5.0 AN R&D STRATEGY TO MEET USER NEEDS

5.1 The Goals for ATD Modeling R&D

As the JAG considered user needs and the R&D to sustain continuous improvement of ATD modeling capability, a recurring theme was the necessity to quantify the uncertainty in ATD modeling predictions far more completely and accurately than is currently possible. Quantifying the uncertainty is essential for two reasons.

First, ATD models must routinely characterize both the deterministic and stochastic contributions to the modeled effects. The stochastic contributions may in many instances override the deterministic processes. As emphasized in chapter 2 and throughout this report, the ATD modeling community must do better at interpreting for the end users of its products the implications of the uncertainty in predictions for the ways in which the predictions will be used.

Second, effective progress in reducing the uncertainty (where possible) through continued R&D requires knowing how much there is and how much each factor contributes to the uncertainty in the product. As detailed throughout chapters 3 and 4, some sources of uncertainty in predictions can be reduced; others cannot (given the inherent nature of the processes involved or the limits of our science of them). Cost-effective progress in reducing uncertainty requires quantifying and distinguishing these various contributions to the uncertainty in the product.

The JAG identified two capstone goals for future R&D: *routinely quantifying uncertainty* and *interpreting the implications of this uncertainty to users*. Supporting these capstone goals are six objectives (figure 8). Some of the objectives, such as *multiple ATD test beds*, correspond roughly to a single program element in the R&D plan. Other objectives, such as *bridging the modeling gap*, will be achieved through contributions from several R&D program elements. Overall, the JAG expects that a sustained and concerted effort of a decade or more will be required to attain all the objectives to the degree envisioned in this report. However, throughout that duration, all of the program elements will produce useful interim results. To reach the capstone goals, the elements of the overall strategy must be sustained, evaluated, and allowed to evolve as the knowledge base grows and the capabilities for ATD modeling improve.

The synopsis below of each objective notes those program elements most directly related to obtaining the objective. Details of the program elements are discussed in sections 5.3 through 5.7; next steps toward achieving these specific objectives and the capstone goals are recommended in chapter 6.

Capture and Use Existing Data Sets. This objective identifies the need to assemble into a modern data format the available (open access) data sets from the many years of ATD experiments and model testing. These historical data are in various forms and storage media: punch card, paper, and electronic media. Oral histories from the participants will provide essential insights into the data quality, the understanding of objectives, and the

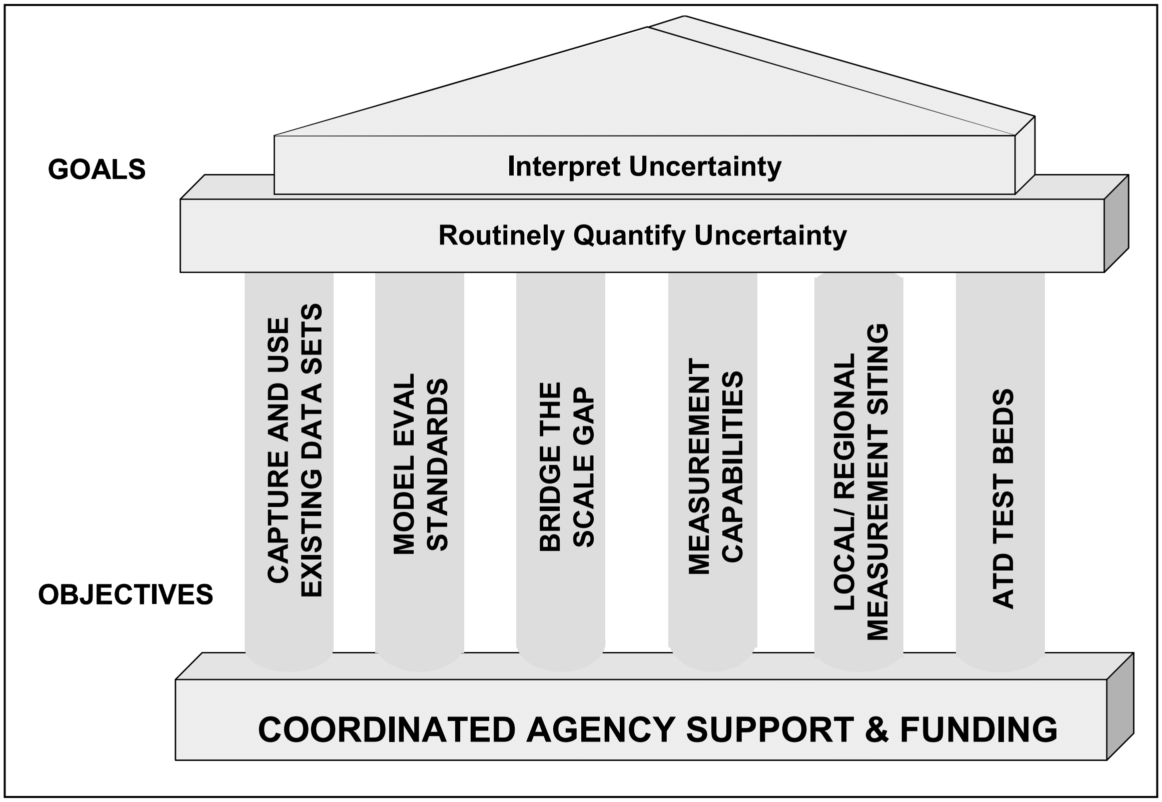

FIGURE 8. Six R&D objectives need to be achieved to support the ultimate goals of quantifying uncertainty and communicating its implications to users.

actual conduct of the field programs—all of which are in danger of being lost. These records of past ATD field experiments are the best extant source of concentration data currently available to quantify uncertainty in ATD models. The data from some of these experiments were not previously analyzed to the extent now technically feasible. The records from others are now worth studying for different objectives than before. Overall, they represent a resource that can quickly provide a useful base to begin assessing ATD model uncertainty. This objective can be achieved through the R&D program element described in section 5.3, Capture and Use Existing Data Sets.

Model Evaluation Standards. Procedures for evaluating the performance of ATD modeling systems are not standardized across the Federal agencies or ATD model user communities. Further, the existing procedures may not fully deal with the complexities introduced by comparing calculations and observations having different inherent space and time averaging. Without common reference standards, model development and implementation tend to remain "stovepiped" within the developing agency, while other development efforts are discounted or go unused. An all-agency effort to establish and maintain a current set of criteria for evaluating model performance by a recognized independent standard development organization (SDO) will alleviate this problem. This objective can be achieved through the R&D program element described in section 5.4, Foster Evaluation Standards for Modeling Systems and Components. Other program elements will help by contributing to the knowledge base needed to set standards and update them as needed.

