1.0 INTRODUCTION

The fundamental reason for modeling atmospheric transport and diffusion (ATD) is to predict the concentration in the atmosphere of hazardous material released from a source or sources (one or more points of release) as the material moves from the source to other locations. The predictions from an ATD model of concentration as a function of space (location) and time, plus other information, can be used for a variety of purposes. Hypothetical releases at particular points and under different conditions (the planning scenarios) can be used by *planners* to identify potential zones of hazardous threats and prepare effective responses to these scenarios. In an actual release situation, the threat may require emergency *responders* to take immediate action to protect health and safety of those in the zones of hazardous threats or to provide aid to those injured or exposed. Model predictions of where concentrations did (and did not) reach levels of concern are also important during the *recovery* phase, which may extend long after the immediate emergency. For less immediate dangers, such as those from *continuing release* of air pollutants with potential long-term effects, the planning, response, and recovery activities may weave into one another. Response activities, in particular, will periodically rise and fall as concentration levels of the hazardous material rise and fall over time.

At the most basic level, an ATD model predicts how motions in the atmosphere—wind and turbulence fields—transport and diffuse the material of interest after its release. Perfect prediction of the smallest motions in the atmosphere is not possible. Inherent constraints arise from limited information about the source, the atmosphere, and the time available to generate a prediction. The information needed about the source and the state of the atmosphere is always limited. Furthermore, some of the motions involved must be described stochastically or as nonlinear dynamic processes. Consequently, getting useful results from an ATD model is always a compromise between timeliness and completeness in portraying how the atmosphere acts on the released material. This tradeoff between timeliness (or resources for the modeling activity) and completeness is starkest for emergency response to an actual incident. No matter how much better the ATD modeling results could be in an hour or two, by then they are likely to be too late to help the first responders. Even the planner cannot wait forever or invest unlimited resources in a single model run. If planning for the one situation that does occur is to be appropriate, many scenarios must be considered and evaluated. Timeliness (and to a lesser extent, resource constraints) are less of an issue for long-term recovery, but the completeness standard often rises very high in that context of use.

Another practical demand on many real-world applications for ATD models stems from the consequences that variations in the prediction of hazard zones can have on large numbers of people. In urban areas, planners and responders are often faced with difficult triage decisions: who most needs help and needs it most quickly? When the complex morphology of urban areas is added to the prediction task—the irregular land-water interfaces of coastal bays and inlets, mountain-valley structures, or just the height and spacing variations of the modern urban built environment—the demands on the ATD model to identify the hazard zones accurately become extreme. *ATD models typically* *must describe atmospheric processes in the most changeable and complex part of the atmosphere.*

The events of September 11, 2001, dramatically sensitized the American public to the magnitude and range of potential terrorist actions aimed at civilian populations. The Nation is now far more aware of the potential threats from airborne technological hazards, such as releases of chemical, biological, radiological, and nuclear (CBRN) materials, not only from a deliberate action with hostile intent but also from industrial and transportation accidents. There is also an increased (and appropriate) expectation that all levels of government will improve their capabilities to share information, coordinate responses, and collaborate on preparations to better protect the public. Thus, there is a new sense of urgency associated with the research needs identified in this report.

1.1 Purpose

Given the objectives of ATD modeling and the constraints and current concerns as sketched above, there is value in a systematic approach to determining the most effective ways to lessen the constraints while making ATD modeling systems more useful for their intended applications, particularly applications of most pressing concern. This report presents a research and development (R&D) plan for providing the ATD modeling capabilities needed to meet established needs of the user communities, with special emphasis on enabling the National strategy for responding to domestic CBRN incidents. Although the report emphasizes homeland security and homeland defense applications, many of the capability improvements identified here will benefit other applications as well, such as air quality monitoring or emergency preparedness planning and response for accidental releases of hazardous materials.

