Developing a dispersion modelling capability utilising ensemble weather forecasts for emergency-response applications

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INTRODUCTION

Awareness of uncertainties in radiological dispersion modelling has grown over recent years, as has the need to better understand and quantify these uncertainties. One approach that has been adopted for operational response is to consider a 'best estimate' and a 'reasonable worst case' for an event. More advanced approaches that consider wider assessment of sensitivities to model inputs include ensemble-based methods, but the requirement for a rapid and unambiguous response is paramount.

While various research and demonstration systems based on ensemble approaches have been developed over the last decade or two, it is only recently that computing power has evolved to a stage where many of these earlier research activities are now becoming tractable for real-time operational prediction capability. However significant challenges, both at a technical and a conceptual level, still remain concerning the efficient generation of ensemble dispersion products and their effective presentation and communication.

UNCERTAINTIES IN EMERGENCY-RESPONSE ATMOSPHERIC MODELLING

Emergency-response modelling of radiological incidents needs to take account of a wide range of uncertainties (Haywood, 2008), from a description of the estimated source term (which is often highly uncertain), the transport of material by the atmosphere and deposition of radionuclides to the ground surface, through to the representation of health (and other) impacts and their consequences in terms of countermeasures, etc.

The focus of this poster is on one link in this chain – uncertainties in the large-scale atmospheric transport – and will demonstrate how an operational ensemble weather prediction system is used to represent this uncertainty. The ensemble approach operates by simulating different realisations of possible future weather states. NWP ensemble systems are designed specifically to represent both the *analysis errors* in the initial model state and the *forecast errors* that arise due to model limitations and deficiencies. Ensembles also provide a means to estimate confidence in a forecast.

MODELLING SYSTEM COMPONENTS

The poster demonstrates initial results achieved by coupling output from the Met Office's global ensemble forecasting system, MOGREPS-G, with the atmospheric dispersion model, NAME.

NAME atmospheric dispersion model

The *Numerical Atmospheric-dispersion Modelling Environment*, *NAME,* is the Met Office's Lagrangian atmospheric dispersion model (Jones et al., 2007). It uses Monte Carlo random-walk techniques to predict the atmospheric transport and deposition to the ground surface of airborne material and is able to handle both gaseous and particulate substances. Processes such as dry and wet deposition, gravitational settling and radiological decay can be represented within the model. Input meteorological fields are supplied by the Met Office's numerical weather prediction model, the Unified Model (MetUM).

NAME was originally developed as a nuclear accident model in response to the Chernobyl disaster in 1986, and it continues to have an important operational role within UK and international frameworks for responding to radiological incidents. It has also evolved as a general-purpose atmospheric dispersion model and is today used for a wide range of emergency-response and research applications, including modelling of airborne volcanic ash and the spread of animal diseases and plant pathogens.

MOGREPS-G global ensemble forecasting system

The *Met Office Global and Regional Ensemble Prediction System*, *MOGREPS*, is the operational ensemble forecasting system developed at the Met Office (Tennant and Beare, 2014) based on the MetUM NWP model. A global ensemble (MOGREPS-G) provides lateral boundary conditions and initial-condition perturbations for a high-resolution regional ensemble (MOGREPS-UK) over the UK area. Only the global component of the system is used for dispersion modelling with NAME in the present study, but future work will aim to extend this to high-resolution prediction over the UK.

A 12-member global ensemble (control + 11 perturbed forecasts) is run operationally four times per day at 00, 06, 12 and 18 UTC. Forecasts are produced out to 7 days at ~33 km horizontal resolution. Perturbations are generated using the Ensemble Transform Kalman Filter (ETKF) approach. Model uncertainties are represented using stochastic physics schemes to target structural and sub-grid scale sources of model error.

DEMONSTRATION STUDY

An illustrative example is presented demonstrating the capabilities of NAME to produce an ensemble-based dispersion prediction, including direct output of statistical products such as ensemble median.

Scenario details

- Hypothetical accident at Barsebäck NPP in Sweden
- 1 TBq emitted over 6 hrs (a typical RSMC source term)
- Release from 09 – 15 UTC on 08/03/2016
- Uniform release between ground level and 500 m
- Modelled radionuclide is Cs-137 (dry and wet deposition)

Meteorological forecasts from 00 UTC on 08/03/2016 are used for the study, so as to simulate a real-time response. All model simulations are run to 00 UTC on 11/03/2016 to give predictions of total deposition of Cs-137 at that time.

Results

Figure 1 shows an estimate of deposition given by NAME using 'analysed' global meteorological fields. This will be adopted as a benchmark against which other predictions are compared. The spatial deposition pattern extends north-eastwards from the power plant across southern parts of Sweden and the Baltic Sea into Finland and north Russia.