Bridge the Modeling Gap. Top-down modeling (from larger to smaller scales) and bottom-up modeling (from smaller to larger scales) do not merge across scales from 50 m to 5 km in realistic environments. This points to a fundamental lack of knowledge of how to model the processes at these scales. In all models, there is an element of turbulence carried in the smallest scales and the unresolved processes. Although there is perpetual optimism that higher-resolution models will give better results, current operational experience does not substantiate this optimism.

The processes are primarily boundary-layer processes mixed with mesoscale phenomena and driven by the large synoptic flows. Specification of initial and boundary conditions for forecast models is difficult because of the complexity of the lower surface. Timing of flow features becomes more critical for ATD needs than for other forecast needs. Furthermore, smaller-scale features are typically lumped into sub-grid-scale processes and treated as a closure problem until some of the processes become effective in altering flows in significant ways. Feedback loops of small to large scale are poorly understood. In most ATD models, the crucial level of interest—within the first few meters above ground—is where the unresolved processes are dominant and mostly stochastic.

The objective of bridging the modeling gap can be met through the combined and coordinated efforts from several R&D program elements. The major contributing elements will be coordinated programs for improved measurement technologies (section 5.5), the multiple ATD test beds (section 5.6), and special studies and experiments (section 5.7). The additional analytical results obtained by capturing existing data sets (section 5.3) will provide early contributions toward this essential and difficult objective. Furthermore, the bottom-up approach of physical modeling and CFD and LES is critical to achieving his objective. Developments in theoretical constructs and understanding of basic processes within the gap will be keys to its closure.

Improved Measurement Capabilities. Measurements are fundamental to advancing the realism of a science-based description or prediction. In ATD modeling, improving the capability to measure concentrations of tracers and atmospheric variables (e.g., wind velocity, turbulence, temperature) *at the scales of ATD model use* is essential to all the identified R&D needs leading to better ATD models. Quantifying the uncertainty in model variables requires in situ and/or remote measurements at the modeled scales. Most applications of ATD models are at much finer scales than are the available atmospheric data, especially in populated areas. To develop better parameterizations, measurements are needed to understand processes not resolved within models.

Tracer measurement capabilities are needed to provide data for quantifying the uncertainty in ATD model predictions. They are also needed to build an experience base for users. Compared with meteorological model users, who routinely receive feedback on their forecasts, ATD model users rarely get real-time experience or feedback at present, except in emergency situations. Users need to build a base of experience with models and develop local knowledge through feedback from real experiences. There is no training ground like real (not "canned") hands-on experience.

Two of the R&D strategy elements will make major contributions to this objective of improved measurement capabilities: the coordination of programs for improved measurement technologies (section 5.5) and the multiple ATD test beds (section 5.6). Supporting contributions will come from further analysis of existing data sets (section 5.3), consensus evaluation standards (section 5.4), and special studies and experiments (section 5.7).

Local/Regional Siting of Instrumentation. Each locality has a unique morphology. Many localities want to provide a network of instruments, within budget limitations, that will reasonably represent wind and turbulence fields needed for ATD concentration fields in emergency conditions. No one plan fits all these sites. Strategies are needed to make reliable recommendations through a combination of modeling exercises, optimization processes, and experience in other areas. Major contributions to this objective can come from analyzing existing data sets (section 5.3) and the multiple ATD test beds (section 5.6). Parts of the coordinated programs for improved measurement technologies, particularly work on optimizing observational network design (section 5.5.2) will support this objective, as will aspects of the special studies and experiments (section 5.7).

ATD Test Beds. Recently, fledgling infrastructures for routine ATD forecasting based on model and local information, such as NOAA's DCNet, have developed in several urban areas. The JAG proposes a strategy of establishing test beds in appropriate areas across the country to address and test ATD models, model needs, and model capabilities on a continuing basis, just as weather forecasting operations and evaluations are conducted. By operating and performing evaluations continuously, by testing new ideas and instruments, and by interacting regularly with users, an ATD test bed becomes a crucible in which ATD modeling is made robust and refined from an art into a demonstrated and verified operational capability.

Most ATD model studies in the past were defined field campaigns operated to maximize the probability of success. Within this context, benign, simple, and nontaxing weather conditions were preferred, although terrain conditions may have been complex. Controlled tracer releases were sampled and atmospheric measurements were made as densely as capabilities and resources permit. As accidental releases and terrorist incidents are not scheduled, little is known from these past studies about the performance of ATD models across the spectrum of daily conditions. The proposed test bed infrastructure will provide this coverage, while building on the results from past studies.

The initial number of test bed installations should be limited so that operational procedures can be developed and refined without squandering scarce resources. Once the prototyping lessons have been learned, the set of installations could expand to cover more locations of priority interest, with each additional location chosen to represent different challenges from those already in place or being installed.

The ATD test bed objective amply illustrates the interdependence among the program elements and the synergy across major applications for ATD modeling. Activities that support air quality forecasting can also employ the test beds and contribute ideas to improve test bed capabilities. Experience developed in working with the test beds will aid in siting instruments to optimize their utility. Measurement innovations, in turn, will feed and stimulate modeling innovations. Models will have access to better parameterizations to close knowledge gaps. New approaches to ATD modeling will develop as test bed capabilities for experimentation and evaluation improve. Baselines for characterizing uncertainty will develop. Improvements in models by reducing uncertainty will be more readily quantified using the test beds, and the performance of different modeling systems or different configurations of one system will be more easily compared and objectively evaluated.

Multiple test beds are a major R&D program element, as well as a major objective. The extensive discussion in section 5.6 explains in greater detail why establishing and maintaining multiple test beds, with several in urban/city environments, is so important to the ultimate goals of quantifying uncertainty and interpreting its implications for users. In addition, the test bed objective will draw on other proposed program elements. Test beds need meteorological and tracer measurement capabilities to test siting strategies and to test and modify the instruments (section 5.5). Test beds should incorporate programs in which users and researchers work side by side in developing and using modeling systems and supporting tools (section 5.2). Standards are likely to evolve, based on test bed capabilities (section 5.4).

5.2 The R&D Aspects of Interpreting Uncertainty Implications for Users

This report addresses R&D needs, not training and outreach. However, some elements of training and outreach to users must be addressed because they impact the R&D process and outcomes. The most important of these elements concern the ability of users to understand how the limitations on model accuracy and precision—limits which the model researcher-developer quantifies in terms of the concept of uncertainty and the mathematics of probabilities—affect appropriate use of the model results. For example, users must have tools that incorporate probabilistic weather information with transport and diffusion applications and associated decision aids. As ensemble methodologies become more widely applied, traditional deterministic realizations will give way to statistical representations of plume evolution. It will be critical that the end user understand the difference between deterministic and probabilistic results and the subsequent effect on consequence management.

