Uncertainty in Atmospheric Dispersion Modeling

Dr. Walter D. Bach, Jr.
Science and Technology Corporation

Mr. Samuel P. Williamson
Federal Coordinator for Meteorological Services and Supporting Research

Ms. Margaret R. McCalla
Office of the Federal Coordinator for Meteorological Services and Supporting Research

Abstract

One of the critical factors of estimating consequence assessments of airborne hazardous material is the description of the space-time evolution of the atmosphere. Prognostic and diagnostic models are used in different scenarios. Models are known to be imperfect, dependent on observations and forecast models. The uncertainty of the model for each given incident varies. Knowledge of the uncertainty and conveying the uncertainty to the user in a manner appropriate to his/her issues are important but they are not well-defined or implemented in user products and services.

This presentation reviews recommendations for addressing atmospheric uncertainty within the nuclear utility industry.

1. Introduction

1.1 Background

Models of the dispersion of airborne hazardous agents estimate the agent concentration for given times and locations based on source information and prevailing and evolving atmospheric conditions. These estimates directly affect the decisions of authorities for protective action of the impacted population. Rishel [1] identified three sources of uncertainty in protective actions as:

> (1) Information and understanding of the event (i.e., principally source location and characterization);
>
> (2) Meteorology and dispersion with principal emphasis on representative observations, status of the instrumentation, and flow complexity; and
>
> (3) The effectiveness of protective action due to exposure time, population sensitivity, and agents, are not well-known.

This presentation addresses the issues of (1) quantifying and using uncertainty of atmospheric transport and diffusion (dispersion) to guide model development and (2) incorporating the uncertainty into products to enhance public safety from hazardous releases to the atmosphere. It is based on the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) report entitled *Federal Research and Development Needs and Priorities for Atmospheric Transport and Diffusion Modeling* FCM-R23-2004 [2].

The OFCM report carefully identified research and development strategies to enable dispersion models to meet a wide variety of users and their needs. Six major objectives united by two overarching goals were identified. These objectives and goals appear in Figure 1.

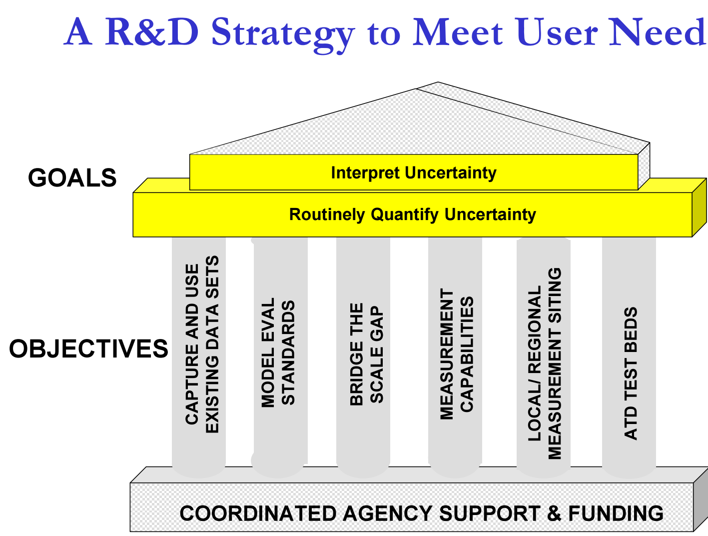

Figure 1. A research and development strategy to meet user needs [2]

The ability to routinely quantify meteorological uncertainty incorporates measurements, measurement capabilities, model assumptions, model limitations, measurement-model interfaces, and the flow regimes across multiple scales – local to global. Research and development on all of these objectives are needed for positive progress.

1.2 What is Uncertainty?

In order to quantify uncertainty and make decisions, there must be an objective measure for it. According to Rao [3], the total model uncertainty is measured by the variance in the *predicted* and the *observed* quantity over a large number of events that have similar properties (an ensemble).

Given that each observation of a material concentration at a given location and time, Co ($\boldsymbol{x}$,t), consists of the actual concentration Co_a and a measure of the measurement error there, δCo, i.e. Co ($\boldsymbol{x}$,t) = $Co_a(\boldsymbol{x},t) + \delta Co(\boldsymbol{x},t)$ and likewise, for the predicted value Cp($\boldsymbol{x}$,t) = $Cp_a(\boldsymbol{x},t) + \delta Cp(\boldsymbol{x},t)$. For an ensemble of n similar events, the mean observed or predicted concentration of the ensemble is given by

$$\overline{C}(\vec{x},t) = \lim_{n\to\infty} [\frac{1}{n} \sum_{r=1}^{n} C^{(r)}(\vec{x},t)]$$

where r identifies a realization of the ensemble. The total model variance can be computed and shown to be the sum of

- Error variance of input data : $<(\delta Cp^2)>$
- Error variance of the observations : $<(\delta Co^2)>$
- Square of model bias : d^2, where $d = <Co_a> - <Cp_a>$
- Stochastic uncertainty : $\sigma_c^2 = < (C^{(r)} - <C>)^2>$

(The terms indicated by <Q> represent the ensemble mean value of the enclosed term Q). The first three terms are potentially manageable by model or observation improvements, as they depend on the observations and the predictions. The last term – the stochastic uncertainty or inherent uncertainty - is not controlled. It is a property of the local atmosphere.