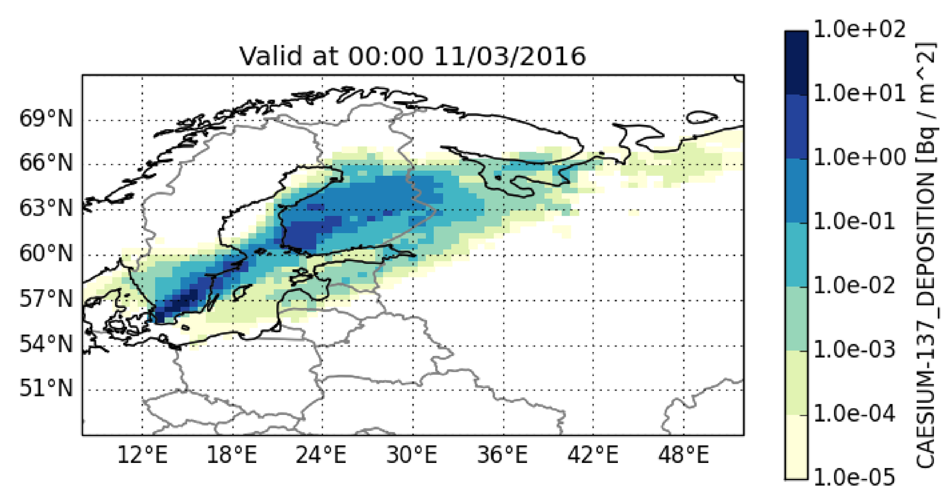

Figure 1. Estimated Cs-137 deposition based on post-event 'analysis' NAME simulation.

The predicted deposition based on the real-time operational global forecast is shown in Figure 2. There is good agreement with the simulation using the analysed fields, indicating that model forecast errors are small on this occasion. However, the extent and nature of these forecast errors would be unknown when the forecast was first prepared, and decision makers might be concerned with the proximity of the plume to Stockholm or scope for impacts in other Baltic states.

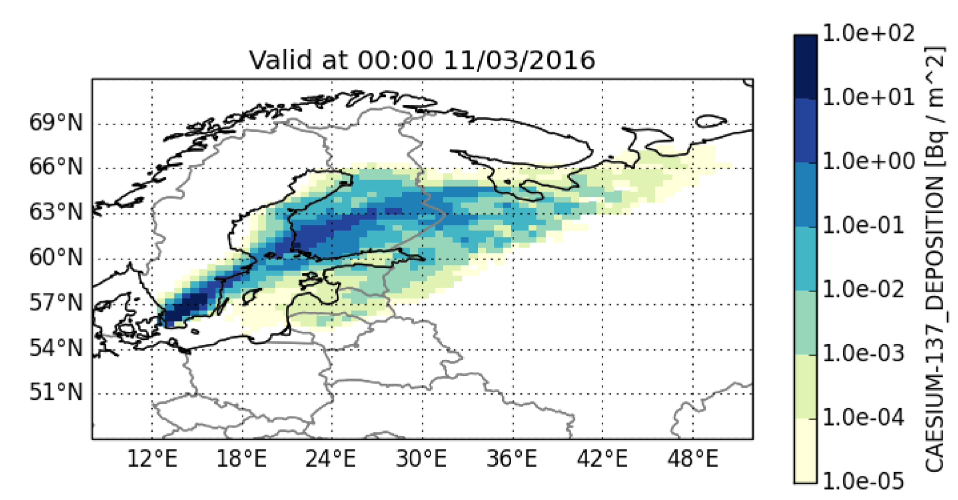

Figure 2. Predicted Cs-137 deposition based on NAME simulation using the deterministic global forecast from 00 UTC on 08/03/2016.

The *postage stamp* plot in Figure 3 depicts deposition based on the 12 individual members of the ensemble forecast with the same base time as the operational global forecast in Figure 2. There are small variations in the plume orientation over Sweden but otherwise good agreement for the deposition pattern. It is interesting to note that no ensemble member captures the greater northward extent of the low-to-moderate deposition values to the north of the main plume over Sweden. However there is a signal for some variability in the extent of the 'tail' extending from St Petersburg back towards Latvia.

