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Air quality and Meteorological Monitoring Strategies in support of Operational Air Quality Forecasting and the Global Earth Observation System: Recommendations to the US EPA

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1. INTRODUCTION

Recently, the US EPA has sought expert advice regarding its future participation in the Global Earth Observation System of Systems (GEOSS) initiative. A panel was convened in mid-March, and a report has been developed. Among a list of recommendations--which the authors describe in a companion paper in this conference (Dabberdt and McHenry, 2004a)--the panel suggested that EPA can assist the GEOSS by providing expertise in operational air quality forecasting.

Toward this end, a second set of recommendations is being developed for EPA. These recommendations are drawing not only from the GEOSS panel report but from other sources, including the US Weather Research Program (USWRP) Prospectus Development Team (PDT-11) meeting held in 2002 (Dabberdt et al., 2004a), a follow-on USWRP workshop convening air quality forecasting expertise held in June, 2003 (Dabberdt et al., 2004b), and the NOAA/EPA plan for operational air quality forecasting (Davidson, 2003).

These recommendations are focusing on particular expertise that EPA has gained through its ability to monitor and quantify trace and criteria pollutants near the earth's surface, and ways these technologies can be used to enhance the observational and model data-assimilation needs of future numerical air quality prediction systems.

In this conference, we present a high-level summary of the background for these recommendations and a follow-on discussion. This summary and follow-on do not represent the final recommendations contained in the report, as these were still in preparation at press time for this paper.

2. USWRP Background

2.1 PDT-11 Background

PDT-11 identified three crucial areas requiring improved physical understanding in order to support advancements in forecasting the quality of the air. These areas were (1) the planetary layer and coupled land-surface; (2) meteorology of the urban zone; and (3) clouds and cloud processes.

Because the height of the mixed layer is so important for air quality forecasts, the PDT-11 panel felt that *the lack of a nationwide network that routinely monitors the diurnal variation of the height and structure of the PBL was a severe constraint* on our current ability to make progress. This problem makes it extremely difficult to evaluate and improve predictive models. Further, enhancing the ability to numerically model boundary layer structure—the PDT-11 concluded—will require comprehensive observational studies including both intensive short-term programs and extended long-term monitoring, while simultaneously linking the PBL observations to corresponding observations of air quality and chemistry.

Extending their thinking toward the urban environment, the PDT-11 recognized that the urban zone is a special case of the more general problem currently restraining more complete PBL understanding. Moreover, because the urban energy balance is strongly modulated by anthropogenic influences, each urban environment, in essence, presents a special case. Thus, some component of the proposed nationwide PBL measurement network should be deployed within urban environments.

Thirdly, the PDT-11 recognized both a lack of in-depth understanding of clouds and their significant and complex effect on air quality. Radiatively, they block or reduce solar intensity, causing both changes in the surface energy balance and changes in the actinic flux that drives photoreactivity. Further, cloud microphysical processes are influenced by chemical composition, and in turn they affect the exchange of pollutants between the liquid and ice hydrometeors and the surrounding environment. Clouds transport and interact with aerosols produced within the PBL; they also process and alter aerosol composition, mass, and size distribution. Accurate prediction of cloud characteristics requires, at a minimum, an accurate

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Table 2.1 Observational/Measurement Recommendations from the USWRP PDT-11

Theme	*Recommendations*
PBL and Mixed-Layer Observation	• Use a nationwide observing network to routinely monitor (with high resolution) the diurnal variation of the height and structure of the PBL.
Land-Surface Characterization	• Improve AQ forecast accuracy by requiring better plant speciation data in vegetation and land-use databases.
Clouds and Cloud Processes	• Create field programs to study cloud formation and microphysics in large urban areas, over a variety of latitudes, topography, and chemistry.
Assimilation Tools	• Integrate observational network and model design to ensure that the scale of representativeness of surface flux data matches the scale of model resolution.
Observations and Measurements	• The use of tethered sondes and commercial communication tower facilities should be considered so that chemical and meteorological data can be obtained at several heights above the surface. • Develop instruments that observe turbulence, PBL structure, and surface forcing parameters with better detection limits and higher-resolution measausements. • Observe both the lowest portions of the nocturnal PBL and the upper reaches of the capping stable layer with sufficient height resolution and temporal continuity; emerging multifrequency UHF profiler technology should be explored. • Install a network of sites with sufficient density in the horizontal and with towers and/or remote-sensing options to obtain vertical data for air quality model evaluation. The network should be operated long enough to allow the study of seasonal or annual variability.

