17th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
9-12 May 2016, Budapest, Hungary

DEVELOPING A DISPERSION MODELLING CAPABILITY UTILISING ENSEMBLE WEATHER FORECASTS FOR EMERGENCY-RESPONSE APPLICATIONS

Andrew R. Jones, Ayoe B. Hansen and Susan J. Leadbetter

Met Office, FitzRoy Road, Exeter, EX1 3PB, United Kingdom

Abstract: The poster demonstrates some initial work from a project at the UK Met Office aimed at enhancing operational capabilities for emergency-response dispersion modelling by improving how uncertainties are represented when assessing accidental releases of harmful materials into the atmosphere. The early focus of this work is on the representation of meteorological uncertainty in the dispersion modelling and explores developing the use of forecasts from an ensemble weather prediction system to generate an ensemble of dispersion model predictions. A demonstration of the application of this system is presented. It is equally acknowledged that other aspects of uncertainty, especially in the description of source terms, are often highly significant and future work will be needed to consider suitable methods to represent and interpret these wider uncertainties in an operational context.

Key words: *meteorological uncertainty, ensemble weather prediction, radiological dispersion modelling***.**

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 might consider wider assessment of the sensitivities to model inputs, including use of ensemble-based techniques, 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. Such developments are now happening at various centres around Europe and beyond. 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 ATMOSPHERIC MODELLING

Emergency-response modelling of radiological incidents needs to examine a wide range of uncertainties (Haywood, 2008), from the description of the 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 the health (and other) impacts and their consequences in terms of countermeasures, etc. The focus of this poster is on one link in this chain, viz. uncertainties in the large-scale atmospheric transport, and will examine how we can use an ensemble weather prediction to represent this uncertainty.

NWP ensemble systems are designed specifically to sample a range of possible future weather states by representing both the *analysis errors* in the initial model state and the *forecast errors* that arise due to model limitations and deficiencies. Uncertainties in the NWP modelling system and in the observations are both accounted for. Ensembles are useful not only in providing possible forecast outcomes (including potential high-impact weather events) but also in giving a means to estimate the confidence in a forecast.
The ensemble approach operates by simulating many different realisations to sample the effect of initial analysis errors and forecast errors – each ensemble member starts from a ‘perturbed’ initial state and uses modified physics schemes in the model integration.

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.

The 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 is designed to predict the atmospheric transport and deposition to the ground surface of airborne material and is able to handle both gaseous and particulate substances. As a Lagrangian model, NAME uses Monte Carlo random-walk techniques to represent the turbulent transport of pollutants in the atmosphere. Processes such as dry and wet deposition, gravitational settling and radiological decay can be represented within the model. NAME is typically driven using three-dimensional gridded meteorological fields supplied by the Met Office's numerical weather prediction model, the Unified Model (MetUM), which provides a real-time dispersion modelling capability ranging from the global scale to kilometre-scale over the United Kingdom.

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. For instance, the Met Office is a Regional Specialized Meteorological Centre (RSMC) under the WMO's Emergency Response Activities programme, providing specialized dispersion products for the European and African regions. The radiological capabilities of NAME include a simple half-life decay scheme for the activity of individual radionuclides (including that of deposited material) as well as more advanced options such as decay-chain modelling and cloud gamma dose calculations. NAME has also evolved in a much broader sense as a general-purpose atmospheric dispersion model and is today used for a wide variety 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). A global ensemble (MOGREPS-G) is used to provide lateral boundary conditions and initial-condition perturbations for a high-resolution regional ensemble (MOGREPS-UK) over the UK area. The MOGREPS system is primarily intended for short-range weather prediction (1 to 2 days ahead), especially in relation to high-impact severe weather events such as windstorms and extreme rainfall. 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.

Global ensemble forecasts from MOGREPS-G are produced operationally four times per day at 00, 06, 12 and 18 UTC. Initial conditions are obtained from the global deterministic 4D-Var data assimilation, while perturbations are generated using the Ensemble Transform Kalman Filter (ETKF) approach, which is a computationally-efficient form of the ensemble Kalman filter. Model uncertainties are represented using stochastic physics schemes to target structural and sub-grid scale sources of model error. The current configuration of MOGREPS-G is shown in Table 1.

Table 1. Operational configuration of the MOGREPS-G global ensemble forecasting system

Domain	Ensemble size	Forecast range	Horizontal resolution	Vertical levels
Global	Control + 11 perturbed members	7 days (T+168)	33 km (mid latitudes)	70 levels with model top at 80 km

DEMONSTRATION STUDY

NAME has the capability to handle multiple meteorological forecast realisations (such as those supplied by an ensemble NWP system) and to derive statistical output products (e.g., the ensemble median) from them. An example will be presented here illustrating use in NAME of an ensemble weather forecast from the MOGREPS global ensemble forecasting system. While it is acknowledged that it is difficult to draw any conclusions from a single case study, it does nonetheless provide some useful insight into the potential benefits of an ensemble-based approach over the conventional deterministic one.