As emphasized in chapter 2, users do not understand, and do not care to learn about, mathematically expressed statements of "uncertainty." As important as those statements may be to the researcher-developer, they are difficult for most decision makers to understand and use constructively. They are even unlikely to be interpreted correctly by the person running the model in a real-life situation, unless that individual has an exceptional level of expertise and understanding.

In short, the ATD modeling system is not an operational tool for consequence assessment tasks until the end users know how to use it correctly. There is an experiential base on which to build, with both positive and negative cases from which to draw lessons.

The efforts to learn how best to make uncertainty information useful to the users of ATD modeling predictions must take into account the three time frames for model use identified in chapter 2: first response (first hour), intermediate response/recovery, and long-term planning/recovery. Research is needed on how to give each user category results that those users can work with effectively. From the discussion in chapter 2, here are just a few preliminary and general distinctions that are likely to be important:

- The most important information for the first responder is knowing what the hazard is and how to deal with it. Details of how the ATD modeler (whoever is running the model) got to the results and the mathematical uncertainties in the predictions are largely irrelevant. However, ways in which the uncertainties in the prediction could affect the response are important. These implications need to be communicated in terms relevant to immediate response decisions.
- In the recovery phase, accountability for each step from the beginning to the end of the modeling activity is necessary.
- Planners may want, and may be able to use in their larger planning, model predictions stated probabilistically.

ATD test beds, an essential ingredient in the R&D strategy (section 5.6), provide the infrastructure where users, developers, and researchers can interact. Users are there to be trained to use the new products and information in their activities. Planners can even use test beds as an integral and essential part of scenario building and what-if analyses (gaming) for preparedness planning. The developers and researchers get to see how users respond, what they need, and where they have difficulty with products in development. These types of activities validate the usefulness of the ATD modeling activity.

Independent, external consensus standards for evaluating modeling systems and tools (section 5.4) also play a major role in interpreting uncertainty for users. Such standards will:

- Build user confidence in products;
- Provide a science-based evaluation process for ATD products; and
- Provide a mediation/facilitation role in dialogue between developers and users on what is needed to do the job.

User training and the development of reach-back capability should be complementary activities. The effective integration of reach-back capability with tool dissemination to users is an intrinsic aspect of R&D, not just a post-R&D training issue. The National Atmospheric Release Advisory Center (NARAC) currently provides a national capability for training and reach-back in the context of incidents of national significance. Analogous training and reach-back support should be extended, perhaps through regional modeling centers, to incidents not at the nationally significant level, such as hazardous material spills. Reach-back capability for levels below incidents of national significance need ongoing coordination among existing infrastructure components, such as the NOAA/ NWS Weather Forecast Offices and regional ATD modeling centers.

5.3 Capture and Use Existing Data Sets

There are a number of existing high-quality ATD data sets from field research studies, which were conducted on terrain conditions ranging from very simple to very complex. The effects of hilly or mountainous terrain on winds and temperature have been studied for decades in the United States and abroad. Significant advances in understanding and predictive capability have evolved from this work. Many of the field studies sponsored by the U.S. Government used tracers, which makes the data potentially useful for testing and improving both meteorological models and ATD models.

Many of these data sets, which were initially used to develop or test parameterizations for ATD models, can yield additional, valuable results on concentration uncertainty. They are the only current source of data for this purpose. New analyses, using tools developed since the studies were first done, can glean useful insights from the high-quality data sets. For instance, data sets that were treated with deterministic models when the studies were done can be re-evaluated with improved representations of the physical processes, including probabilistic models that incorporate stochastic representations of aleatory uncertainties. Many of the issues now recognized as important for meeting user needs—such as short-term fluctuations in concentration and fuller quantification of uncertainties—were not major objectives at the time the studies were done. For example, in past experiments tracers were used to estimate time-averaged concentrations, not short-term fluctuations. In some instances, the data sets were not thoroughly analyzed initially because of agency-funding limitations. Appendix A includes a partial annotated list of the past studies known to the JAG members to have data sets with substantial untapped potential for further analysis.

One shortcoming of the data sets in their current condition is that they are housed in different laboratories and stored in different formats. The available data sets should be put into a format that allows the ATD research community to access and use them easily. For example, the Atmospheric Studies in Complex Terrain (ASCOT) program was sponsored by the Department of Energy (DOE) and conducted from the late 1970s to the early 1990s. The ASCOT data were stored at whichever DOE national laboratory was leading the field effort in that year. Data sets were collected at the Argonne, Lawrence Livermore, Los Alamos, and Pacific Northwest national laboratories, and probably elsewhere. Efforts are underway to collect and archive the ASCOT data sets.

It will be far more cost-effective to archive and re-analyze these data sets than to repeat the underlying field studies at great expense. (In fact, data capture, reanalysis, and preparation of the data in accessible format could be a good opportunity for graduate student research and/or employment.) The data capture activities should include transferring the experimental data and associated metadata into an electronic format that provides ease of access for analysts. For many of the studies listed in Appendix A, the effort should also include gleaning undocumented details and contextual information about the studies from the memories and expertise of the personnel who performed them.

Several of the longer range transport studies are already incorporated in NOAA's Data Archive and Tracer Experiments and Methodology (DATEM).[1] This archive may provide a framework for future archival activities.

For several of these valuable data sets, work is already underway to perform additional analyses. Several simulations of the Prairie Grass field experiments have been done using more recent modeling approaches (Irwin et al. 2003; Hanna et al. 1990; Irwin 1984). The Metropolitan Tracer Experiment (METREX) data (Draxler 1985) have been re-examined in some DCNet modeling efforts.

While some important cities and industrial facilities are located near mountains or in hilly terrain, much of the Nation's population and critical infrastructure are located near ocean coastlines or near large lakes. A modest number of field studies that collected both meteorological and tracer data within coastal zones have been conducted, usually for specific purposes such as testing and refining models of rocket effluent plumes. The data are often not as detailed as desired because it was difficult to make detailed measurements over large bodies of water, especially measurements aloft. Nevertheless, these data sets have value as a starting point for research on ATD in coastal urban environments.

Reanalysis of these data sets can provide insights for designing test bed experiments (section 5.6), optimizing observational network design (section 5.5.2), and for special studies (section 5.7). This would allow more rapid progress toward improving ATD modeling system products.

In terms of cost/benefit ratio, capitalizing on existing field data sets should be a top priority. With a modest level of effort, substantial short-term gains can be realized from these analyses in quantifying the uncertainty in existing ATD models and products. As discussed above, the strategy is time-sensitive with respect to providing input to the implementation of ATD test beds, planning for additional special studies, and capturing undocumented information about the past experiments while those who conducted them remain available.

