Air Quality Forecasting

A Review of Federal Programs and Research Needs

Air Quality Research Subcommittee
of the
Committee on Environment and Natural Resources
CENR

June 2001

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The September and October 2000 meetings of the Air Quality Research Subcommittee of the Committee on the Environment and Natural Resources (CENR) focused on a discussion of federal programs related to air quality forecasting. This report provides a brief summary of the current state of science as discussed at these meetings, with some additional material that was not presented at the meetings due to time constraints. A complete and comprehensive review of the science related to air quality forecasting is clearly beyond the scope of this report. Rather, the report provides a brief overview of the science, identifying key knowledge and capability gaps, and is intended as an information piece to guide the development of future federal research programs relative to air quality forecasting. This report is a scientific and programmatic document, as the preceding Subcommittee reports have been, and it is not intended to represent governmental policy.

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1.0 Introduction

Air quality in the United States has improved dramatically in the three decades since the Clean Air Act was first promulgated. It is a measure of the Nation's commitment to clean air that these gains came during a period of considerable growth (the population increased by more than a third and the Nation's Gross Domestic Product increased by almost a factor of ten) when air pollution would be expected to increase. However, there is more work to be done. Air pollution is still a widespread problem in the United States, with over 100 million individuals in 114 different areas exposed to levels of air pollution that exceed one or more health-based ambient standards [U.S. EPA, 2000].

A recent study sponsored by the Health Effects Institute [Kaiser, 2000] estimates that exposure to high levels of particulate matter alone is responsible for more than 60,000 deaths each year in the United States. Haze from car and truck emissions, industrial pollution, and wildfires obscures some of the most dramatic vistas in the country and can pose a substantial hazard[1].

Air pollution places a very real economic burden on the country. The American Lung Association estimated [Cannon, 1990] that air pollution related illness costs approximately $100 billion dollars (1988 dollars) each year in the United States. High levels of ozone can reduce the yields of economically important agricultural crops. These losses have been estimated [Adams *et al*., 1989] to be $1.7 billion dollars (1980 dollars) each year.

1.1 The Need for Air Quality Forecasts

A system for forecasting future air quality cannot, by itself, solve the problems described above. Forecasts, if they are reliable and sufficiently accurate, can however play an important role as part of an air quality management system working in concert with more traditional emissions-based approaches. The applications of air quality forecasts fall into the following broad areas:

- <u>*Health Alerts*</u> – Many cities currently provide warnings to the public when air pollution levels exceed specified levels. The more reliable the forecast is the more effective it is. These warnings are directed at specific populations that are particularly sensitive to air pollution (e.g., asthmatics). Interest in finding innovative ways to protect these individuals has heightened in recognition of

[1] In 1997, thick smoke from regional forest fires in Southeast Asia were blamed for the Garuda Airlines Airbus crash near Sumatra, and the collision of two ships in the Strait of Malacca. A total of 263 were killed.

lack of a discernable health threshold for exposure to ozone or fine particles, which implies that no level of emissions reduction will protect all individuals.

- *Supplementing Existing Emission Control Programs* – In many parts of the country, the air quality standards are exceeded only infrequently, a few days out of the year. The availability of reliable air pollution forecasts affords local environmental regulators the option of "on demand" or intermittent emission reductions on those days, thus avoiding the high cost of continuous emission control. This approach is currently being successfully employed in several areas of the country and could be expanded were reliable forecasts available. Many cities also offer free access to public transportation on "ozone alert" days to reduce automobile emissions. The accuracy of these forecasts is critical due to the high cost associated with these programs.

- *Operational planning* – Regional haze can impair and even endanger activities such as private and commercial aviation. Aerial photography and visits to many National Parks are significantly impacted by the presence of haze. A reliable visibility forecast could improve safety and efficiency by permitting the scheduling of these activities during the most favorable periods. The U.S. Forest Service (U.S.F.S.) is planning a 10-fold increase in prescribed burns. Since these activities are regulated under the Clean Air Act, the U.S.F.S. will have to demonstrate to local regulators that they can schedule these burns so that no National Ambient Air Quality Standards will be violated, requiring some form of air quality forecast.

- *Emergency response* – Wildfires consumed more than 4 million acres of forest in the United States during 2000. The vast amount of smoke generated by these burning forests affects the visibility in the area that can cause accidents, increase traffic congestion and even jeopardize aviation safety. The availability of reliable smoke forecasts offers rerouting options for automobiles and air traffic to reduce the possibility of accidents. The information provided by these forecasts can also provide an initial assessment of the impact of these wildfires.

1.2 Air Quality Forecasting Techniques

A wide variety of techniques, ranging from the simple to the complex, have been used to produce air quality forecasts. To date, most of these efforts have focused on producing 1- to 3-day ozone forecasts. The techniques that have been used to produce these forecasts are described in a recent report [U.S. EPA, 1999]. The techniques used to forecast ozone concentrations are representative of those that can, or could, be used for other pollutants. They fall into three broad categories:

Climatology – The use of climatology to predict air quality is based on the assumption that the past is a good predictor of the future. This approach relies on the association of elevated pollution levels with specific meteorological conditions. The application can be as simple as assuming persistence (i.e., if pollution levels are high today they will also be high tomorrow) or can involve the development of complex weather typing schemes (i.e., identifying recurring weather patterns that are accompanied by high pollution levels) to forecast air quality. These approaches are usually used to predict exceedances of specific thresholds not ambient concentrations. These approaches do, however, have the advantage of being reasonably simple and inexpensive to implement and operate.

