ASSESSING THE METEOROLOGICAL UNCERTAINTIES IN DISPERSION FORECASTS USING NWP ENSEMBLE PREDICTION SYSTEMS

Andrew Jones
Met Office, United Kingdom

INTRODUCTION

In a typical emergency-response situation, the dispersion of an airborne pollutant is usually modelled in a deterministic fashion. Here there is an implicit assumption that the large scale meteorological flow field is well known and the source term is either (approximately) known or can be represented as some 'standard' release. The dispersion model itself might include stochastic components (e.g. random-walk schemes within Lagrangian models), although the purpose of such schemes is usually to represent some aspects of the dispersion, such as plume spread, rather than to explicitly model uncertainties in the dispersion predictions. In practice, there can be large uncertainties in the atmospheric flow (both the synoptic-scale meteorology and local details in the flow field). The specification of the source term might also have large uncertainties, especially in the early stages of an incident when there may be few details available about the release. Further sources of uncertainty might also be important in any particular application, e.g. the influence of concentration fluctuations at short ranges, in-situ transformations during transport, or response characteristics of receptors.

One method to represent uncertainty in dispersion problems is to adopt an ensemble approach in which the dispersion modelling is repeated a number of times, with each individual run using different estimates of input parameters, to produce multiple realisations of a scenario. In its simplest form, this might be a sensitivity study examining a dispersion model's response to perturbing a single or few specific parameters. Another approach is the so-called "poor-man's ensemble" or multi-model technique, where a collection of predictions from different models is brought together for analysis. In the present paper, the ensemble approach is applied to meteorological uncertainties via the use of numerical weather prediction (NWP) ensembles in a single dispersion model. In fact, the principle could be extended to a multi-dispersion plus multi-NWP modelling system, or to a Monte-Carlo style simulation where other uncertainties in the modelling, e.g. in the source representation, are also represented.

The multiple realisations in an ensemble allow estimates to be produced for the likelihood of particular scenarios or events, such as exceeding a specific threshold at a given location, and so support a risk-based approach to dispersion modelling. However some care should be observed when interpreting results because the method might not actually determine 'true' probabilities in the same sense that an ensemble NWP system is intended to do. In weather forecasting, ensemble systems are designed to sample all realistic solutions of the model phase-space so as to be representative of the forecast spread (uncertainty). However, the additional uncertainties in dispersion modelling, such as those associated with the source description, often have error distributions that are poorly understood. This makes it difficult to capture the phase-space of real solutions and so obtain a faithful representation of the uncertainties in the dispersion problem.

MODELLING THE ETEX 1 CAMPAIGN USING AN ENSEMBLE APPROACH

The Lagrangian dispersion model NAME III is used with ensemble forecasts produced by the ECMWF VarEPS suite to generate ensemble dispersion predictions of plume transport for the ETEX 1 tracer release.

European Tracer EXperiment, ETEX

The European Tracer EXperiment, ETEX (*Van Dop, H. et al.*, 1998), was a major long-range tracer dispersion experiment conducted in 1994. ETEX involved two separate atmospheric releases of perfluorocarbon tracers from a site in western France and subsequent detection using a sampling network of 168 ground-level stations distributed over a large part of Europe. The ETEX data set, especially the ETEX 1 release, has been used extensively in validation of long-range dispersion models.

NAME III dispersion model

The Numerical Atmospheric-dispersion Modelling Environment, NAME III (*Jones, A. et al.*, 2007), is a Lagrangian model designed to predict the atmospheric dispersion and deposition of gases and particulates. Releases from pollution sources are represented by particles or puffs depending on spatial scales being considered. In the current application, the particle scheme is used. One or more species are emitted on each particle/puff, which subsequently follows a stochastic trajectory in a model atmosphere driven by appropriate meteorological data.

NAME III is capable of utilising meteorological data from a variety of sources, e.g. fields from an NWP model, radar rainfall estimates, and single-site observations. Effects such as plume-rise (for buoyant or momentum-driven releases), radioactive decay of radionuclides, and chemical transformations can be modelled if necessary. At short ranges, NAME III functionality includes modelling of short-period concentration fluctuations and the effects of small-scale terrain or isolated buildings on dispersion.