5.4 Foster Evaluation Standards for Modeling Systems and Components

For this report, the term "performance evaluation" means ascertaining, as objectively as possible, how well a meteorological, ATD, or air quality modeling system is performing the tasks for which it was designed or used. The evaluation of model performance is essential to providing users with reliability measures and modelers with standard methods for assessing potential improvements. Various review groups have concluded that there is

[1] For further information on DATEM, see the Internet homepage: http://www.arl.noaa.gov/datem/.

a need to develop a common process for development of “consensus-based” evaluation procedures and metrics (OFCM 2002, NRC 2003, Dabberdt et al. 2004). Models simulate only a portion of the natural variability, thus their operational tasks are limited by the assumptions made in the construction of the model and the physical processes that are characterized. Differences between what is predicted and what is observed result from a combination of errors in model formulation (which can lead to systematic biases), propagation of measurement and input uncertainties (which can be amplified due to nonlinear effects), and the fact that nature contains more variability than do the models.

The *Standard Guide for the Statistical Evaluation of Atmospheric Dispersion Model Performance,* ASTM D 6589 (2000), provides a framework for describing how observations and predictions differ. This standard employs the concept of ensembles, which in reality are imperfectly known. Ideally, one would compare the observed and predicted ensemble averages to objectively characterize any systematic bias in the model’s predictions. This approach has had some success for evaluation of short-range dispersion models by sorting observations into pseudo-ensembles, but much work remains to be done.

Because uncertainties propagate forward in a prediction model, it is helpful to assess performance in a “front to back” sequence. For instance, the performance of the air quality/concentration model is dictated to a certain extent by any uncertainties in the characterization of the meteorology. The transport and diffusion of the emissions is based on the stated meteorological conditions. Often a portion of the emission specification (e.g., the dependence of surface spill evaporation on temperature and wind speed) is based on the representation of the meteorological conditions. Certain chemical processes are strongly influenced by the presence of and dynamics within clouds.

After reviewing the state of practice, the JAG concluded that standardized “physics-based” evaluation metrics are needed. Current skill scores and evaluation methods ignore the fact that the frequency distributions of the observations and predictions are inherently different; they have different sources of variation, as explained in ASTM D 6589 (2000). Thus, the JAG does not recommend attempting to catalogue and make use of current skill scores, as they have limited value, and then only if one realizes that seemingly correct predictions can be attained through a combination of offsetting errors. More sophisticated physics-based metrics would allow objective statistical tests to be made of whether differences in the results produced from various models should be deemed significant. From such statistical comparisons, measures of success can be developed.

Different user needs will likely require different ways of evaluating model performance. Nevertheless, evaluation of all ATD models will have many common points of concern. The Federal agencies should agree on meeting this need for common model performance methods and metrics through a group under the aegis of an SDO. (An example is ASTM International, Committee D22, which has already developed ASTM D 6589.)

This approach to standards development is consistent with, and perhaps required by, Public Law 104-113.[2] In addition, other considerations favor development of ATD model performance standards by a standing committee of technical experts from a variety of disciplines. The SDOs have proven systems for developing technical standards. If information is needed, they can hold technical symposia to address specific concerns. If experts from various disciplines are needed, an SDO has a vast resource of experts within its technical committees for consultation. SDOs routinely review existing standards for needed updates. A standing SDO committee can provide continuity in methods development under the standard. Perhaps most important, development of a standard by an SDO carries the cachet necessary for public acceptance.

With a view toward development of model evaluation methods, the JAG anticipates that the variety of user needs will provide fertile ground for development of a variety of performance metrics and methods tailored to specific user requirements. Furthermore, advances in modeling capabilities (e.g., models that provide a quantitative prediction of the distribution of possible individual outcomes) will place ever-increasing demands for development of new performance metrics tailored to specific user needs. In these dynamic conditions, a one-time definition of a set of performance metrics will not serve a useful purpose. A standing committee can provide continuity in standards development, acquire expertise over time, and leverage lessons learned to meet new demands over time.

Further work is also needed on performance standards for instruments to detect and measure hazardous airborne species, particularly hazardous gases. Although essential to consequence assessment systems for those hazards, this need is beyond the scope of this JAG's expertise and terms of reference. There are, however, other committees and working groups already established that can address these needs.

5.5 Coordinate Programs for Improved Measurement Technologies

Advances in all scientific endeavors come from the interaction of theory, model, and measurements. The measurement instruments to provide data for multiscale ATD modeling or for quantifying model uncertainties at the scales of interest to the users of ATD model predictions are scarce, and their use is far from routine. New and improved

---

[2] On March 7, 1996, President Clinton signed into law *The National Technology Transfer and Advancement Act of 1995*. This law, codified as Public Law 104-113, serves to continue the policy changes initiated in the 1980s under Office of Management and Budget (OMB) Circular A-119, *Federal Participation in the Development and Use of Voluntary Standards,* which are effecting the transition of the Executive branch of the Federal Government from a developer of internal standards to a customer of external standards. Section 12 of Public Law 104-113, Standards Conformity, states that "… all Federal agencies and departments shall use technical standards (defined as 'performance-based or design-specific technical specifications and related management systems practices') that are developed and adopted by voluntary consensus standards bodies, using such technical standards as a means to carry out policy objectives or activities determined by the agencies and departments." Public Law 104-113 further states that "… Federal agencies and departments shall consult with voluntary, private sector, consensus standards bodies, and shall … participate with such bodies in the development of technical standards."

measurement techniques will add substantially to the development of theory and models appropriate for ATD user applications. Many parts of the modeling process need a variety of data types—for example, wind velocity, temperature, and flux data—so a variety of instrument types and capabilities are needed.

The instrument development process often requires a long lead time: typically a decade or more from prototype development to a fielded system. However, to overcome barriers and shortcomings in ATD modeling and its use within the time frame set by national priorities, this development lead time must be shortened. In both the near term and longer term, the focus should be on developing instruments that, once their capabilities are demonstrated, can be used routinely in the ATD test beds and in special studies of ATD modeling issues. In the near term, the emphasis should be on incorporating and extending existing technologies. Development of a nationwide system, akin to the WSR-88D NEXRAD system, remains a vision for the future.

The current trend toward compact, low-cost units closely networked into distributed systems is an appealing model for ATD instrumentation. An example is a distributed, compact phased-array Doppler radar system that is under development at the University of Massachusetts. Its key advantages are low cost, low maintenance, compact size, and connectivity. These features enable a network to be scaled to appropriate sizes and therefore widely applicable.

New instrument development should focus on the R&D problems identified earlier in this report (e.g., chapter 3 and section 4.3): initial conditions, boundary conditions, closing the modeling gap from microscale to mesoscale, and improving tracer capabilities. Both remote and in situ measurement technologies are likely to be used. The remote technologies may employ active sensors (e.g., radar or lidar) or passive sensing (e.g., radiometric techniques) from platforms on the ground or aloft (carried on aircraft or satellites). One can expect that new system developments will use concurrent advances in digital signal processing to extract data at a high rate and with sufficient resolution. These systems will provide on-board processing and communicate information to the appropriate users—modelers, data assimilators, or emergency responders.