Statistical Methods – The association between specific meteorological parameters and air quality can be quantified using a variety of statistical techniques. In fact, these are probably the most common techniques in use for ozone forecasting. In their survey, *EPA, 1999* has identified three statistical approaches that are in use:

- Classification and Regression Tree (CART) – This technique uses specialized software to identify those variables (meteorological or air quality) that are most strongly correlated with ambient pollution levels. These variables are then used to predict future pollution levels based on current air quality and forecasted meteorology.

- Regression analysis – The association between pollutant levels and meteorological and aerometric variables can be quantified by analyzing historical data sets using standard statistical analysis packages. The resultant multi-variant linear regression equation can be used to forecast future pollution levels.

- Artificial Neural Networks – Another way of analyzing historical data is to identify atmospheric parameters that influence air quality and quantify that association through the application of adaptive learning and pattern recognition techniques, such as neural networks. Neural networks are intended to mimic the way the human brain recognizes recurring patterns. Networks have been developed that identify weather patterns that are associated with elevated ozone levels (see U. S. EPA, 1999 and references therein). Presumably, the same technique could be applied to other pollutants.

These approaches, while more complex than the ones discussed in the previous group, are reasonably simple to develop and use, requiring only modest computing resources and specialized knowledge.

Three Dimensional (3-D) Models – Although the techniques described above have many strong points, they have a common weakness. They assume a certain amount of stability in terms of the processes that affect air quality. Any change in emissions or climate (short and long-term) will serve to diminish the skill of these techniques. One way around this problem is to employ a more deterministic approach to the prediction of air quality. Deterministic 3-D air quality models seek to mathematically represent all of the important processes that affect ambient pollution levels. These models are actually comprised of several submodels that work together to simulate the emission, transport, and transformation of air pollution. Examples of submodels include:

- Emissions models – These models simulate the time-dependent, spatially-distributed emissions of the pollutant in question, and/or (in the case of secondary pollutants such as O_3) its precursors, from both anthropogenic and natural sources.

- Meteorological models – These models forecast meteorological conditions that determine transport and mixing and influence chemistry (solar intensity, temperature, humidity, etc.), emissions (e.g. temperature), and deposition. Trajectory models use the 3-D meteorology from these models in consort with emissions data to forecast ambient levels of reasonably unreactive pollutants like dust and smoke.

- Chemical models – These models use fundamental chemical kinetic rate parameters, spectroscopic properties, and thermodynamic relationships to simulate the transformation of primary (emitted) pollution into secondary pollution, including the composition and morphology (size distribution and optical properties) of aerosols.

Three-dimensional air quality models are classified as being either Lagrangian or Eulerian depending on the method used to simulate the time-dependent distribution of pollution concentrations. Lagrangian models follow individual air parcels over time using the meteorological field to advect and disperse the pollutants. This approach results in a computationally efficient system. However, it is difficult to properly characterize the interaction of a large number of individual sources when nonlinear chemistry is involved. Eulerian models use fixed grids (vertically and horizontally) and solve the appropriate chemical equations simultaneously in all cells, including exchange of pollutants between cells. Typically the computational requirements are reduced through the use of nested grids, with a coarse grid used over rural areas (where concentrations tend to be reasonably homogenous) and a finer grid used over urban areas (where concentration gradients tend to be more pronounced). These models can also accommodate a plume-in-grid treatment by performing a semi-Lagrangian calculation for large point sources (e.g., power plants) during the early stages of plume dilution. These models can produce three-dimensional concentration fields for several pollutants but require significant computational power and expertise.

Virtually all of the techniques described above start with a meteorological forecast. Therefore, the reliability of the air quality forecast is dependent on the reliability of the weather forecast. Weather forecasters use a number of tools to predict tomorrow's weather. Local forecasters will typically use the output from several different models in combination with local knowledge and experience to produce an accurate forecast. The same must be true for an air pollution forecast. A skilled forecaster will combine several of the techniques described above to ensure that the prediction is as accurate as possible.

1.3 Elements of an Air Quality Forecasting System

As with a weather forecasting system, an air quality forecasting system must contain a compatible combination of two components. These components are a suite of predictive models/techniques tailored to specific needs of the customer community and an observation network capable of providing real-time measurements of atmospheric composition needed to initialize the models and evaluate the quality of the forecast.