assessment of surface energy fluxes and the PBL, cloud microphysics, local convergence zones and outflow boundaries, and large-scale forcing including frontal systems and the accurate depiction of stagnant or progressive surface high pressure systems. Thus, PDT-11 recognized the need for field measurement campaigns that study processes governing cloud formation and microphysics, particularly in large urban areas.

PDT-11 also identified the need for improved capabilities for estimating uncertainty and predictability, and for evaluating models. For example, uncertainties in the model's initial state, emissions, deposition rates, and boundary values must be considered. Further, imperfectly represented feedbacks between the meteorological and air quality components also contribute to uncertainty. Thus, the utilization of atmospheric-chemical models – a-la NWP – to characterize the three and four-dimensional chemical state of the atmosphere must be a priority. This implies the development of chemical data-assimilation capabilities, including optimal interpolation, variational data-assimilation, and Kalman filters.

Since these capabilities are dependent upon observations being available, the PDT-11 returned to its first theme, suggesting that more extensive measurements are essential. **Table 2.1** summarizes the observational, measurement, and monitoring recommendations made by PDT-11.

2.2 AQF Workshop

Following the PDT-11 meeting, a follow-up workshop on Air Quality Forecasting (Dabberdt et al., 2004b) was held in April of 2003 in Houston, Texas. The charge to this follow-up workshop from the USWRP lead scientist asked that the fifty-invited workshop participants identify and delineate critical meteorological issues related to the prediction of air quality.

Table 2.2 below summarizes the recommendations pertaining to observations, measurements, and monitoring that emerged from the AQF workshop. Note that the first five themes are essentially equivalent to the themes emerging from PDT-11, with a sixth theme recommending the establishment of regional testbeds. There is signficant overlap between and among the recommendations listed in Tables 2.1 and 2.2. There is a call for improved observation of the PBL emerging clearly from both USWRP activities. These improvements include both a routine national capability along with improved vertical resolution to include chemistry, while exploiting pre-existing infrastructure where possible.

The USWRP recognizes that data-assimilation will be essential for improving numerical air quality prediction (NAQP, McHenry, et al., 2004) systems. Some of the “nuts” and “bolts” of the proposed new measurement capability is articulated across workshops, including ideas that encompass both meteorological *and* chemical parameters.

Table 2.2 Observational/Measurement Recommendations from the USWRP Air Quality Forecasting Workshop

Theme	*Recommendations*
Boundary-Layer Structure and Modeling	• Develop new meteorological instruments/techniques for volumetric sampling of the PBL
Surface-Atmosphere Interface and Emissions	• Develop high-resolution emission inventories for aerosols and aerosol precursors • Develop high-resolution methods to estimate emission rates • Strengthen emission inventory methods, both top-down and bottom-up
Clouds and Aerosol Microphysics	• Conduct field studies of aerosol-cloud interactions
Data Assimilation	• Develop methods for assimilating new PBL meteorological measurements • Develop and test DA techniques for gases and particulates for designing optimal measurement networks
Instrumentation and Measurements	• Develop new meteorological instruments/techniques for volumetric sampling of PBL • Develop methods for assimilating new PBL meteorological measurements • Specifiy method for routine CCN measurements in urban areas • Develop an aerosol-sonde • Develop low-cost, easily deployable techniques for real-time aerosol characterization • Explore innovative approaches to upper-air chemistry measurements • Design optimal monitoring networks for gases, PM, and UV radiance • Develop improved vertical profiling methods for O3 and aerosols • Improve methods for using satellite chemical measurements • Develop ACARS-like system for chemical and PM measurements
Establish Regional Air Quality Testbeds	• Conduct field studies or aerosol cloud interactions • Specify method for routine CCN measurements in urban areas • Deploy high-density surface sampling networks for chemical and physical properties of aerosols and gases.