The report includes:

- A discussion of user needs for consequence assessment systems (a general name for typical applications in which ATD models are employed, including but not limited to emergency response/recovery and preparedness planning applications);
- Extraction of ATD modeling capabilities required to support the users needs;
- Analysis and prioritization of the gaps between the required capabilities and current Federal ATD modeling capabilities (requirements pull), plus opportunities for new and emerging science and technology to fulfill user needs better in the future (technology push);
- A strategy to fill the gaps and provide improved capability through an interrelated set of coordinated R&D activities implemented by Federal agencies with ATD modeling programs or related research, development, or technology transition programs; and
- Recommendations for next steps in implementing the R&D strategy.

The R&D plan and recommendations presented here are intended to support and guide Federal agency efforts to fund their most pressing research needs and to encourage multiagency collaboration and cooperation on shared objectives. The plan will help to facilitate participation from entities in other sectors (academia and industry) and coordinate Federal activities with local, regional, and state governmental entities.

1.2 ATD Models in a Consequence Assessment System

For all the applications of ATD models mentioned above (and discussed more fully in chapter 2), users actually work with a complete consequence modeling system (or the functional equivalent of such a system, composed of several pieces). Figure 1 shows how an ATD modeling system fits within a complete consequence assessment system. The functions typically considered as part of the ATD modeling system are represented by the bold black boxes. The other functions are in lighter boxes.

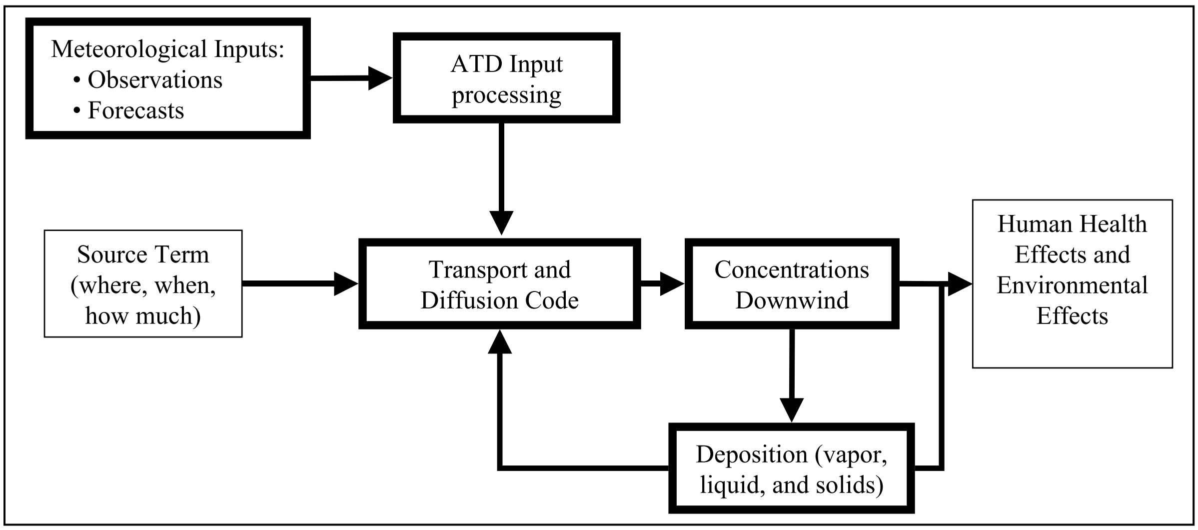

FIGURE 1. The functional components of a complete consequence assessment system, with its embedded ATD modeling system shown by bold lines.

The purpose of a consequence assessment system is to assess the consequences of specific hazards on people and the environment. To do this, the functional components must work together, passing information from one component to the next as shown by the arrows in figure 1.

- The **source term** component includes information about the identity and physical state of the hazard or hazards for which consequences are being assessed, the release mechanism(s) involved, and the mass of hazard released per unit time. For CBRN weapons, the release mechanism is the agent delivery system. For an industrial accident, it could be a leaking transfer line or burning truck trailer.
- **Meteorological inputs**, in simple terms, describe the local weather conditions at the time a source term release occurs and forecasts for these conditions through the time the substance is airborne. At a minimum, ATD models require inputs on wind speed and direction and a measure of turbulent activity, with the implicit assumption that these conditions do not change. A more complete meteorological

specification may include clouds, precipitation, temperature, pressure, humidity, surface heat and momentum fluxes, and more complex turbulence parameters.