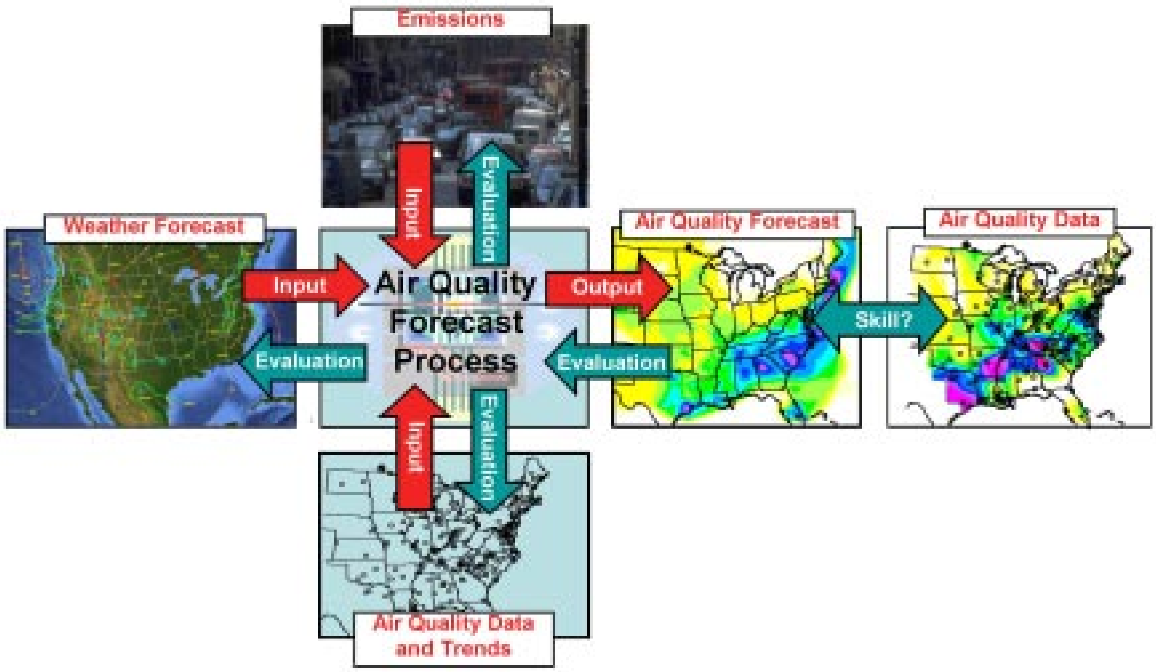

Fig 1.1 Schematic showing the interrelation among the main elements of an air quality forecasting system. A well designed forecast system includes both a process for producing the forecast and an observing system to evaluate the quality of the forecast and identify areas where improvement is needed.

A comprehensive observing system must be an integral part of any forecast system that is developed to predict future air quality. It is only by comparing actual and forecast pollution levels that we can assign confidence to future forecasts and identify areas where improvements are needed.

Traditionally the evaluation of air quality models (whatever their form) has fallen into two broad categories:

- ***Operational evaluation –*** An operational evaluation involves a direct comparison between the forecast pollutant fields and the observed pollutant distribution. For example, in the case of ozone the model predictions would be compared against the concentrations measured in the regulatory network, and some skill score calculated based on a point-by-point comparison at the monitoring sites. The existing regulatory network for ozone is well suited to such an evaluation. Unfortunately the situation for other pollutants (e.g., fine particles) is not as good since those monitoring networks are less dense and the instruments not as sensitive, or in some cases as selective, as is desired.

- ***Diagnostic evaluation* –** An operational evaluation will tell you how close the model came to the correct answer; a diagnostic evaluation will tell you if you got the right answer for the right reason. As the name implies, a diagnostic evaluation requires the measurement of parameters (both meteorological and chemical) that control pollutant formation and distribution, not just the concentration of the pollutant that is being forecasted. To perform a diagnostic evaluation, concentrations of pollutant precursors and key intermediates need to be tracked to evaluate the performance of the emissions model and the chemical processor (if one is used), while meteorological parameters such as mixing height and winds aloft will aid in the evaluation of the meteorological processor.

1.4 Air Quality Forecasting as a Way to Improve Understanding

As techniques for forecasting air quality improve and their use expands, we should not overlook the opportunity to use this process to improve our understanding of the processes that control the formation and distribution of air pollution. The meteorological research community has benefited enormously from the experience gained through an operational forecasting enterprise. The ongoing evaluation of the daily weather forecasts is used to identify areas of insufficient understanding and guide research.

The same opportunity exists for advancing the understanding of atmospheric processes that control ambient pollution levels. By evaluating the success of forecasts produced by different techniques we have the opportunity not only to evaluate the relative merits of these techniques but also to test our knowledge of key processes and identify areas where more information is needed.

2.0 Existing Federal Programs to Forecast Air Quality

The large number of organizations throughout the United States that currently perform operational forecasting of air quality is testimony to the interest in and need for this information. The great majority of these programs focus on providing ozone forecasts, primarily for urban areas during the summer months. The organizations performing the forecasts include federal agencies, state agencies, universities, industry, and consulting companies. The methods cover the range of complexity and sophistication from simple statistical approaches to full-blown photochemical grid models. Several federal programs to conduct, support, and disseminate these forecasts are described briefly below.