Scenario details

The modelling system is demonstrated for a hypothetical accident scenario at the (now closed) Barsebäck nuclear power plant (12.92° E, 55.74° N) in Sweden. An RSMC-type source term is used, in which 1 TBq (= 10^{12} Bq) of radioactivity is released at a constant rate over a 6 hour time period starting at 09 UTC on 08/03/2016 and ending at 15 UTC on 08/03/2016. The material is released into the atmosphere uniformly between the ground level and an elevation of 500 metres. The modelled radionuclide is Cs-137, which is subject to dry and wet deposition. Model simulations are run for 63 hours to generate output fields valid at 00 UTC on 11/03/2016. Meteorological forecasts from the 00 UTC forecast cycle on 08/03/2016 are used for the study, so as to simulate a real-time response that would occur for a real event.

Results

Results of the NAME simulations are shown for the total deposition of Cs-137 at 00 UTC on 11/03/2016. Figure 1 shows an estimated deposition field produced by NAME retrospectively using 'analysed' global meteorological fields. This will be adopted as a benchmark against which the other predictions can be compared. The deposition pattern extends north-eastwards from the power plant across southern parts of Sweden and the Baltic Sea into Finland and northern Russia.

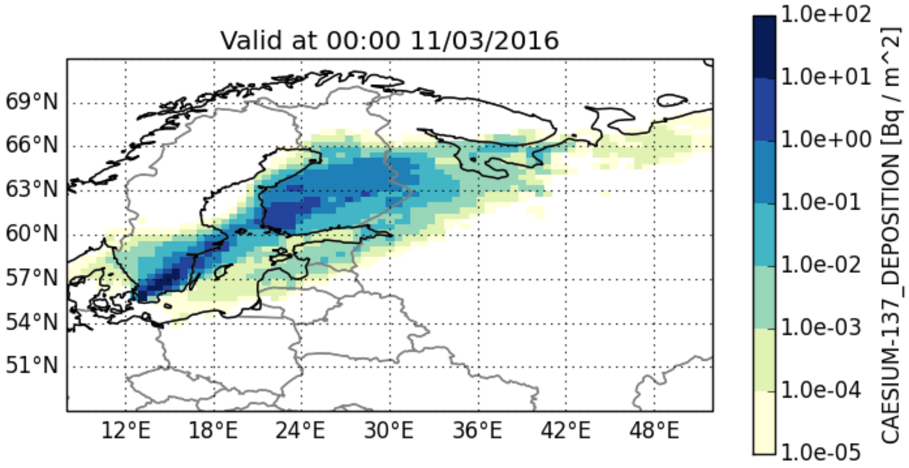

Figure 1. Estimated Cs-137 deposition at 00 UTC on 11/03/2016 based on a post-event NAME simulation using 'analysed' global meteorological data.

The predicted deposition from the NAME simulation using the real-time operational global forecast is shown in Figure 2. There is clearly very good agreement with the simulation based on the analysed met 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 the scope for impacts in other Baltic states. Differences can be observed (mostly at low-to-moderate deposition values) to the north of the main plume over Sweden and the extent of the 'tail' extending from St Petersburg back towards Latvia.

The *postage stamp* plot in Figure 3 depicts the modelled deposition based on the 12 members of the MOGREPS-G ensemble forecast with the same base time as the operational global forecast in Figure 2. There is good agreement for the deposition pattern across the ensemble. There are small variations in the plume orientation over Sweden but magnitudes of deposits are broadly consistent. It is interesting that no ensemble member captures the greater northward extent of the low-to-moderate deposition values here. However there is a signal for some variability in the extent of the 'tail' over Latvia.

While there are some benefits to viewing the separate ensemble members individually, it can be difficult to analyse and interpret the information in a usable way. Statistical processing can assist in identifying the main signals contained within the ensemble. For instance, percentiles calculated over the ensemble are shown in Figure 4. The *median* forecast (50-th percentile) is often adopted as a central measure of the ensemble forecast and would be a reasonable choice in this instance, though the 75-th percentile appears to give a better indication of deposition values over Finland and highlights better the presence of the ‘tail’. The 100-th percentile can be viewed as a ‘worst case scenario’ *at any location* (noting that a ‘worst case’ could not occur at all locations together) and would be useful to decision makers in giving an indication about the maximum extent of the area that could be affected and where remediation measures might need to be considered. The level of agreement for exceeding particular thresholds (not shown here) is also a useful method of assessing agreement between the ensemble members, though the choice of suitable thresholds needs careful consideration.