Table 2.2 (continued)

3. THE EPA GEOSS PANEL (EGP)

On March 9-10, 2004, the U.S. Environmental Protection Agency (EPA) convened a panel of 14 experts in Research Triangle Park, NC, to discuss and make recommendations pertaining to the proposed GEOSS. The specific charge to the panel was to provide EPA with expert recommendations and guidance concerning opportunities for EPA's participation in GEOSS. Because GEOSS is fundamentally an observation "system of systems", EPA's role in GEOSS is expected to be synergistic with its growing commitment to air quality forecasting.

The GEOSS panel identified capability that will be needed for GEOSS and for which EPA can provide leadership. These areas include, not surprisingly, all of the major USWRP themes noted above with more or less emphasis. About equal emphasis was placed on data-assimilation, with somewhat more emphasis on the land-surface, including biogenic and anthropogenic emissions. Less emphasis was placed on observing clouds and aerosol microphysics, but special attention was paid to both satellite remote-sensing and to urban challenges. Finally, the need for improved PBL observation was considered within the EGP discussion on measurements and sampling (Dabberdt and McHenry, 2004b).

The EGP's overall recommendations related to measurement, monitoring, and observation are listed below. Though these recommendations were made for GEOSS specifically, they apply generally to the air quality forecasting methods needed for the continental US.

- A focused effort is needed to design and establish multisensor 3-D measurement networks and observing strategies for air chemistry, meteorology, and surface characteristics (bootstrapping on existing meteorological measurement networks)

- Additional effort is required to improve the use of current and future satellite data for air quality forecasting, dynamic emission inventories, and surface characterization

- Urban air quality forecasting should receive special emphasis, especially urban needs pertaining to sub-grid scale processes and variability

- Testbeds are a critical component in the development of a successful program and the transfer of technology from research to operations; EPA has much relevant experience and should take a leading role

4. TESTBEDS

As an organizing principle for their recommendations to EPA, the EGP extended and enhanced the *testbed concept* articulated in the previous USWRP findings. Testbeds provide a means to establish continuously functioning resource systems—measurements, forecast models, data-archival, and data access—that enable refinement and system optimization prior to full (national) deployment.

Regional air quality testbeds offer the opportunity for deployment of integrated monitoring technologies while leveraging off of existing networks. Ideally, such testbeds would be limited in scope but “nested” within an intentionally integrated national array of multisensor real-time datastreams, many of which currently exist but are applied to specialized problems separate from the larger issue of air quality forecasting.

A testbed is seen as a facility that enables and expedites the development of observational, modeling, and dissemination methods and their transfer from research to operations. As such, it is a system that is established for evaluating the components of modeling and observing systems (instruments, sensors, locations of sensors, NAQP and data assimilation models, data communication, etc.), the configuration of the observing systems, the data quality methods, end-user applications, and data and forecast-product dissemination methods.

The EGP noted that a testbed is a device for effecting the achievement of GEOSS goals, thereby providing a proof-of-concept for GEOSS tools, mechanisms, and relationships. This can be directly applied to US national air quality forecasting. Testbeds can be for the short term, but the main emphasis here is for longer-term maintenance of such a system to provide for establishing baseline configurations, and for homogeneity and continuity of products from future systems. Data management for these systems is critical for successful utilization. In principle, testbeds can cover various spatial scales (e.g., urban, global) and include all aspects of observing, data transfer, processing, analysis, assimilation, modeling, and distribution of data and products.