2.1 Environmental Protection Agency (EPA)

The forecasting program under EPA's AIRNOW Project was developed as part of a multi-faceted program designed to provide the public with real-time and forecast information on ozone air quality. The scope of the current forecasting effort is 38 states and 154 cities (Figure 2.1) providing next-day ozone forecasts to EPA's AIRNOW Project. Many States have been doing ozone forecasting for several years, but there had been no coordinated effort to collect these forecasts and make them available to the public on a National basis. That is the primary focus of the AIRNOW forecasting program.

Figure 2.1 Cities (circles) and areas (shaded states) for which ozone forecasts are available in 2001.

In the process of developing this coordinated effort, EPA has established excellent partnerships with the national media such as USA Today, The Weather Channel, and the national Weather Service Providers (Weather Central, Weather Services International, Kavouris, AccuWeather). It is through the partnerships with the State and Local Air Agencies along with these media partnerships that EPA has been able to facilitate the wide distribution of the air quality forecasts across the United States. The technical aspects of the forecast program are relatively simple.

All of the forecasts are provided to EPA from State or Local air quality forecasters using a variety of forecasting techniques. In some areas, these forecasts are made for independent cities, while in other areas, the forecasts are a result of a regional collaborative effort. Also, for the New England States, EPA receives city-specific forecasts as well as a monitor-specific forecast that is interpolated and mapped. The key role for EPA in this process is to acquire and compile the forecasts.

EPA developed a simple web-based system to facilitate the submittal of air quality forecasts by State or Local Air Quality Agencies. This system is designed to accommodate multiple pollutants (ozone, particulate matter, carbon monoxide, nitrogen oxides and sulfur dioxide) and multiple day forecasts (up to 4 days). All of the forecasts are then merged into one comma-delimited text file and delivered to a variety of locations. Initially, all of the forecasts are posted on the AIRNOW website (www.epa.gov/airnow) under the "Air Quality Forecasts" and "Where I Live" pages. In addition, the forecast files are then electronically delivered to the media partners for distribution. The forecast system is designed to allow for updates by the local forecaster at any time during the day. A current version of the forecast file is delivered to the AIRNOW website and media partners every hour from 6:00 AM until midnight. This allows for updated forecasts to be delivered in a timely fashion should the initial forecast change.

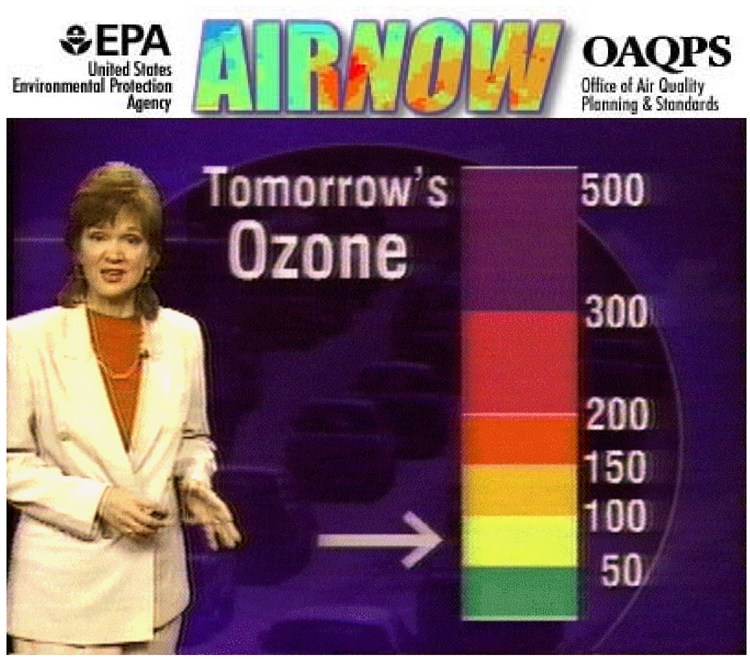

Figure 2.2 Ozone forecasts are provided for 154 cities on EPA's AIRNOW web site (www.epa.gov/airnow)

While EPA does not issue the actual forecasts, they are involved in supporting the forecast programs at the State and Local level. Through EPA's Environmental Monitoring for Public Access and Community Tracking (EMPACT) program, the Office of Air Quality Planning and Standards has provided resources to support the forecasting efforts in several areas of the United States. EPA developed the guidance for developing an ozone forecasting program and provided that guidance to the State and Local Air Agencies. EPA will be developing similar guidance for forecasting particulate matter during fiscal year 2001. Finally, EPA has supported the distribution of the forecasts to the public and media through website development and partnerships with external weather groups. It is this national "top-down" support that has increased the number of forecast areas in the United States.

Now that the forecasting program is operational, it would be useful to suggest some enhancements that could improve the quality and coverage of the forecasts. While the final word on any air quality forecast will always reside with the State or Local Air Agency, it would be very helpful to have some type of national forecast model that could assist areas that do not have the capability to generate their own forecasts. Even areas with experienced forecasters would benefit from a forecast model. Air quality forecasting is similar to weather forecasting. The models make a prediction and the local forecasters adjust that prediction based on local knowledge and information. An air quality forecast model would be utilized in a similar manner.