ECMWF Ensemble Prediction System

Forecast models of the atmosphere are chaotic systems where very small differences (errors) in the initial state can be greatly amplified by non-linear processes. The European Centre for Medium-range Weather Forecasts (ECMWF) produces operational global ensemble forecasts twice daily using their Ensemble Prediction System, VarEPS. These ensemble forecasts (*Buizza, R. et al.*, 1999) consist of an unperturbed 'control' forecast together with 50 'perturbed' forecasts starting from subtly different initial conditions constructed by adding dynamically-defined perturbations to the operational analysis. Perturbations are constructed using a singular vector method (the singular vectors determine, approximately, the most unstable modes of growth in the forecast error during the early part of the forecast period). In addition to perturbing the initial state, stochastic parametrisation schemes are used to perturb the physical tendencies in each individual member to represent errors in the forecast model and sub-grid scale uncertainties. The resulting ensemble is designed to be representative of synoptic-scale uncertainties in the medium-range forecast period (beyond T+48 hours).

Modelling set-up

A series of research experiments have been conducted using the operational configuration of the ECMWF VarEPS suite (IFS cycle 31r1) to produce ensemble NWP forecasts for the ETEX 1 modelling period, 23-26 October 1994. The results obtained using an EPS forecast with initialisation time 00 UTC on 23 October 1994 are discussed in the present paper.

In the ETEX 1 campaign, the perfluorocarbon tracer PMCH was released at an average rate of 8.0 g/s from 16:00 UTC, 23/10/94 until 03:50 UTC, 24/10/94. Stack height was 8 m a.g.l. The release location was near Rennes, France (2.008°W, 48.058°N). A 60-hr dispersion forecast is produced (start time: 15 UTC, 23/10/94; end time: 03 UTC, 26/10/94) over a European-wide domain. The ETEX 1 release is modelled by NAME III for each member of the ensemble in sequence. Statistical processing of results is then performed automatically within NAME III.

RESULTS

This discussion focuses on dispersion predictions at the end of the model simulation, 03 UTC on 26/10/1994. Figure 1 shows the actual ground-level air concentration measurements taken over the preceding three-hour interval. The observed plume is stretched out in an approximate north-west to south-east orientation extending from southern Norway across to Hungary.

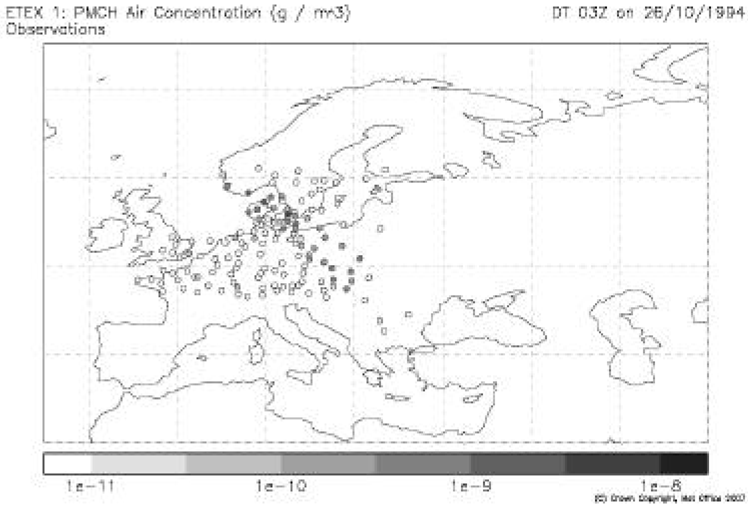

Fig. 1; ground-level air concentration measurements valid at 03UTC, 26/10/1994.

Figures 2-4 illustrate various predictions of ground-level air concentration averaged over the same period. Figure 2 shows the predicted dispersion based on the control forecast only, and demonstrates a typical example of a single deterministic product. In this particular instance, the control forecast provides a good representation of the plume position. The control forecast is straightforward to interpret but conveys little information on potential uncertainties in the prediction. In contrast, Figure 3 provides a 'postage-stamp' view of all 51 predictions in the dispersion ensemble. Individual members can be inspected to assess the range of possible outcomes (most likely scenarios, extremes, etc.) but the quantity of information presented can be overwhelming and makes it difficult to assimilate the predictions into a useful view of the event. Statistical processing can assist in distilling usable information from the variety of ensemble members. Quantities such as ensemble mean and various measures from the probability distribution can be calculated over the ensemble.