These technologies would address the following *observational themes* that repeatedly appear in the three expert reports:

- The Planetary Boundary Layer
- The Land-Surface and its relationship to the atmosphere, to biogenic emissions, and to ecosystem feedbacks
- Anthropogenic Emissions
- Clouds and Aerosols
- Data-Assimilation
- The Urban Environment

A host of existing and planned, in-situ and remote-sensing technologies have been proposed as described above to address the observational need. In this section specific recommendations are made to EPA with regard to establishing such a testbed or testbeds and their observational and monitoring components.

Recommendations Concerning Testbeds. The EGP recommended that EPA, in the context of GEOSS, promote and lead the establishment of testbeds, and cooperate with other agencies in operating and maintaining them. The number and scale of the testbeds need to be chosen using modeling tools and considering the range of key GEOSS and EPA applications. Further, EPA should seek to take on a leading role in developing testbed requirements, configurations, and evaluation criteria. *As a minimum requirement, both an urban-scale and a rural-scale testbed should be developed.* EPA should take the lead in establishing the urban testbed(s). The rural testbed(s), on the other hand, should be established jointly, considering the needs of multiple agencies and the location of existing networks and coverage of satellite and radar. Coordination of this effort needs to be established and priorities determined.

Actions emerging from the EGP that are required in developing effective testbeds include the bulleted items that follow. Those colored in yellow are directly related to measurement and monitoring. Those colored in blue rely on measurement and monitoring capacity, but do not represent that capacity itself.

- Develop methods and strategies for determining optimal 3-D measurement-network configurations for both chemical and meteorological variables (one approach is to over-sample with the testbed and evaluate design strategies, such as data denial experiments).

- Test alternative sampling strategies (e.g., adaptive sampling; aircraft vs. balloon soundings vs. remote sensing-based mobile sampling strategies using public vehicles or commercial vehicles).

- Test data assimilation methods (including network design applications).

- Test new instruments and measurement systems (e.g., low-resolution aircraft AQ soundings vs. high-resolution balloon soundings vs. continuous, high-resolution remotely sensed profiles), both for chemical (gases and particles) and supporting meteorological measurements.

- Test data communications, telemetry strategies (e.g., Internet vs. GPRS [General Packet Radio Service] cell phone vs. dedicated network) and common formats and protocols.

- Test alternative "business models" for acquiring and maintaining measurement, communications, and database systems, for providing forecasts and other services, and for distributing data to intermediate and end users; in other words, use the testbed to determine how to make the system financially viable.

- Evaluate various strategies for domestic applications and for international applications in developing, third-world countries.

- Explore synergies with other applications, such as emergency response, weather forecasting, and public information.

- Contribute to model development, evaluation, and data analysis methods, and to development and testing of new and improved data assimilation models.

- Test alternatives for capacity building, e.g., training, education, documentation.

- Provide opportunity for science investigations and quality data sets for "exploratory" science questions.

- Develop and test effective means for disseminating to end users various air quality and other environmental data, including forecast products.

- Create mechanisms for establishing effective relationships among the public, private, and academic sectors.

5. DISCUSSION

At press time, the final set of recommendations to EPA for air quality and meteorological monitoring strategies in support of operational air quality forecasting and the Global Earth Observation System of Systems is undergoing review and final acceptance by the Agency. This review follows an internal panel meeting on 2 November, 2004. Concepts for testbeds, drawn from the above resources and Agency experience, under discussion at that meeting included:

- improve and test chemical data assimilation methods
- develop and assess chemical and meteorological observing strategies
- test improved chem. and particulate sampling systems
- mixing layer observing strategies/methods
- cloud processes and observing strategies (e.g. dual-pol radar obs.)
- top-down emissions estimates
- wildfire emissions of VOC, CO, NO and particulates
- biogenic emissions and flux sites
- land surface properties and models type, resolution and performance of urban canopy models
- model evaluation criteria
- database management and information system
- collaboration with other agencies (e.g. NASA, NOAA, DHS)
- role of academia and private sector
- number/location of testbeds

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