Scenario DOCTORAL TRAINING PARTNERSHIP

NERC SCIENCE OF THE ENVIRONMENT

Optimal mitigation of sampling error in ensemble data assimilation

Lead Supervisor: Ian Roulstone, University of Surrey, Department of Mathematics
Email: i.roulstone@surrey.ac.uk

Co-supervisors: Jonathan Flowerdew, Met Office; Sue Hughes, University of Surrey

Kalman filters are used to estimate the state of dynamical systems in areas as diverse as aircraft control, image processing and econometrics. They combine an existing state estimate with new observations, based on estimates of their respective error covariances. One important application is providing the initial states for numerical weather forecasts, a field known as data assimilation (DA). This case is particularly challenging due to the large problem size (hundreds of millions of state elements, thousands to millions of observations), constrained processing time, and the complexity and flow-dependence of the forecast error covariances. This motivates the use of 'ensemble' methods, where these covariances are estimated by running a set of forecasts which sample the uncertainties in initial state and model formulation (Fig. 1). The ensemble covariances reflect the specific weather situation on that day, based on the full physics of the main forecast model. They also provide a 'low order' representation of the solution space, which helps to reduce the computational cost of the filter.

With recent increases in computing power, it has become possible to run local short-range weather forecasts with horizontal grid spacings of a few kilometres. This improves the representation of 'convective-scale' features such as clouds and thunderstorms, increasing the accuracy and usefulness of the forecasts. It also raises new challenges for the data assimilation, such as the variability of the covariances associated with the new high-resolution detail, the additional variables like cloud and precipitation which are of interest in such forecasts, and the complex and dense observation types such as radar and cloud-affected satellite observations which we would like to assimilate.

The Met Office has built an experimental convective-scale ensemble DA system and run some initial trials with promising results. Alongside such practical experiments, some theoretical and idealised work is required on the ensemble assimilation methods, and this is where you come in. The key problem in ensemble DA is that the inevitably small ensemble size leads to statistical noise in the sample covariances. All practical ensemble DA systems use some form of 'localisation' to balance the signal in the ensemble-estimated covariances against the sampling noise, but this is typically specified as an ad-hoc function of distance. Flowerdew (2015) showed how a statistically optimal localisation could be derived, and related to the underlying parameters of the system (Fig. 2). This PhD project will develop a number of the ideas from that paper, and consider similar approaches to advancing other aspects of ensemble DA theory. The precise choices can be adapted to your interests and progress during the project. Your advances will be directly useful in guiding the development of practical ensemble DA systems at operational weather forecasting centres such as the Met Office.

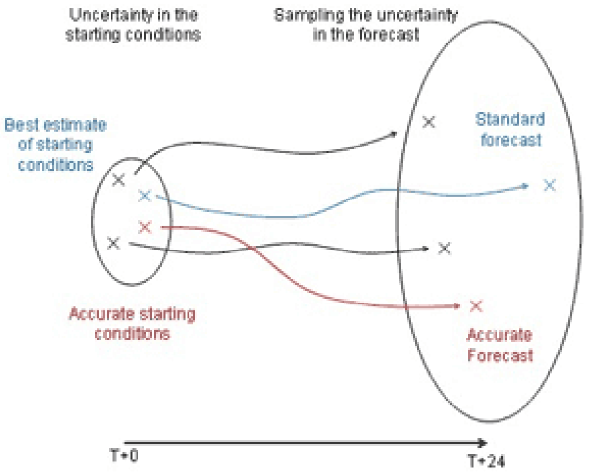

Fig. 1: Schematic of ensemble forecasting. By running multiple forecasts which sample the uncertainty in initial state (left) and model formulation, we obtain a sample of the possible outcomes (right), from which we can calculate statistics such as the covariances required for DA. http://www.metoffice.gov.uk

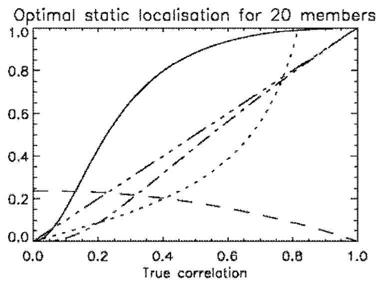

Fig. 2: The solid line shows the optimal localisation factor for a single observation, as a function of the true correlation between the background forecast errors for the observed quantity and the model variable being updated. The remaining lines show other terms in the optimal localisation calculation. From Flowerdew (2015). © 2015 British Crown Copyright, Met Office.

Training opportunities:

You will gain experience of applying your mathematical skills to an important application in environmental science. You will have close contact with Met Office scientists developing practical ensemble DA systems. The Met Office is a world-leading provider of weather and climate services to government, the public and industry, with experts in different aspects of data assimilation, ensemble prediction and weather forecasting. It provides regular seminars covering a wide range of topics in weather and climate science and prediction. In addition, advanced undergraduate and graduate courses will be available at Surrey and Reading, and you will have regular contact with academics and other SCENARIO students working in data assimilation.

Student profile:

The successful candidate will need:

- A solid grounding in mathematics, engineering or a physical science. Some knowledge of statistics would be beneficial.
- Ability to understand and develop software for scientific experimentation and data analysis. Familiarity with the principles of object-orientated software development would also be an advantage.
- An organised approach to work with strong problem-solving skills.
- Interest and enthusiasm for understanding a physically-relevant mathematical problem.
- Good oral and written communication skills.

Funding particulars:

Eligible students will receive the usual NERC award including stipend and university fees. CASE funding may be available for this project, depending on the internal prioritisation of funds within the Met Office.

References:

Flowerdew J. 2015. Towards a theory of optimal localisation. *Tellus A* **67**: 25257.

http://www.metoffice.gov.uk/research/areas/data-assimilation-and-ensembles/ensemble-forecasting/explanation

http://www.reading.ac.uk/nercdtp