5.5.1 Tracers

Improved tracer capabilities are essential to progress in ATD modeling. Without an effective tracer technology for routine measurement of controlled or otherwise known releases, evaluation of ATD model concentrations—their uncertainty, their time averages, their variance, their intermittency—cannot be achieved. The task of identifying a suitable tracer, as discussed in section 4.3.1, is interwoven with the tasks of developing in situ and remote-sensing capabilities. Tracer selection must consider the measurement capability, as well as the measurement and diffusion properties of the hazards the tracer will represent.

5.5.2 Meteorological Data

The meteorological data of principal interest are in the ABL—the least measured part of the ATD-modeled atmosphere. The ABL is essentially the connecting layer between the large scale flows above it and the land or water surface beneath it. It includes the fine-scale flows affected by surface conditions.

Some near-term gains can be achieved by extending the capabilities of cutting-edge technologies to improve temporal and spatial resolution of wind field measurements. In particular, the capabilities of WSR-88D (NEXRAD) radars to measure winds and retrieve temperature profiles in clear air need to be explored. Doppler LIDAR systems are resolving boundary-layer wind fields and aerosol features within the modeling scale gap. Measurements of boundary-layer height and wind profiles above 100 m are currently available with 915 MHz radar wind profilers at widely scattered locations. Their vertical resolution may be increased by using new techniques under development at NOAA's Environmental Technology Laboratory. However, the spatial variability of the wind profile is poorly captured by these systems. Adding mobility to eye-safe Doppler lidar measurements by placing them on aircraft, as suggested in a National Research Council report (NRC 2003), can expand the capability for area coverage, especially for emergency response to hazardous material ATD. Networking of smaller, more compact systems also promises greater capability.

Measurement of the temperature distributions horizontally and vertically at meso-gamma scales to microscales is important for understanding ABL processes, especially in transitional and stable conditions. The temperature (density) structure governs the buoyancy of the atmosphere. These conditions are particularly important for ATD near the ground because density currents can control local flows even in simple terrain, while momentum and kinetic energy from a low-altitude jet (30–100 m AGL) may also be driving near-surface processes. Horizontal thermal gradients define the urban heat island and drive mesoscale and microscale circulations by differential heating (sea breezes, mountain breezes), which affects local transport and diffusion.

The spatial variability of the temperature field would be a longer-term goal of a coordinated measurement program to support ATD modeling. Currently, most vertical temperature profile measurements are made in situ using balloons or kites to lift the sensors through the ABL. This process is labor-intensive and provides observations representative of only a small part of the atmosphere. Although current remote radiometric measurement techniques can produce local temperature profiles, they resolve the horizontal variability poorly, if at all. In most cases, the measurements using existing instrumentation have insufficient sampling rate and fidelity to compute heat flux profiles. High-resolution remote measurements of temperature profiles in the lowest 200 m of the atmosphere—comparable to in situ measurements on a meteorological tower—would provide major advantages for understanding processes at the surface and in near-surface layers. Raman scattering of selected electromagnetic frequencies is another promising remote-sensing technique still in early stages of development.

For the meteorological component of ATD modeling, atmospheric moisture needs to be measured with precision comparable to that of temperature measurements. Differential absorption lidar systems have been used to measure water vapor along lines of sight and within scan volumes. This technology needs further exploration and, if warranted, development for ATD and other ABL-sensing applications.

Measurement systems of the future need not be confined to the sensor technologies available today. Innovation in design and implementation of sensing systems must be actively encouraged and pursued. The atmosphere affects acoustic and electromagnetic propagation in ways that vary with the frequency of the wave phenomenon and the atmospheric conditions. Just as radar meteorology developed from the observation that clouds interfere with radar detection of aircraft, new sensing technologies for the future require critical thinking now about ways to acquire knowledge of atmospheric state variables from this “noise” in signals propagating through the atmosphere. From this perspective, a program for advancing measurement technology to support ATD modeling is highly dependent upon the sensor development community—in Federal laboratories, small business, industry, and academia—and is not confined to the meteorological community.

5.5.3 Implementation

Many Federal agencies and the National Science Foundation have existing programs to develop research instrumentation related to the atmospheric sciences. The DoD University Research Instrumentation Program provides for purchase of existing equipment or parts to make new sensor systems. Most agencies sponsor SBIR and STTR programs, which can provide substantial funding to move proof-of-concept and prototype systems toward commercial development. Coordinated efforts among the agencies are required to leverage their instrumentation opportunities to support ATD R&D.

5.6 Establish Multiple ATD Test Beds

For the purposes of this report, an ATD test bed is an infrastructure of atmospheric instruments including, as a minimum, an array of tower-mounted meteorological sensors capable of continuous observations. These observations should include not only measurements of the standard meteorological properties but also eddy fluxes of heat, moisture, and momentum. However, the JAG considers the type of test bed installation recommended in this report to be far more than a simple monitoring network. First, the test bed should provide a location and infrastructure to support the short-term deployment of other instrument systems, which could be ground-based, airborne, or satellite-based. Second an ATD test bed must have strategically located remote probing systems to yield wind speed and direction profiles, extending through the planetary boundary layer. Third, the test bed’s instrumentation should be tested and upgraded as developments dictate. Fourth, and most important, the observation data should be routinely scrutinized to improve the understanding of the wind, temperature, tracer, and turbulence fields (both horizontally and vertically) across and above the region encompassed by the test bed. Because of the importance that the JAG attaches to this element of the R&D strategy, a full discussion of several aspects of test bed implementation and operations are included below.

These basic requisites for an ATD test bed derive from the major reasons for implementing and sustaining a test bed infrastructure and operational capabilities. Section 5.6.1 presents the reasons related to meeting R&D needs detailed in chapter 4. Additional reasons for the test bed strategy, presented in section 5.6.2, relate to the critical work of transitioning existing and forthcoming ATD products into operations, as discussed in section 3.3.

While test beds are most often mentioned in connection with cities, an ATD test bed need not be limited to an urban environment. Section 5.6.3 presents the rationale for implementing a number (but not all) of the test beds in urban environments. Section 5.6.4 compiles requirements for effective implementation of multiple test beds, consistent with the strategy proposed here. Finally, section 5.6.5 notes some key management issues that must be addressed, if this strategy is to achieve its potential gains cost-effectively.

5.6.1 R&D to be Supported by ATD Test Beds

As a tool for R&D, test beds enable benchmarking of options for ATD modeling systems and components in specific applications and conditions (the ATD environment of the test bed location). The data from the test bed, whether by itself or supplemented by short-duration intensive studies, can be used to test and refine predictive models. Results from test beds can be used in validating ATD modeling systems and components and as input to decisions on selecting, refining, and extending the modeling system and products to improve their suitability for specific consequence assessment needs. The experimental data from test beds also provide feedback to fundamental research on ATD processes and conceptual model improvement.