Overall, the forecasting approach developed under AIRNOW has been very successful. It has succeeded because it continues to give the authority for the forecast to the State or Local agency. A Federal forecast tool will be beneficial, but we cannot overlook the importance of having the local agency have the final word with regards to the actual forecast. Local conditions (thunderstorms, topography, etc) can have a significant impact on air quality conditions and we must always make sure that component is covered. In addition, the credibility of a forecast made at the local level will always be greater than one made at the national or Federal level.

2.2 National Oceanic and Atmospheric Administration (NOAA)

NOAA has a goal under its forecasting mandate to extend, over the next decade, the current weather forecasting capability to include predictions of future air quality. During the past several years, as the first steps in this process, NOAA has developed several experimental air quality forecast products and made them available on the World Wide Web (http://www.arl.noaa.gov/ready.html). The air quality forecasts are generated using high-resolution meteorological forecast models coupled with a sophisticated air-mass trajectory analysis (HY-SPLIT) and, in the case of ozone, complex, photochemical grid models. These forecasts are being used primarily as a learning tool to evaluate current capability and identify areas where improvements are needed. Some of these forecasts are provided on a routine basis (e.g., ozone forecasts during the summer months), some are provided in response to specific events (e.g., natural disasters), and some are provided to support air quality research (e.g., intensive field campaigns).

Ozone Forecasts

In a cooperative effort, scientists from NOAA and the Pennsylvania State University (PSU) have developed the Hybrid Single-Particle Lagrangian Integrated Trajectories with a generalized non-linear Chemistry Module (HY-SPLIT CheM) model to calculate the spatial and temporal distribution of different chemical species in the troposphere over a regional scale [Stein *et al.*, 2000]. The simulation accounts for the advection, dispersion, chemical transformation, and deposition of the different pollutants. The model uses the 1995-1996 Ozone Transport Assessment Group (OTAG) emissions inventory [EPA, 1999] and Carbon Bond IV gas-phase chemistry coupled with a Lagrangian transport scheme to forecast ambient ozone concentrations. Ozone forecasts are provided on a grid resolution of 0.5^o x 0.5^o for the Northeastern US (Figure 2.3).

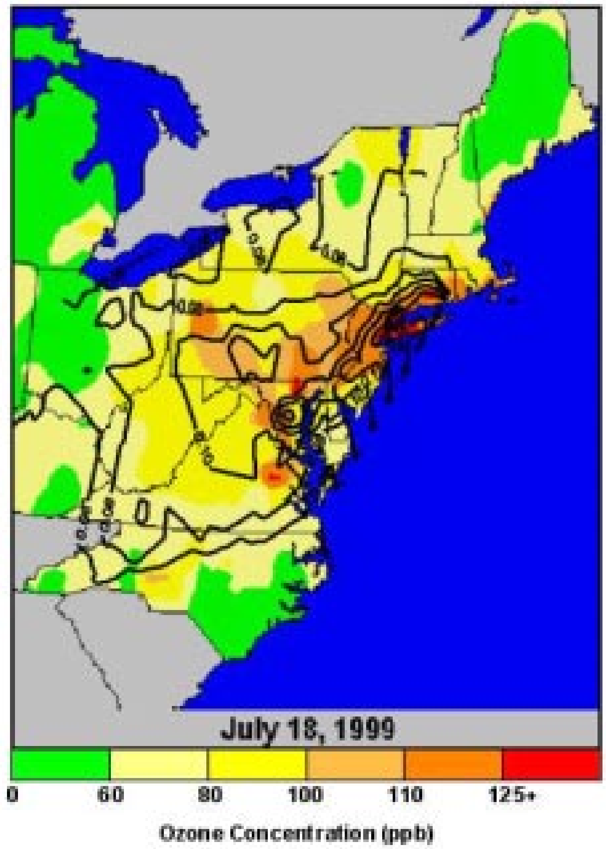

Fig. 2.3 Comparison of ozone forecast using the PSU/NOAA hybrid model (isopleths) with data from the EPA AIRS network (colors).

NOAA is also performing ozone forecasts on an experimental basis using a high-resolution coupled meteorology/chemistry model [Grell *et al.*, 2000]. This Eulerian grid model uses the PSU / NCAR nonhydrostatic mesoscale meteorological model MM5 coupled with the RADM-2 gas-phase chemical reaction scheme. To date, the model has been used primarily to support flight planning during intensive field campaigns designed to study atmospheric processes related to air quality.

The comprehensive data sets acquired in intensive field campaigns, which include measurements from ground based instrumentation, remote sensing technology, and highly instrumented aircraft, are being used to evaluate the meteorological and chemical components of the NOAA forecast models.

Smoke from Forest Fires

NOAA is actively engaged in the prediction of smoke dispersion from forest fires. The NOAA HY-SPLIT model is being used in this application. The initial development was in the context of fires in Mexico, Brazil, and parts of the USA. However, these applications have recently been extended to the recurring fires in Indonesia, with plans to include Singapore in FY 2001. NOAA also provides a quasi-operational smoke forecast system that is used by the Idaho National Engineering and Environmental Laboratory in its fire-fighting and control-burn programs. A comparison of a smoke transport forecast for a forest fire in eastern Idaho during August of 2000 with a satellite image is provided in Figure 2.4.