- **ATD input processing** involves processing the available meteorological forecast information and observational data to prepare it for use in the modeling done by the transport and diffusion code. Input processing might, for example, include a diagnostic model in which available wind observations are used to estimate three-dimensional wind fields that reflect the impact of local terrain and conserve mass. It may also involve *data quality acceptance and quality control* (data QA/QC), such as applying criteria for whether additional observational data are accepted into the model run after initialization. ATD input processing may be used when meteorological observations are ingested into a localized wind field forecast. It may also be used to generate a nowcast (forecast for the next 1 to 6 hours) using the forecast fields from a prognostic meteorological model as a first guess and refining them by assimilating observational data that were not available at initialization. Sometimes these input processing functions are not considered part of the ATD modeling. For reasons that will emerge in chapter 3, this report includes them as a component within the ATD modeling system.
- **The transport and diffusion code** is the software engine that computes advection (transport solely by the mass motion of the atmosphere) and diffusion. The code describes, in sets of computation instructions to a digital computer, the combined effects of time-averaged transport (which has traditionally been viewed as a deterministic process) and diffusion. The principle mechanism of diffusion is turbulence, which has traditionally been represented as a stochastic process. A deterministic process is governed by and predictable in terms of definitive laws, such as dynamic equations. A stochastic process evolves in time according to probabilistic equations; that is, the behavior of the system is determined be one or more time-dependent random variables.
- **Deposition** refers to the way in which the ATD modeling system represents processes that remove the hazardous material of interest from the air carrying it and deposit it on the Earth’s surface (land or water). Substances released into the atmosphere will continue to reside there, continually diluted by mixing processes, until they are removed by reactions with other components of the atmosphere or are deposited to the surface. In some instances, deposited materials have the potential for subsequent resuspension by wind or volatilization.
- **Concentrations downwind** refers to the model’s prediction of how much of the hazard of interest (what concentration) will be in the air at particular locations and times after the release.
- **Human health and environmental effects** are the consequences of ultimate interest to most users of a consequence assessment system. From the prediction of concentrations downwind and other information, potential impacts on human health and safety and on the environment are estimated.

In conformance with the terms of reference under which this R&D plan was prepared, the functional requirements for characterizing the source term or the human health and environmental effects components of a complete consequence assessment system will not be analyzed. R&D needs are not defined for the capabilities needed in those components, nor does the R&D plan include activities to address capabilities needed in those areas. However, these components are considered from the perspective of being, respectively, an essential input to and output of the ATD modeling system. As such, they do influence the capabilities required within the ATD modeling components and the R&D to provide those capabilities.

The analysis in chapter 3 will return to figure 1 to analyze in detail the capabilities needed for each component of an ATD modeling system. For the moment, however, the principal message of figure 1 is that, for the purposes of this R&D plan, *an ATD modeling system is always a tool for the larger purpose of a consequence assessment application*. Differences in the specific objectives of that application will often mean that the ATD modeling system must be tailored to *fit the tool to its task*.

1.3 Scope and Context of the R&D Planning Activity

The activity leading up to this ATD R&D plan began shortly after the terrorist attacks on the World Trade Center and the Pentagon on September 11, 2001. In December 2001, under the direction of the Federal Committee for Meteorological Services and Supporting Research (FCMSSR), the Federal Coordinator for Meteorology established the Joint Action Group for the Selection and Evaluation of Atmospheric Transport and Diffusion Models (JAG/SEATD). The task of the JAG/SEATD was to evaluate the ATD modeling systems available to address threats to homeland security. The group's final report, published in August 2002, included a list of candidate research needs and concluded that the current ATD modeling systems available for Federal agency and military use should be refined and prioritized to reflect operational needs (OFCM 2002). The FCMSSR concurred with this recommendation, as documented in Action Item 2002-2.1 of the Record of Actions from the FCMSSR meeting of October 12, 2002. The Federal Coordinator for Meteorology then initiated a phased effort to address the recommendation.