As a permanently installed measurement system with supporting infrastructure and resources, a test bed can produce all-season, all-weather, 24-hour quantitative data on local environmental conditions. This capability is critical for broadening ATD modeling system performance evaluations beyond fair weather conditions and for establishing the historical base for ensemble forecasting. For R&D to improve ATD models, instrumentation is needed that can measure concentrations as a function of time and distance from release point (e.g., through use of tracers or surrogates), as well as measuring air transport and diffusion parameters.

Short-term deployments of additional instrument systems at a test bed, to supplement its fixed monitoring infrastructure, are useful both for testing new instrument systems and for advancing the understanding of ATD processes and factors at that location. Short-term deployments of remote-sensing systems, for example, can be used to update databases of surface-land interactions needed for microscale predictions even after the remote-sensing instruments are removed. Land cover, building location and spatial relationships, surface roughness, surface thermal variation, ultraviolet light intensity in open spaces, and urban canyon morphology, as well as other urban characteristics of importance to ATD models, can be derived from remotely sensed data and incorporated into the data infrastructure of the test bed.

After review and discussion, the JAG concluded that the best way to get the data needed to feed better stochastic models is to have test beds where measurements can be made over time, under the full range of meteorological conditions that can occur at a site of interest. Test beds are the best way to produce the measurements and parameterizations needed to characterize uncertainties. They can support R&D on quantifying uncertainty, such as ensemble techniques and Monte Carlo simulations, as well as R&D on probabilistic models (models that incorporate stochastic representations of the physical processes controlling transport and diffusion).

Because of the substantial level of effort and duration of investment needed to sustain not just one but multiple test beds, the benefits this strategy can provide relative to other field study approaches is worth consideration. Among the many merits of this strategy, the following are particularly significant:

- Test beds are necessary to support the long-term measurement of atmospheric processes in urban airsheds and the archiving of the measurement data with associated ATD modeling results.
- A well-instrumented, well-characterized test bed is an excellent tool for testing, evaluating, and incorporating measurement innovations in operational settings. An even better tool is to have multiple test beds, representing a range of complex environments (particularly urban environments), in which the strengths and limitations of various measurement innovations and approaches can be compared across environments.
- Test beds are excellent tools for research on data QA/QC and data assimilation techniques.
    - The permanence of test beds makes them uniquely well suited for R&D to improve the assimilation of surface-based, satellite-based, and airborne remote-sensing data into the mesoscale meteorological models that provide input to ATD modeling systems.
    - The strategy proposed here is consistent with test bed work by NASA and by NOAA on better methods of assimilating satellite data into regional meteorological models (for example, the WRF and Eta models), which are often used to feed ATD models.
- Test beds provide the infrastructure to encourage and support synergy and collaboration among developers working on different system components. (The DCNet installation provides a current example that should be encouraged and expanded.)
- Test beds provide the infrastructure and reproducibility needed to develop and test methodologies for optimizing observational network design in general and design for urban areas in particular. (Section 5.5.3 contains further discussion of optimizing observational networks.)

- A permanent test bed can be used to conduct experiments on "sources of opportunity," such as a benign but detectable emission from a point-source release. For urban environments, these opportunistic field studies can provide a cost-effective and pragmatic complement to planned experiments.

For all of these R&D functions, one needs an instrumented test bed with sufficient density of observations to provide ground truth for comparison with model predictions.

In addition to supporting R&D for ATD modeling, a test bed in an appropriate location can serve other R&D and operational objectives. Its monitoring infrastructure can improve local weather forecasts and nowcasts by characterizing the local variability of temperatures and precipitation. The monitoring network could be used, for example, to determine specific locations within the test bed region where freezing conditions are present, or whether an expected sea breeze front has propagated through the area. A test bed can also provide continuous support to air quality studies (essential nowadays in many urban areas) and provide assistance for emergency response when required.

Thus, the test bed capabilities proposed here can serve purposes other than increased understanding of ATD processes. This multiple use aspect may serve to increase the available funding through cost sharing and to add to the political support for the project. The multiple functions for an ATD test bed—particularly test beds located in densely populated areas—are important for sustaining the long-term (10 years or more) public and political support for the installation, without which the ATD modeling R&D cannot be fully achieved.

5.6.2 The Role of ATD Test Beds in Transitioning New Capability to Operations

Sections 2.6 and 3.3 make the argument that developers of ATD modeling systems must begin taking more responsibility for the successful transition of forecasts and related products into operations. The task of development is not complete until the new capability has been proven useful in operations. The JAG members agreed that test beds are probably the best approach for (1) bringing users into the development process early and (2) providing productive, ongoing interfaces between fundamental research, model development for application, and operational use of developed products. Particularly when located in densely populated regions, test beds provide the following benefits, which complement and support these R&D-relevant objectives:

- Test beds can accelerate user training in real environments.
- Test beds encourage sustained, repeated input and feedback from users.
- Test beds provide developers and governmental funding entities with a powerful tool for leveraging application support across diverse users and user communities.

As an example, test problems can be run at a test bed with users directly involved. The lessons learned from the exercises can be used by researcher-developers to refine the output the model must provide, if it is to meet those users' needs. The refined specifications for the output in turn define the modeling system's input data requirements. At the same time, all of the interactions with users help to educate them about the modeling system's output, including its measures of uncertainty and the implications of those measures for the users' decisions. Thus, the involvement of users in test bed exercises provides a training ground for emergency response personnel who can return to their response/preparedness roles and use the more sophisticated predictive results effectively when the improved products become operational.

5.6.3 Why Test Beds in Cities?

Stated simply, urban test beds are needed because that is where the need for properly performing consequence assessment systems (as defined in chapter 1) is greatest. In our larger urban areas, the population is at risk from increasing levels of hazardous aerosols and gases of many kinds, including urban pollutants that affect air quality. Many of these urban regions are also at risk from point- or line-source releases of CBRN hazards, unintended or deliberate. Test beds established in several cities will provide the data to improve the currently limited capability to forecast the ATD of airborne substances in urban areas, regardless of the substance in question.

As discussed in section 4.2.1, urban environments are complex with respect to factors affecting atmospheric transport. We need to develop and refine the capability to forecast the meteorological conditions of urban areas at the microscale relevant to reliable prediction of concentrations and exposure regimes downwind from source-term releases. The urgency of making progress in this area is intensified by the hard reality (discussed in chapters 3 and 4) that purely deterministic approaches fail to describe the range of possible outcomes necessary for emergency management decision making. This is especially true for environments characterized by deep street canyons, complex building morphology, and other land cover features that influence local wind conditions as much as, or more than, external meteorological conditions affect them. For the reasons discussed in section 4.2.4, coastal urban environments require special attention.