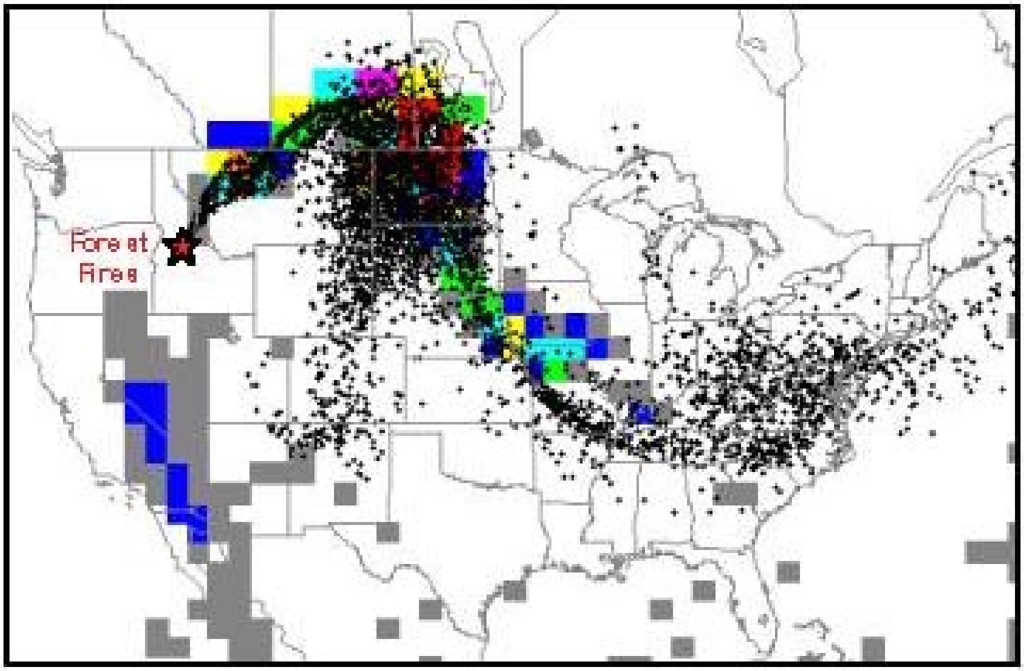

Figure 2.4 Comparison of smoke forecast using NOAA's HYSPLIT model (black dots) with aerosol column measurements from NASA's TOMS satellite (colored grids – hotter colors represent higher aerosol loadings) for 18Z on August 10, 2000 for a fire in eastern Idaho.

Volcanic Ash

NOAA also conducts research and development on volcanic ash transport and dispersion modeling. Since 1992, the National Weather Service (NWS) has used the Volcanic Ash Forecast Transport And Dispersion (VAFTAD) model to protect aircraft from hazards associated with volcanic emissions. NWS has provided volcanic ash forecasts using VAFTAD output about 150 times in each of the past three years.

2.3 National Park Service (NPS)

As a Federal Land Manager and steward of some of the Nation's most pristine areas, the NPS works to ensure that the lands under their jurisdiction are protected from the impacts of pollution. To quantify levels of air pollution within the many National Parks and

Wilderness Areas the NPS has, for many years, operated an air quality monitoring network. These efforts to quantify air pollution exposure and deposition have been expanded in recent years to include the issuance of ozone advisories when ozone pollution reached or was forecasted to reach unhealthy levels (Figure 2.5).