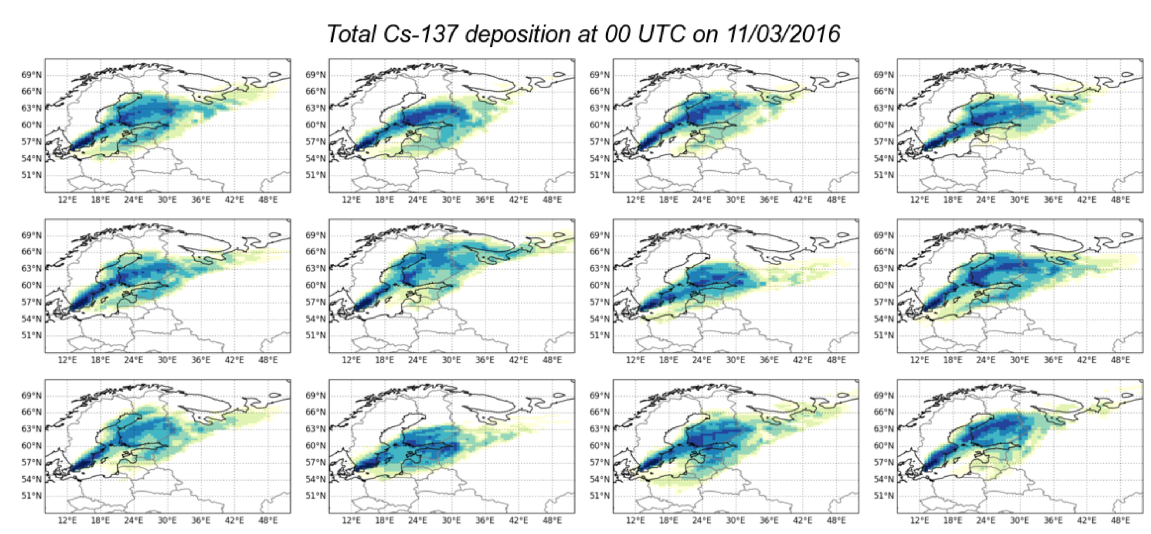

Figure 3. Predicted Cs-137 deposition using each ensemble member of the MOGREPS-G forecast from 00 UTC on 08/03/2016.

Viewing the separate ensemble members can bring benefits, but equally it can be challenging to analyse and interpret information in a usable way. Statistical processing can help to identify signals contained within the ensemble. For instance, *percentiles* of the ensemble distribution can be calculated or the *level of agreement* amongst members on exceeding particular threshold values (though selection of thresholds may need careful consideration). Some examples of ensemble statistics are shown in Figure 4.

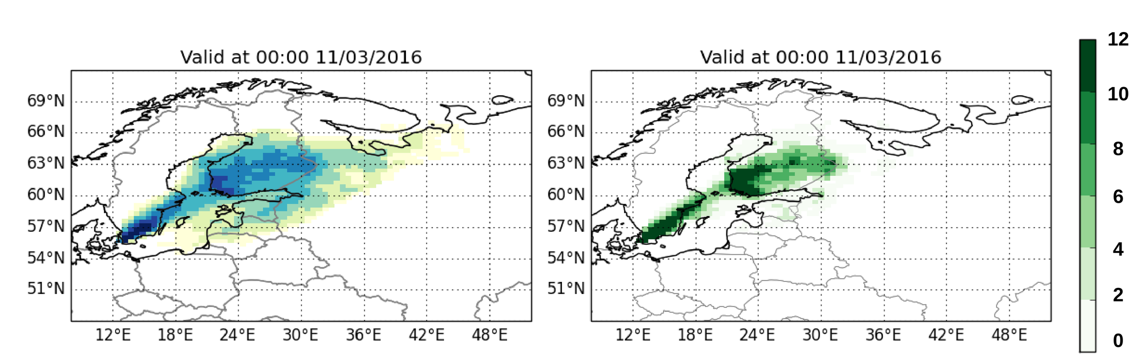

Figure 4. Statistical products: (left) ensemble median (or 50-th percentile) of Cs-137 deposition ; (right) number of the 12 ensemble members in agreement of deposition value > 0.1 Bq/m^2.

DISCUSSION

While it is acknowledged that it is difficult to draw conclusions from a single case study, it does nonetheless provide some useful insight into how an ensemble-based approach might offer potential benefits over the conventional deterministic one in aiding the response to an emergency. The *median forecast,* Figure 4 (*left*), is often adopted as a central measure of an ensemble forecast and it would be a reasonable choice to use in this instance. It is also evident in Figure 4 (*right*) that the area where the majority of ensemble members agree on an exceedence gives a good match to the analysis result and a better representation of the high deposition zone than from the deterministic forecast – in particular, at identifying an apparent lower deposition amount over the sea between Sweden and Finland.

FUTURE WORK

Further work planned under this project at the Met Office includes:

- Investigating use of *clustering techniques* for efficient generation of ensemble dispersion results
- Examining how to represent uncertainty in the meteorological *analysis* state
- Development of methods to represent other types of uncertainty (e.g., source term sensitivities)
- Design of application-specific uncertainty products to effectively *communicate* uncertainties

Engagement with end users and decision makers is viewed as a crucial aspect of this work to ensure that products are not just scientifically robust but also helpful for informing decisions.

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