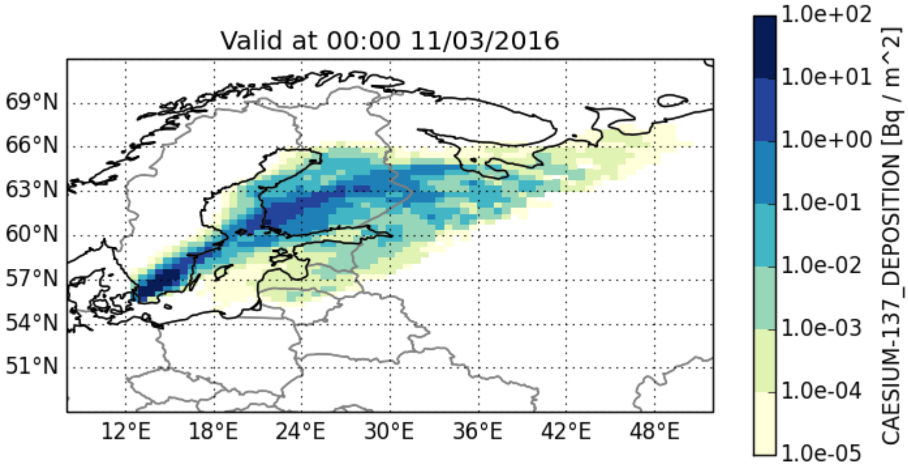

Figure 2. Predicted Cs-137 deposition at 00 UTC on 11/03/2016 based on the NAME simulation using the 00 UTC (on 08/03/2016) forecast cycle of the (deterministic) operational global forecast model.

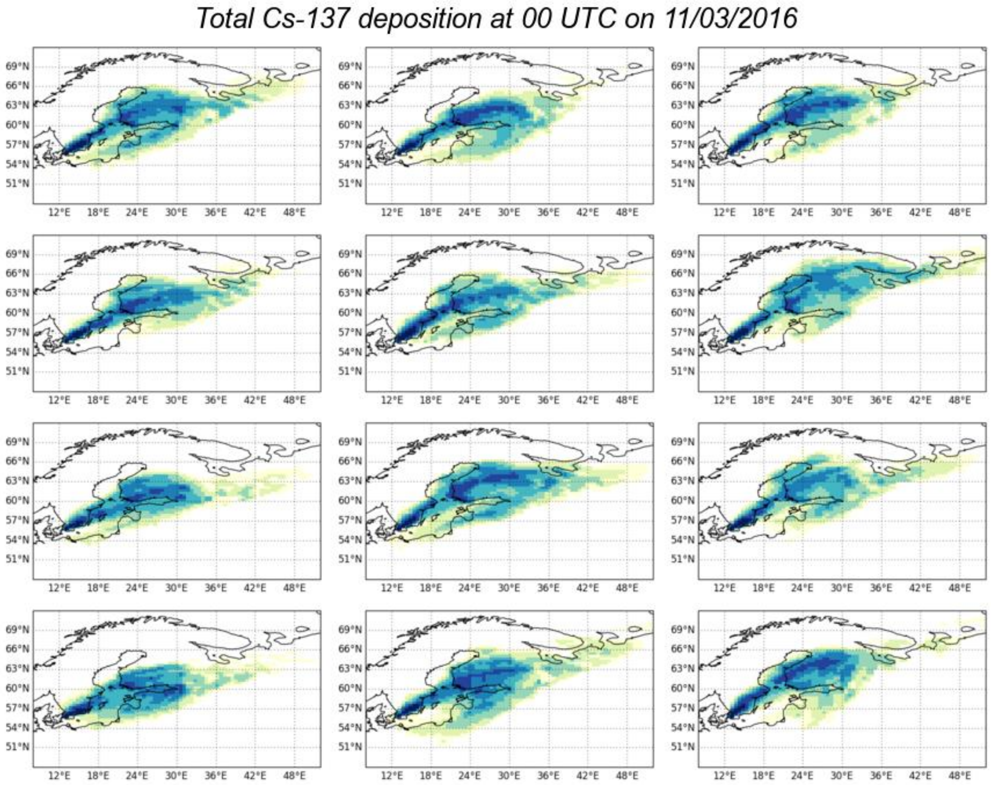

Figure 1. Predicted Cs-137 deposition at 00 UTC on 11/03/2016 using each ensemble member from the 00 UTC MOGREPS-G forecast on 08/03/2016.

