Maximising the value of observational data in ensemble data assimilation for hazardous weather prediction

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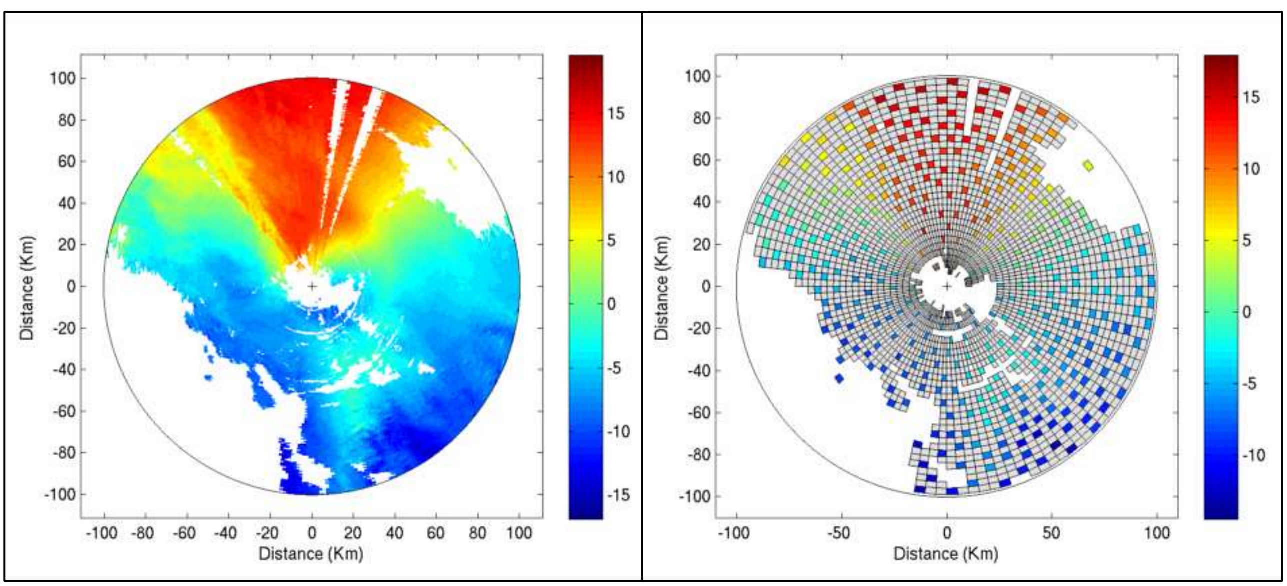
In a changing climate, an improved ability to forecast hazardous weather is key to the management of risk for society. In weather forecasting systems, large numerical models solve nonlinear equations describing physical processes in the atmosphere. Data assimilation is routinely used to improve weather predictions by combining billions of variables from these numerical model simulations with millions of observations of the atmosphere. Data assimilation can be thought of as a machine learning or mathematical optimization approach, where a cost function is minimized. The cost function is essentially a weighted measure of the distance from forecast states (numerical simulations) and the available observations over a fixed time window, weighted by the *uncertainties* (error statistics) in the data. Thus, weather forecast accuracy relies on accurate estimates of the uncertainty in weather observations. However, less than 5% of some key observation-types are assimilated, in part because these uncertainties cannot be properly quantified and accounted for. Thus, a key research question is how to characterize and treat observation uncertainty in an assimilation system. This project will investigate mathematical methods to approximate observation uncertainty that preserve observation information content while being sufficiently efficient for practical use in operational weather prediction.



a) Available Doppler radar wind observations (after pre-processing)

b) Averaged observations used in data assimilation

A large proportion of available observations are not used for data assimilation, due in part to difficulties in characterizing and accounting for observation uncertainty.

In recent years, there have been great improvements in forecasting high impact weather events such as intense rainfall leading to flooding, via the use of very fine (1.5km) grid-spacings. It is important to be able to predict precise locations and timings for hazardous weather events to enable appropriate mitigating actions (such as deployment of temporary flood barriers). However, hazardous weather predictions, such as forecasts of intense summer rainfall, are sensitive to the detailed starting conditions. We address this in two ways:

- Using dense observation data from remote sensing instruments (e.g., satellites and ground based-radar) providing detailed information about the current state of the atmosphere. We need good estimates of the spatial relationships for the uncertainties in these observations to make best use of them for weather forecasting.
- Using novel *ensemble methods*. These methods use multiple forecasts driven from slightly different starting conditions, to explicitly represent the flow-dependent nature of the forecast uncertainty.

The interactions between the flow dependent forecast uncertainty from the ensemble, and new approaches to estimate observation uncertainties are not well understood. In the project, theoretical investigation and simplified model experiments will be used to provide valuable insights with potential to trial the best techniques with real data in the Met Office operational system. The project is flexibly designed to allow the student to tailor the project towards to their own strengths and interests, whether that is the development of mathematical theory, numerical implementation or physical insights into the sources of observation uncertainty. This will be facilitated by the use of a new software package (JEDI) that gives a choice of model complexity, from simple idealized models that run quickly on a laptop to the full operational numerical weather prediction system requiring a large database of observations and parallel computations.

The student will join a supportive research team in Reading's Data Assimilation Research Centre and be affiliated to the National Centre for Earth Observation (NCEO), giving wider opportunities for training and networking. The project is a collaboration of the University of Reading with the Met Office, the UK's national weather service. The researcher will be supported by advice from Met Office experts throughout the project, and access to Met Office software and observation data while on a placement. The research is expected to increase the proportion of high-resolution satellite data assimilated, leading to better forecasts of high impact weather and better value for money for investments in in satellite data.

Training opportunities:
The student will receive full academic, technical and transferable skills training through Masters level courses, short training courses and summer schools. The student will be given the opportunity to undertake a three-month placement at the Met Office (in Reading, Exeter or via online participation).

Student profile:

This project would be suitable for highly motivated students with a degree in mathematics, physics or another scientific or engineering discipline with a high mathematical content. Previous computer programming experience is desirable but not essential, as training can be provided.

Funding particulars:
This project is co-funded by the NERC SCENARIO DTP and the National Centre for Earth Observation *(TBC!)*. It has additional co-sponsorship from the UK Met Office in the form of a CASE award. This will supply an additional £1000 per annum to the Research Training and Support Grant for three years and also funds travel and subsistence for the student to undertake a 3-month placement at the Met Office.

References:
- Data assimilation: The secret to better weather forecasts https://youtu.be/YPAWYjPf_Pk *(non-technical video)*
- Tabeart, J. M. (2019) On the treatment of correlated observation errors in data assimilation. *PhD thesis, University of Reading* https://doi.org/10.48683/1926.00088830

https://research.reading.ac.uk/scenario/