble. As for the ESRF filter, no perturbation of observations is necessary. Sakov and Oke show the DEnKF performs almost as well as the ESRF filter and significantly better than the traditional EnKF with perturbed observations. It thus combines the simplicity and flexibility of the traditional EnKF method, with the robustness and superior performance of the ESRF. The DEnKF also readily permits the use of Schur product-based covariance localisation schemes.

At NILU we will incorporate a bias correction algorithm based on the ideas of Dee and da Silva (1998).

Land Surface model:

The ***JULES*** model (Blyth et al. 2006) is a community land surface model developed at the UK Met Office. It is built upon the MOSES (Met Office Surface Exchange Scheme) model, which combines a complex energy and water balance with a dynamic vegetation model, TRIFFID (Top-down Representation of Interactive Foliage and Flora Including Dynamics). MOSES has been coupled successfully to the UK Met Office climate model.

JULES simulates how soil and vegetation respond to atmospheric changes in temperature, humidity, wind, sunshine and precipitation. JULES predicts soil temperature (which we can consider analogous to LST) and moisture. Soil temperature and moisture (along with near-surface meteorology) then affect plant transpiration, soil evaporation, plan growth and soil respiration. The surface fluxes of heat, water vapour and carbon (CO_2 and CH_4), which result from these changes, are then calculated.

In collaboration with Met No, we will use the ***SURFEX*** model (developed within the ALADIN project). Elements include:

1. Physical parametrizations: soil and vegetation; sea and ocean; town; lake;

2. Accurate databases for surface parameters: orography; soil texture; land surface parameters;

3. Surface energy budget;

4. Water cycle;

5. Initialization fields: area of interest; resolution; databases; prognostic variables (e.g. temperature).;

6. Surface schemes (inputs, outputs);

7. Coupling with atmospheric model;

8. Diagnostics: temperature & humidity, fluxes.

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Overview:

•The EnKF is well suited for land DA (e.g. Reichle et al. 2007) because of the characteristics of the land surface (heterogeneity; non-linearities, on-off processes). This avoids computing adjoints (as for 4d-var), which is problematic given non-linearities and on-off processes at the land surface. The EnKF also provides cost-effective representation of the background error.

•As well as using DA to test methodology and produce land surface analyses to study specific phenomena (Houser 2003), we will test model and observational information. Feedback from this research will benefit NWP and climate prediction by allowing a better use of Earth Observation data; better simulation of land/atmosphere processes; and improved initial states for prediction at various temporal scales. This will also help monitor the land surface, increasingly important for addressing climate change issues.

•We will make best use of observational and model information using DA ideas. This will help improve observational and model error information, and prepare for receipt of future observations.

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