Locating a test bed in an urban area (or in a region of coverage that includes an urban area) also has the potential to leverage diverse interests into sustained support for the test bed. A test bed infrastructure, as well as the data and studies produced using the test bed, can support emergency preparedness planning. Using the test bed for disaster planning and response exercises conducted by municipal or regional authorities increases the developer–user interactions. As noted in the previous section, these interactions feed back into R&D efforts to develop products that are better suited to meet evolving user needs.

However, urban environments (or densely populated regions including suburban areas) are unlikely to provide coverage of all the environments of interest to all the consequence assessment communities described in chapter 2. Military operations, for example, or modeling of industrial accidents located away from population centers (such as transcontinental pipelines, nuclear power facilities, or military facilities) may be better served by an ATD test bed in a non-urban setting. (The special studies discussed in section 5.3 provide an option for covering some of these conditions.) The rationale for having a number of the ATD test beds in cities does not mean that all of them should be urban.

In summary, a number—and probably the majority—of the multiple test beds needed to implement this R&D strategy fully should be installed in high-priority urban regions. For a program of nationwide coverage sufficient for national interests, some of the test bed installations may not cover urban or even suburban regions. The siting decisions should reflect the objective of providing experimental coverage to test ATD modeling capabilities across the full range of environments in the Nation.

5.6.4 Requirements for Effective Test Bed Implementation

Test Bed Site Selection

The proposed ATD test bed strategy includes implementing multiple test beds. The number of installations must be adequate to represent the Nation's diverse environments, particularly urban environments in different meteorological regimes (air-land-water interactions and climatic patterns). For the strategy to be cost-effective, a limited set of ATD test bed sites must be carefully selected, representing the major climatic and meteorological regimes of the Nation.

The previous section explained the importance of siting a number of ATD test beds in urban areas or metropolitan regions. Another siting objective should be to locate several of the test beds in coastal or lakeshore urban locations. Previous studies near ocean coastlines and large lakes have been limited. Thus, an initial task in the test bed strategy will be to weigh these objectives, along with other factors such as the ability to leverage costs with other users, to determine the number and optimal locations for ATD test beds.

Baseline Capabilities of Each Testbed

As discussed above, the ATD infrastructure should aim to support R&D, the transition of products to operations, and local forecasting and air quality monitoring in urban areas. To accomplish these aims, each test bed installation needs the following capabilities:

- Operate and archive data continuously;
- Continually test and evaluate existing analysis techniques;
- Develop techniques for utilization of tracer sources of opportunity;
- Perform periodic, controlled tracer experiments in both simple and complex meteorological conditions; and
- Test and evaluate new measurement technologies and tracers.

Each test bed in the program must have adequate base instrumentation. There should be a baseline of instrumentation common to all the ATD test beds, to ensure that comparisons can be made across the different environments they cover. The lessons learned from one test bed installation should be used to optimize the installation of those that follow.

Involvement of User Communities

In line with the arguments for user involvement made in section 5.6.2, potential user communities for the test bed should be involved in installation planning from its early stages.

Long-Term Resource Commitment

Perhaps the most difficult requirement to fulfill—and one that must be addressed as part of the site selection process—is the provision of sufficient long-term funding to sustain implementation and operations over an extended period. For some of the R&D needs specified in chapter 4, a decade or more will be required to achieve the longer term results that the JAG has envisioned. The decision to proceed with a test bed program should be with full recognition of the commitment necessary to reap the potential return on investment. Periodic review and evaluation of R&D projects must be built into the test bed management approach to ensure that progress is being made and that the envisioned outcomes are still supportable.

Short-Term Gains

At the same time that many substantial results will come only from long-term efforts sustained over years, there will be valuable interim results and products from the test beds. One short-term gain will be the evaluation and comparison of alternative ATD modeling systems (and system component options deployed within one overall modeling system) under comparable conditions. Testing across multiple, comparably instrumented sites is essential for the ultimate goal of compiling a set of models fully evaluated for a defined set of scenarios. Appropriate selection of a model from this evaluated set can then be made for any of a wide range of applications important to users. The near-term results from evaluation of existing modeling capabilities will establish criteria for deciding what further R&D should be done for modeling and measurement systems and methods.

Partnering to Provide Sustained Support and Direction

Stable, long-term resource allocations from a single Federal agency or program are difficult to sustain over multiple years of budget appropriations and administration priorities without strong partnerships from within and outside the Federal sector. Partnering is also essential to ensure that users' needs at the local and regional levels continue to guide and inform each test bed's projects. The test bed program at the Federal level should provide mechanisms to involve state and local public entities as partners with Federal funding agencies, as well as engaging the academic R&D community. Public-private partnerships with mutually consistent long-term objectives should be encouraged.

Coordination across Test Bed Installations

The ATD test bed implementation program should require coordination across test bed installations to ensure that data are sharable and accessible. This coordination should include cross-installation activities and standards for data archiving, data access, and technical support to data users. There should also be coordination, where appropriate, with other atmospheric modeling efforts, including physical model facilities, modeling test beds for meteorological models, and air quality monitoring test beds for atmospheric chemistry and other air quality factors beyond transport and diffusion.

5.6.5 Test Bed Management Issues

This report does not recommend a particular management approach for ATD test beds. Implementing agencies and their partners will need to make decisions on a management structure based on a range of factors, many of which are beyond the scope of this report. However, there are some issues and concerns related to the program objectives presented in sections 5.6.1 through 5.6.4 that the selected management approach must be capable of handling.

For the proposed ATD test bed implementation strategy to be effective, long-term planning and continuity of direction are essential. The strategy also requires channels for communicating upcoming possibilities for collaboration and leveraging among interested parties on studies, test and evaluation programs, and operational training and exercises. One approach that is worth considering is to have a single executive director for a test bed installation (e.g., a test city), who would have a scientific/technical policy board for advice. However, the executive director would retain decision authority and responsibility for a coherent, productive, and sustainable program covering research, development, testing, and evaluation.

Program coordination and funding of test bed oversight functions by participating agencies could use any of several established mechanisms, such as competitive proposal solicitations. Existing contracting capabilities in the lead agency should be used as appropriate.

5.7 Plan and Conduct Special Studies and Experiments

In addition to a set of long-term test bed installations, special studies and experiments will be useful for particular purposes. These special studies would be field campaigns rather than sustained activities. A special study could be motivated by the requirement to address a specific, isolatable physical process, such as deposition or resuspension. It could be designed to explore transport and diffusion in a unique yet consequential environment, such as high-altitude droplet dispersion. Another rationale for a study could be to extend the utility of past field experiments (captured through the program element discussed in section 5.3) by relating historical data to current methodologies and instrument capabilities. A study could also be designed to extend recent test bed results to a broader range of conditions not covered by the set of operational test beds.