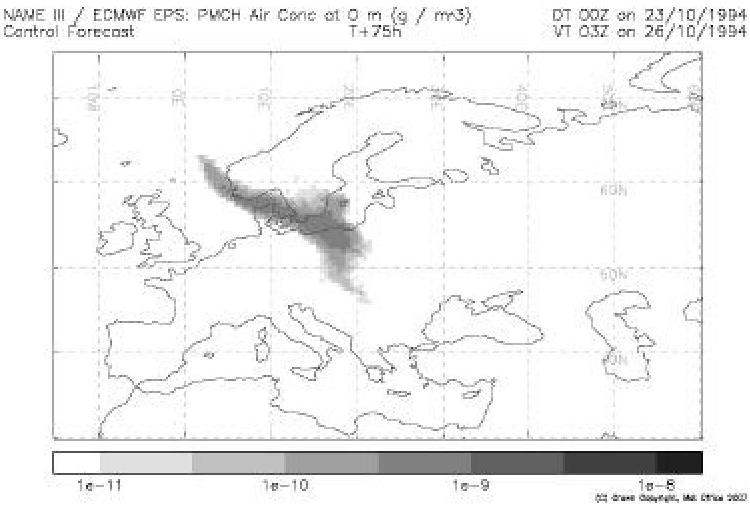

Fig. 2; dispersion prediction based on control forecast.

Figure 4 shows predictions using the ensemble mean and ensemble median (50-th percentile). The ensemble mean can be useful for highlighting areas where there is a possible impact, but it is also influenced by low-probability outlier solutions and tends to produce rather bland predictions. The ensemble median is often regarded as a more useful prediction as this identifies the core impact area by filtering out the 'noise' of outliers. Other percentiles (minimum, maximum, etc.) and the probability of exceeding certain thresholds can also be constructed from the ensemble distribution. For instance, Figure 5 illustrates the level of agreement between individual members on exceeding various thresholds for ground-level dosage (time-integrated concentration). Products of this type can be valuable in identifying both the core impact areas of a plume and the low-likelihood alternative scenarios.