For the first phase, the Federal Coordinator established the Joint Action Group for Atmospheric Transport and Diffusion Modeling (Research and Development Plan), or JAG/ATD(R&DP), and charged it to perform the following tasks:

- Review the proceedings from the Office of the Federal Coordinator for Meteorology (OFCM) special session at the George Mason University (GMU) Transport and Dispersion Modeling Conference (OFCM 2003) and identify any additional research needs that resulted from the conference.
- Review the results of the Joint Urban 2003 experiment at Oklahoma City (DTRA/DOE 2003).
- Identify any scenarios that are not addressed satisfactorily by the modeling systems documented in the JAG/SEATD report.

- Develop a methodology for characterizing and prioritizing the research and technical needs and for linking those needs to stated operational requirements.
- Consult with subject-matter experts as required (based on the needs of the JAG members).
- Identify the tools required for transitioning successful research results into operations through interagency cooperative efforts like observational and modeling testbeds, field and urban studies/experiments, and a common model evaluation methodology.
- Develop a comprehensive plan that documents the research and technical needs of the ATD modeling and operational communities. The plan should prioritize the most pressing R&D needs and provide a roadmap to address those needs within the OFCM coordinating infrastructure.

This R&D plan is the response of the JAG/ATD(R&DP), hereafter referred to as "the JAG," to the above terms of reference. Expanded feedback on the plan was solicited during the 8th Annual GMU Conference on Atmospheric Transport and Dispersion Modeling on July 14, 2004, and the OFCM Urban Meteorology Forum on September 21-23, 2004, which included participation from the academic, public, and private sectors.

Research areas that were considered within the scope of phase 1 included but were not limited to meteorological inputs and input data processing, directly measured dispersion inputs, and transport and diffusion calculations. Research needs associated with but not limited to source characterization, common default source terms, chemical mixtures, chronic health effects, and common frameworks for the display of results in geographic information systems (GISs) will be included in a later phase.

To understand existing Federal operational modeling capabilities, the JAG has relied heavily upon the earlier JAG/SEATD study (OFCM 2002). The JAG/SEATD explored these capabilities in considerable detail but with limitations imposed by incomplete understanding of each modeling system. The JAG/SEATD determined that, of the 29 distinct ATD modeling systems it studied, many emphasized processes and factors that were peculiar to a specific application. Some of these systems provided a commendable representation of atmospheric dispersion processes. Many were integrated into consequence assessment systems with extensive source characterization and health effects for specific substances. These capabilities reflected investments by the Federal agencies that developed the ATD modeling systems over a significant period.

The current JAG studied the R&D needs listed in the JAG/SEATD report, as well as the report's recommendations. It also reviewed the proceedings from the OFCM special session of the 7th Annual GMU Transport and Dispersion Modeling Conference (OFCM 2003) and the National Research Council report, *Tracking and Predicting Atmospheric Dispersion of Hazardous Material Releases, Implications for Homeland Security* (NRC 2003). From the review of these documents, the JAG developed a preliminary list of research needs.

Next, the JAG conducted teleconferences and several panel sessions dedicated to specific topics, to facilitate as much participation as possible by Federal agency representatives and subject-matter experts in drafting early versions of the R&D Plan. Subject-matter experts were invited to assist in reviewing and revising the list of candidate R&D needs. The JAG also reviewed the Joint Urban 2003 field experiment (DTRA/DOE 2003) and discussed a framework for transitioning successful research results into operations through interagency cooperative efforts. Among the cooperative efforts considered were test beds for observing systems and modeling, field studies and experiments including ones conducted in urban areas, and a common model evaluation methodology.