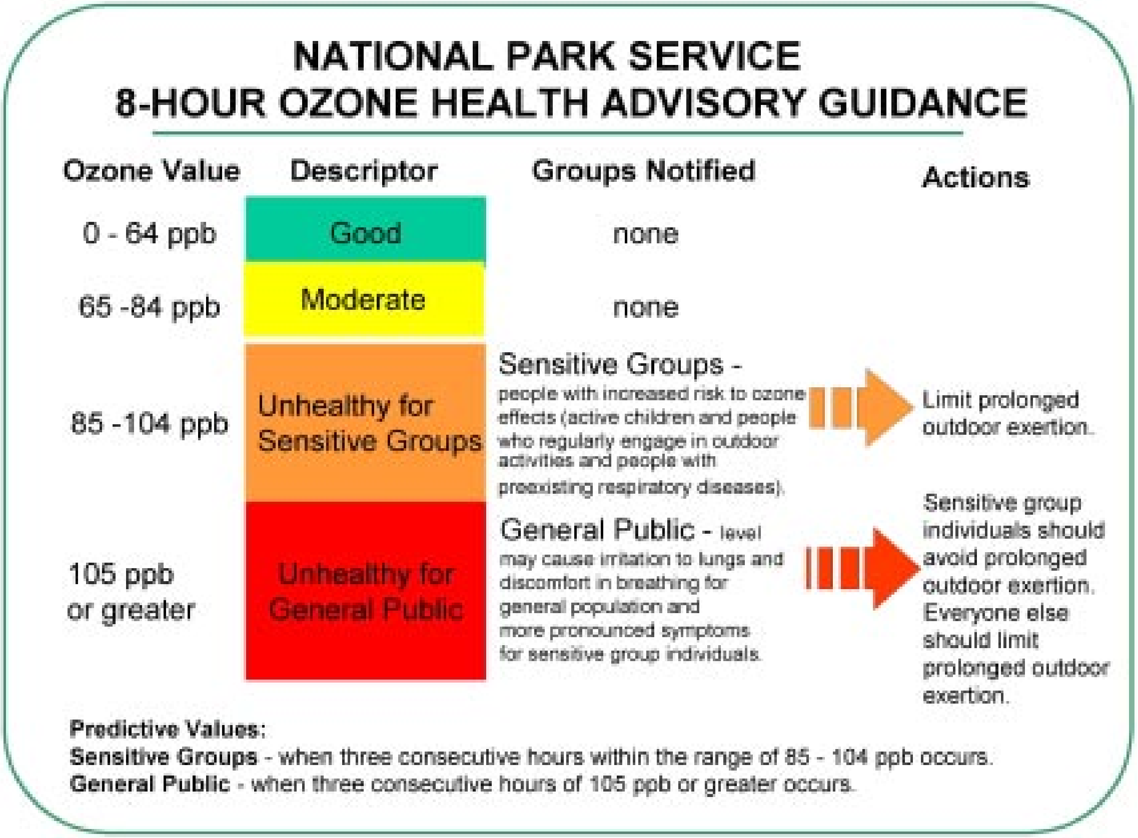

Figure 2.5 National Park Service guidance for the issuance of ozone advisories.

The NPS currently issues ozone advisories for the following National Parks:

- Acadia
- Great Smoky Mountains
- Mammoth Cave
- Sequoia – Kings Canyon
- Shenandoah

The ozone forecasts for the National Parks are a mix of in-house efforts by the NPS staff and collaboration with other organizations, primarily through the EPA AIRNOW program. An advisory is issued for that day when in-park monitoring data indicate that 3 hourly values have exceeded 85 ppb. Often these advisories are issued too late in the day, and a better system is needed so that a forecast is available the day before.

3.0 Research Needs to Support Air Quality Forecasting

The interest in and need for a robust capability to predict future air quality is clear. A wide variety of techniques are currently being used with mixed results. The majority of current efforts focus on ozone. A number of the approaches have been carefully evaluated and some have demonstrated impressive skill, while others have been less rigorously evaluated and the quality of the predictions is essentially unquantified. The current ozone forecasts are largely a collection of disparate efforts, primarily the work of State and Local air regulatory programs, with very little consistency in approach or methods used to perform evaluations of forecast skill. The work to date, while encouraging, would clearly benefit from a better coordinated national effort, including a program of focused research and development, that would facilitate and augment work at the local level. This support is particularly important as interest grows in forecasting pollutants other than ozone (e.g. particulate matter, visibility, carbon monoxide, etc.) and extending the forecasts to rural and remote areas (e.g. National Parks and Wilderness Areas).

3.1 Defining Customer Needs

In designing an air quality forecasting program and identifying the research that is needed to support the effort it is essential that the needs of the user community be understood and considered. A number of potential applications of air quality forecasts have been discussed earlier in this report. In order to determine the relative importance of each and maximize the usefulness of the forecasts and provide focus for any supporting research we must look to the user community for answers to several basic questions related to forecast needs/requirements, including:

- For what pollutants are forecasts needed? What are their relative priorities?
  - ozone, particulate matter, carbon monoxide, visibility, sulfur dioxide, air toxics, others?
- What is the time scale for the desired forecast?
  - How far in advance?
  - For what period; hours, days, weeks?
- How accurate does the forecast need to be and what form should it take?
  - Probability of exceeding a standard level.
  - Predicted concentration range.
  - Ambient concentration with estimated uncertainty.
- What is the spatial scale?
  - city, region, other

The applications of air quality forecasts are rapidly evolving. As the reliability and coverage (number of pollutants for which forecasts are produced and the temporal, and spatial extent) grows, new uses will be identified that we cannot now foresee. Therefore, a close and effective relationship among the user community, operational forecasters, and those involved in evaluating and improving forecasting methodologies must be maintained. Thus, the process of defining customer needs and requirements must be ongoing with effective communication between developers and users.

3.2 Understanding Processes

The coupling of emissions to ambient pollution levels is controlled by a number of key atmospheric processes (mixing, transport, chemical transformation, deposition, etc.). The prediction of ambient pollution levels relies on an understanding of how these processes influence the formation and distribution regardless of whether the approach to forecasting involves a parametric or deterministic approach. Therefore, efforts to improve the reliability of air pollution forecasts will benefit from an improved understanding of these atmospheric processes. Areas where improved understanding would benefit efforts to develop and/or improve air quality forecasting systems include:

Linkages between weather and air quality: Ambient levels of pollution (e.g., ozone and fine particles) are clearly dependent on the emissions of precursor pollutants like NO_x, VOCs, and SO_2. Meteorological parameters like solar intensity, temperature, wind speed, and mixing height greatly influence the day-to-day and seasonal-to-interannual variations in atmospheric concentrations. These associations form the basis of many of the statistical models used to forecast air quality. A better understanding of the couplings between meteorology and air quality can point to approaches that will improve the quality of these techniques.