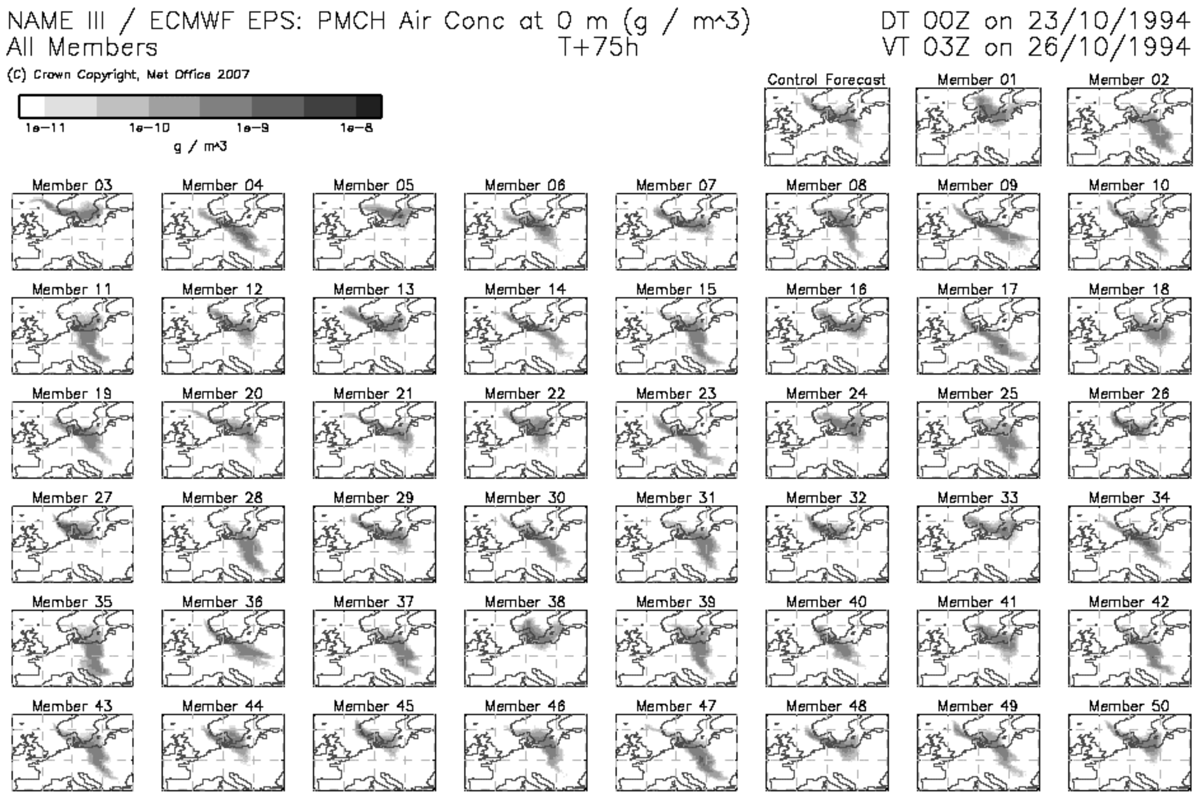

Fig. 3; 'postage-stamp plot' showing all 51 members of the dispersion ensemble.

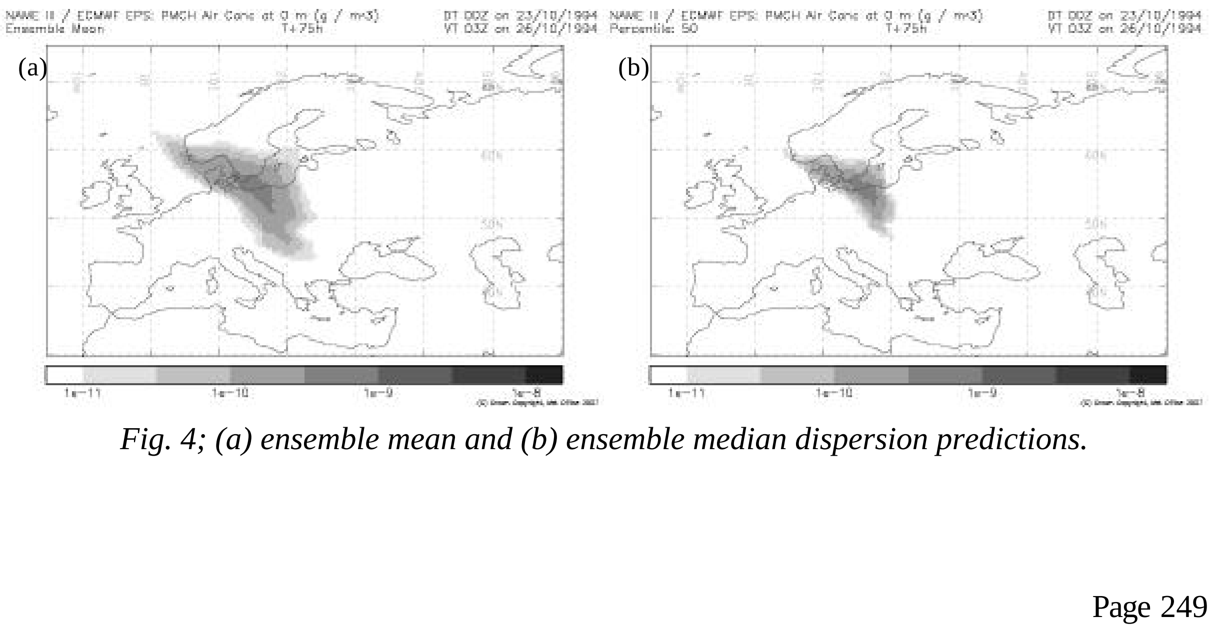

Fig. 4; (a) ensemble mean and (b) ensemble median dispersion predictions.