Careful consideration must be given to the choice of the parameters used to identify the ensemble. Total model variance will be very dependent on the ensemble. Temporal and spatial averaging of the observations and model estimates, the location of the observations and the model will all affect the uncertainty. For example, model uncertainty in eastern Tennessee will be different from the uncertainty of the same model in eastern Idaho.

2 Quantifying and Interpreting Uncertainty

2.1 Why is Quantifying Uncertainty Important?

Uncertainty permeates all aspects of life and life decisions. In atmospheric modeling of an event, knowledge of the uncertainty of the situation can be critical to public safety decisions. Safety factors are developed based on actual or perceived, "gut-feeling" uncertainty. Decision-makers want to know: "How reliable is your estimate?" Knowledge-based uncertainty gives realistic guidance to the answer.

Dispersion model users rarely quantify uncertainty even though it provides a measure of the robustness of the observing and the modeling system employed. It provides a measurable baseline for assessing needed or proposed improvements to the modeling system. Quantifying uncertainty adds confidence to the quality of the concentration estimates and decisions made from them.

2.2 Guidance for Quantifying Uncertainty

The OFCM report addresses the six objectives for dispersion modeling in general and makes specific recommendations for prioritizing research and addressing uncertainty. The Nuclear Utility Meteorological data Users Group (NUMUG) community has fixed, well-characterized sources; is required to carefully maintain networks of meteorological and concentration sensors; and is required to maintain dispersion modeling capability. Some NUMUG locations have extensive historical data archives. Consequently, the NUMUG locations are prime candidates for capturing and using those data sets and model predictions to quantify uncertainty at their locations. Such activity strongly enhances capabilities in the event of accidental or planned releases.

Additionally, the NUMUG sites provide excellent opportunities for establishing larger test beds to develop expanded data bases for use with dispersion models used locally or elsewhere. Such test beds should operate continuously and examine uncertainty in all weather conditions – fair or foul. They should routinely quantify uncertainty and develop feedback among modelers and users assessing the usefulness of the product (i.e., the quantified model uncertainty communicated to the model users). Unfortunately, most model evaluations rely on a few well-controlled tracer experiments to assess their capabilities and do not address uncertainty directly. Most field experiments are conducted when atmospheric conditions are favorable for success.

New technologies for measurements of meteorological variables such as temperature, humidity, winds, and turbulence are needed to characterize local environments. Emphasis should be directed toward volumetric measurements (e.g., Doppler wind lidars), rather than point measurements. Test beds need improved technology to provide less costly and robust tracers and remote and in situ measurement. The NUMUG leadership can help lead this developmental area needed for quantifying uncertainty.

2.3 Guidance for Interpreting Uncertainty

To serve users better, modeling systems must routinely quantify the various mathematical uncertainties in model results. Secondly, model developers must find useful ways to communicate the practical import of these uncertainties to the users. In turn, the users must explore ways to guide developers in making the uncertainty communications relevant to the user's needs. There may be multiple means of conveying the uncertainty between the model developers and users. Ongoing, sustained interaction between developers and users is the only way to determine which representations will work best for which users, while still adequately representing the uncertainty.

3 Recommendations

The NUMUG community has the beginnings of modeling and observational infrastructures which can allow the community to begin routinely quantifying model uncertainty at multiple locations within the nation. Initial goals would be to establish a benchmark of uncertainty for several dominant ensembles that represent a large fraction of atmospheric occurrences. From the benchmark, improvements in models and observing systems can be quantitatively evaluated. Additionally, by working with users of model products and through cooperation of both users and modelers, methods of incorporating the uncertainty into user products and services can evolve. These two processes (i.e., benchmark establishment and user/modeler cooperation) can begin to illuminate and intelligently use modeling uncertainty within protective actions when required.

REFERENCES

1. Rishel, J., 2011: *Direction-Specific Initial Protective Actions: Forum Discussion of Technical, Policy, Health Risk and Other Considerations*. Presentation: Emergency Management Issues-Special Interest Group Annual Meeting, Charleston, S.C.

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