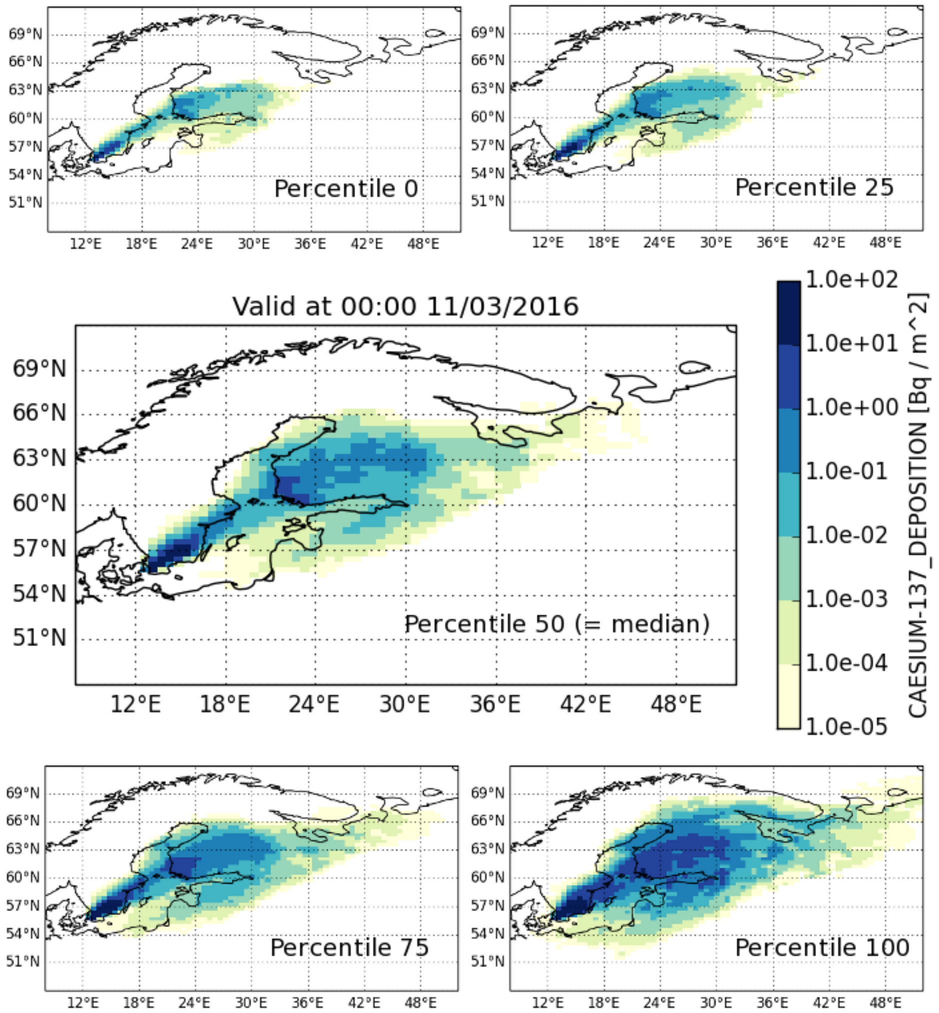

Figure 2. Percentile plots of Cs-137 deposition at 00 UTC on 11/03/2016 calculated over the 12 ensemble members shown in Figure 3.

FUTURE WORK

Further cases will be examined to establish the extent to which results seen in this initial demonstration case are more generally applicable. Further planned work includes investigating the use of *clustering techniques* for the computationally efficient production of ensemble-based dispersion results, and examining how to represent uncertainty in the meteorological '*analysis*' state. Further work will also consider development of appropriate methods to represent other types of uncertainty (e.g., source term sensitivities) and the design of application-specific uncertainty products that *communicate* uncertainties effectively with end users. Engagement with 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.

REFERENCES

Haywood, S.M., 2008: Key sources of imprecision in radiological emergency response assessments, *J. Rad. Protection*, **28**, 169-183.

Jones, A.R., D.J. Thomson, M. Hort and B. Devenish, 2007: The U.K. Met Office's next-generation atmospheric dispersion model, NAME III, in Borrego, C. and Norman, A.-L. (Eds) *Air Pollution Modeling and its Application XVII* (Proceedings of the 27th NATO/CCMS International Technical Meeting on Air Pollution Modelling and its Application), Springer, pp. 580-589.

Tennant, W. and S. Beare, 2014: New schemes to perturb sea-surface temperature and soil moisture content in MOGREPS. *Q.J.R. Meteorol. Soc.*, **140**, 1150-1160. doi: 10.1002/qj.2202