The JAG considered whether there were incident scenarios of recognized importance for which all of the current ATD modeling systems were totally unsuited. The conclusion was that all of the identified scenarios can be at least minimally addressed by one or more modeling systems. The JAG also discussed the challenges from releases of CBRN material due to high-altitude intercepts of ballistic missiles. In consideration of these realities, the R&D plan proposed in this report makes thorough and imaginative use of all available tools to address the dispersion issues confronting the Nation. Overall, the R&D plan reinforces the need for expanded theoretical and physical modeling studies, for dedicated field studies conducted in the circumstances of intended application, and for close coupling of all such activities with the development of improved models. These elements of an overall strategy accept and build upon the standard approach of continuing exploration of contributing processes. They acknowledge the powerful needs of current times and the urgency with which new and refined products are desired. They recognize that rapid transfer of the findings to the user community is necessary. To accelerate this transfer to operations, an essential element of the proposed strategy is to deviate from the usual approach to meteorological research and couple the user community more closely with the R&D program for ATD modeling.

The JAG prepared a draft R&D plan in time for review within the OFCM coordinating infrastructure prior to the 8th Annual GMU Transport and Dispersion Modeling Conference in July 2004. The main elements of the plan, including the recommendations for next steps in implementing it, were presented at that forum during a special OFCM session. This session enabled representatives from the public, private, and academic sectors to comment on them. Their comments were used to revise the report as appropriate.

The R&D strategy and recommendations in this report were presented at the OFCM Urban Meteorology Forum in September 2004 to solicit feedback from non-Federal organizations. This forum provided an opportunity for commercial interests and academic institutions to consider how their resources complement or supplement the approach to research and advanced development described in this document.

The report will be submitted to FCMSSR, through the Federal Coordinator and the Interdepartmental Committee for Meteorological Services and Supporting Research, for its endorsement of the report's recommendations. After the FCMSSR review, the responsible agencies within the Federal meteorological community will coordinate an approach for implementing the recommendations.

1.4 Structure

The report consists of six chapters and five appendices. Chapter 1 provides an introductory view of the purpose of ATD modeling systems and introduces the plan's scope, context, and general argument structure. Chapter 2 describes the operational needs of users of ATD modeling systems from their perspective, with particular attention to the similarities and differences in operational context and consequence assessment requirements of the major segments of the user community.

Chapter 3 interprets the operational user needs into required capabilities of ATD modeling systems and the inputs to those systems. Chapter 3 also begins the analytical task of comparing these requirements with existing capabilities, to identify gaps between what current systems can now do and what users need them to do. Chapter 4 goes further into this assessment of capabilities against requirements. It focuses on three broad areas:

- Improvements to both ATD models and the meteorological models that typically provide input data for them;
- Improvements to measurement technologies, to provide both the data needed to improve results with current modeling capabilities and the data required to take full advantage of the proposed modeling improvements; and
- Improvements required at the interfaces between data and models—areas that require a joint analysis and will involve accommodation and innovation from both sides.

Chapter 5 presents the set of interlocking program elements that the JAG adopted as the best approach for addressing the R&D needs identified and prioritized in chapters 3 and 4. The exposition of each program element covers the capabilities to be achieved through it, the rationale for this element as the best approach to meet user needs, and the relationships among the elements as components of an overall R&D Plan.

Chapter 6 contains the JAG's recommendations for actions to implement the plan in Chapter 5. Most of the recommendations include specific implementation actions to be taken if the basic recommendation is endorsed by FCMSSR.

The appendices include supporting details for the main lines of argument in chapters 3 through 5. Appendix A provides a historical perspective on the current state of meteorological and ATD modeling capabilities. It includes brief summaries of a set of past ATD field studies, which the JAG considers to be prime candidates for capturing existing data for new R&D objectives (section 5.3). Appendix B is a summary of current ATD modeling capabilities and R&D programs. It supports the analysis of gaps and opportunities in chapters 3 and 4. Appendix C is a more technical treatment of some of the key considerations underlying the general argument of chapter 3 and section 4.1 on the necessity to incorporate more probabilistic methods, representations, and output information in ATD modeling systems. Appendix D is a glossary of acronyms used in the report. Appendix E lists the JAG participants.

Reference information for the technical literature and other source citations in the body of the report (chapters 1 though 6) is listed after chapter 6 and before Appendix A. Each of appendices A through C contains its own reference list.