CONCLUSION

The ECMWF Ensemble Prediction System has been successfully used with the NAME III dispersion model to produce an ensemble of dispersion predictions that accounts for the impact on atmospheric transport of synoptic-scale uncertainties in the atmospheric evolution. The identification of low probability but possibly high impact alternative solutions is possible using this technique. By its nature, an ensemble approach can produce large amounts of information, as illustrated by a quick glance at any postage-stamp style of chart, but after suitable statistical processing, more usable products such as ensemble mean, median and percentiles can be retrieved. However some care needs to be taken when interpreting these predictions: the user should consider precisely what uncertainties are being adequately represented by the method *and* those which are not. It is generally safer to view probability distributions as describing the agreement amongst ensemble members rather than as 'true' probabilities. Future work will aim to investigate the use of clustering techniques (one promising approach to improve the efficiency of ensemble dispersion modelling) and also the impact of forecast lead time on predictions.

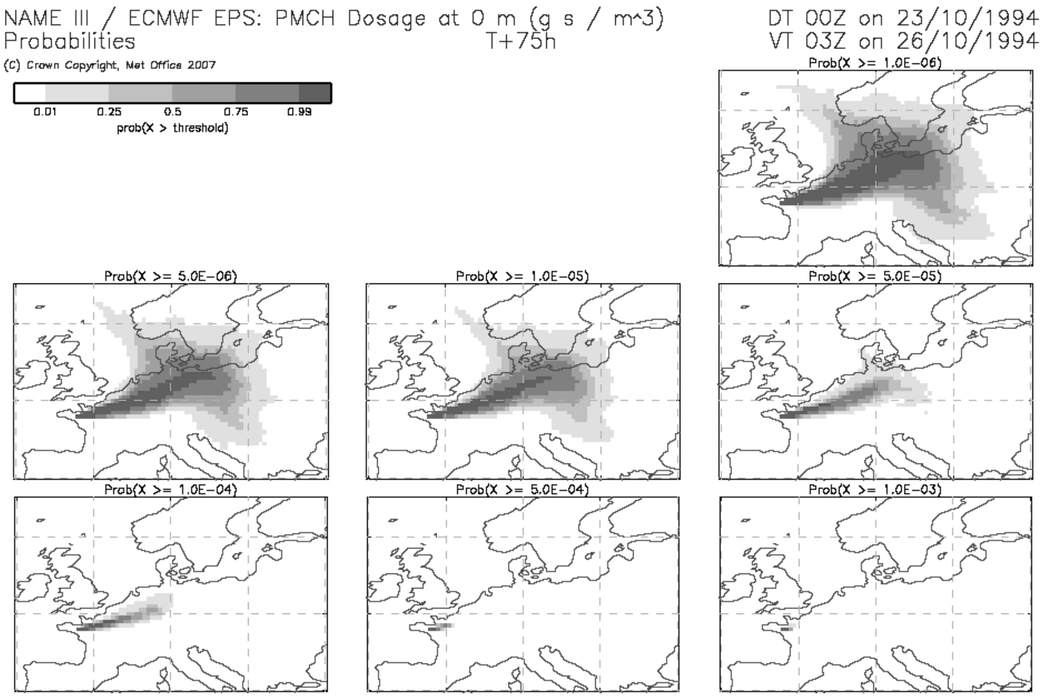

Fig. 5; probabilities that the total dosage will exceed specified thresholds. These are not 'true' probabilities but instead represent the level of agreement amongst ensemble members.

ACKNOWLEDGMENTS

I wish to thank Caroline Woolcock at the Met Office, and Paul Dando and Carsten Maaß at ECMWF, for their kind assistance during this work.

REFERENCES

Buizza, R., M. Miller and T. N. Palmer, 1999: Stochastic representation of model uncertainties in the ECMWF Ensemble Prediction System. *Q. J. R. Meteorol. Soc.*, **125**, 2887-2908.

Jones, A., D. Thomson, M. Hort and B. Devenish, 2007: The U.K. Met Office's next-generation atmospheric dispersion model, NAME III. In *Air Pollution Modeling and its Application XVII,* Borrego, C. and A-L. Norman (Eds.), Springer, 580-589.

Van Dop, H. et al., 1998: ETEX: A European tracer experiment; observations, dispersion modelling and emergency response. *Atmospheric Environment*, **32**, 4089-4094.