One example of an important physical process to be studied on a special basis is the resuspension of hazardous materials once they have deposited on surfaces through settling, precipitation scavenging, or sorption to local materials. Deposited aerosol particles may be resuspended by the direct action of the wind or by abrasion of the surface (by other particles, foot traffic, vehicles, surface treatment, and so on). Deposited chemical species that sorb to local particles may also be resuspended. Because resuspension depends on a suite of complex factors, including the particle and surface morphology, specific chemistry, and local fluid mechanical effects, resuspension models tend to be highly parameterized. In the absence of surface disturbance, resuspension rates decrease with time, hence resuspension is of greatest concern in the following cases:

- In the immediate short term after deposition;
- For highly toxic materials, where small resuspension rates could pose grave concern; or
- Where surfaces are likely to be disturbed, as during clean-up operations, normal urban operations, or large fluctuations in meteorological conditions such as a surface freeze followed by a quick thaw.

When winds shift, resuspension can lead to a secondary plume and deposition pattern. Studies are needed to explore and quantify the following issues: (1) What is the effect of changing meteorological conditions on resuspension, including wind gusts and temperature effects? (2) How can we best model urban and vehicular resuspension? (3) For disturbed conditions, on what time scale can surfaces be considered sufficiently clean? (4) When do sorbed chemical species resuspend, and are “dust flux” models sufficient to describe these effects? Resuspension can be studied in field experiments through secondary collections of the released species, after initial plume passage.

Special studies are also warranted for unique yet pertinent situations, such as high altitude releases, which have the potential to impact large populations. Field testing of a high altitude release would contribute to a better overall understanding of the risk and consequence associated with missile defense—an important national and homeland security topic. Previous studies of high altitude releases such as Cristal Mist (Diehl 1994; Kaman Sciences Corp. 1996) identified the importance of various high altitude processes, such as clear air turbulence, for predicting ATD and deposition. However, recent technological advances in remote-sensing and monitoring tools, notably lidar, could significantly improve upon earlier efforts. A carefully monitored and controlled meteorological study where stable droplets and/or particles are released at high altitude could be used to validate parameterizations of important processes associated with high altitude meteorology and dispersion. A possible field experiment would include the release of droplets/particles of different size (10 microns to 1 mm) and at different altitudes (above 1 km, above 10 km, above 20 km). The released droplets/particles could be carefully tracked and recorded as they settle and deposit over a large area. Depending on the altitude of release and droplet/particle size, the monitored area could be very large—potentially hundreds of square kilometers.

Repeating conditions of selected classic studies, but with new measurement technologies used alongside the old technologies, can increase the value of the old data sets by enabling cross-test comparability and longitudinal studies. Early field experiments were conducted within the then-available tracer and measurement technologies and with particular objectives. Results from these studies were used to develop, improve, or confirm ATD modeling assumptions and parameterizations. Recent significant advances in those capabilities offer the opportunity to revisit the classical field studies and evaluate and improve the parameterizations formulated in the classical arena. Reductions in uncertainty of models by the infusion of new technology can be quantified. Improved understanding of the earlier results may be possible. As an example, a large number of dispersion tests were conducted at Hanford, Washington, with zinc sulfide tracer particles, which have a high deposition rate. Comparative tests could enable data mining for the effects of deposition on the initial data and interpretation of field results (Doran and Horst 1985). In addition, certain meteorological parameters now understood to be crucial to transport and diffusion prediction, like surface heat flux and boundary-layer height, were not always documented in classic field studies. The results from the classic studies must be interpreted with estimates of these important parameters, introducing more variability and uncertainty than is necessary. If modern instrumentation and methods could be applied to the classic problems, a more complete set of measurements would result. This would provide a basis for improved characterization of transport and diffusion effects.

With respect to coverage of special situations, a permanent test bed facility cannot be established for every set of conditions of interest. The gaps can be filled in with one-time experiments that provide a basis for interpolating and/or extrapolating from test bed results and old data sets. Special studies and experiments can also focus on the roles of particular physical processes to improve process-specific parameterizations.

Test beds cannot cover all of the many challenges of ATD models. While urban domains are emphasized in this report, field campaigns in different circumstances will be needed to assess the multiscale properties of transport and diffusion. Some special studies may address terrain-driven and urban-driven flows, like the Department of Energy's Vertical Transport and Mixing (VTMX) field study in 2000. Even after the initial study, the complex flows affecting lateral and vertical mixing in a stably stratified basin were not resolved. One conclusion of that study was the necessity for more temporally and spatially complete measurement of the sub-basin-scale motions near the ground and aloft.

One purpose of test beds is for routine, day-by-day investigations of ATD modeling capability and evaluation. On occasion, special one-of-a-kind studies will be needed to address particularly difficult modeling performance issues. Within the framework of a test bed, additional instrumentation may supplement the test bed's usual instrumentation suite to conduct a major field campaign. Such studies would be based on specific science objectives.

Special studies can also be used outside the framework of the established test bed installations to address specific questions and issues. The greater understanding gained from a carefully designed special study could advance the theory and practice of atmospheric modeling. As an example, many individual field programs have examined components of the diurnal cycle for modeling mesoscale features. This field study produced a set of insightful science questions and issues, which are summarized in the following list, developed at the VTMX workshop in September 2002.

Issue 1. The performance of mesoscale numerical models in describing the wind, temperature, and turbulent structure of the valley atmosphere was mixed.

- Basic flow patterns and temperature fields were captured, but …
  - the timing of important events (e.g., flow reversals) was often off by one or more hours, and
  - details of the flows over certain segments of the valley were in error (e.g., jet structure, flow strength).
- The vertical temperature structure showed persistent biases, which are not yet understood.
- The agreement between modeled and observed turbulent heat fluxes and turbulent kinetic energy was unsatisfactory.

Issue 2. Aspects of radiational heating and cooling in valleys do not seem to be adequately accounted for in numerical models. For example, extreme cooling is observed in sinkholes.

- Can this behavior be explained and modeled?
- How relevant is this phenomenon to larger-scale valleys and basins?

Issue 3. Wavelike features and ascending or descending layers of air were common along the side walls and may be common elsewhere. Their significance for vertical transport and mixing is unclear.

- What is actually happening during these events?
- What causes them?
- Is there any hope that they can be modeled or predicted?
- Does it matter?

Issue 4. LES and DNS look promising, but can they deliver useful improvements in parameterizations for mesoscale models?

- How can we generalize from highly idealized modeling conditions to the real world?
- What insights into the basic physics of stable atmospheres can be gained?

This list does not exhaust all of the questions and issues that special studies could address, but it does reflect current questions, results, and issues that have arisen in the context of the VTMX program and other recent field studies.