Nighttime transport and chemistry: Because of the important role that photochemistry plays in the formation of ozone and other secondary air pollutants, the vast majority of the intensive atmospheric process studies conducted to date have focused on the daylight hours. Analysis of data from intensive field studies [e.g., Banta *et al*., 1998] has shown that nighttime mixing and transport plays a significant role in the redistribution of urban pollution throughout the region. During the day, under the stagnant conditions associated with most pollution episodes, only limited horizontal transport of the pollution plumes is expected. However, at sunset a shallow nocturnal inversion layer may form that can isolate the boundary layer pollution from the surface, reducing the loss of ozone, PM and their precursors via deposition. The formation of this layer also reduces the frictional resistance for the air masses above the nocturnal layer, allowing this pollution to be more effectively transported over larger distances. Moreover, the emissions from smokestacks of major point sources, such as power plants, may enter the atmosphere at night above the nocturnal inversion directly into the nighttime residual mixed layer.

Nitrogen oxide and VOC emissions continue to react with ozone at night, leading to additional reactions involving the nitrate radical. These processes can significantly affect the reactivity and concentration of the pollutant mix that populates the atmosphere during the next diurnal cycle. Thus, the accurate prediction of tomorrow's air quality requires a better understanding the chemistry and transport in the nighttime atmosphere.

Heterogeneous processes: Aerosols participate in a variety of chemical and physical processes in the troposphere. On a regional scale, these processes are associated with regional air quality as related to visibility and the effects of fine particles on human health. In this regard, there is a natural synergism between pollutants like ozone and sulfur dioxide and fine particles. A basic scientific understanding of the chemistry and physics of the atmosphere is prerequisite for an effective predictive capability and that the concentrations of pollutants in the atmosphere are often co-dependent because of interacting chemical reactions.

With this in mind, new research is needed to elucidate:

- how chemical processing on aerosols influences ozone formation
- how the atmospheric oxidation leading to ozone formation leads to aerosol formation
- how atmospheric chemistry influences the growth and chemical composition of aerosols.

Emissions: Day-to-day changes in emission rates need to be taken into account to accurately forecast air quality. The potential effects of changes in temperature include increased biogenic emissions of VOC, increased VOC emissions from motor vehicles, and increased nitrogen oxides emissions due to increased power demands. Variations in activity levels at major industrial facilities will also impact air quality. Research is needed to develop methods to adjust seasonal emission inventories to reflect the probable emission levels during the forecast period.

3.3 Evaluating / Improving Models

The models used for forecasting air quality can be divided into two broad categories, 1) parametric models and 2) deterministic models. Regardless of the form of the model it is important to evaluate model performance so that there is some way to quantify forecast reliability and identify areas for improvement. The wide variety of approaches and the form of the forecast produced in current forecast models make it very difficult to objectively and quantitatively compare different techniques. Also, the factors that control pollution levels vary from one region to another and mean that a model/technique that works well in one region may not perform well in another.

In the case of statistical models, a systematic evaluation of the various techniques and their relative performance would provide a useful guide for areas that are considering developing a forecast capability.

In the case of deterministic models (e.g., photochemical grid models), there is a need to evaluate model performance in a number of key areas, including:

Meteorology: Many of the most severe air quality episodes occur during air mass stagnations when there is very little synoptic forcing. There is a need to evaluate model performance under these conditions. There is also a need to evaluate the models for specific geographic areas where there are terrain-induced effects on air quality (e.g., coastal areas where land/sea-breeze recirculation can play a role, and mountainous areas where the mixing and transport is very complex).

Chemistry: Many of the newest photochemical grid models include modules to simulate particle emission, production, transport and deposition. The development of fast response instrumentation for the characterization of particle composition and morphology affords the opportunity to evaluate the performance of these models for a variety of emission mixes and meteorology.

Emissions: Most air quality modeling efforts conducted to date have relied on emission inventories developed by state regulatory agencies. In most cases, these inventories have not been rigorously evaluated. Also, there has not been a comprehensive study to examine the coupling between emissions and meteorology. The quality of the predictions from emissions-based air quality models is directly proportional to the quality of the emissions used in the model. There is also a need to evaluate the day-to-day variability in biogenic and anthropogenic emissions and their dependence on meteorological variables, and to determine the sensitivity of air quality models to this variability.

The greatest uncertainty in forecasting air quality impacts from natural disasters such as volcanic eruptions and wildfires is associated with the source term. A better quantification of emission rates could dramatically improve the reliability and therefore the usefulness of such forecasts.

There are a number of data sets that have been accumulated as part of comprehensive field campaigns in which both the physical and chemical condition of the atmosphere has been characterized in some detail for the study period. Several of the NARSTO data sets (e.g., Southern Oxidants Study – SOS campaigns in Nashville and Texas, NARSTO-NE, and Southern California Ozone Study - SCOS) provide a rich resource for model evaluations such as those described above.

3.4 Observing Systems

A well-designed observing system is essential to the success of any air quality forecasting system. The need for information on the chemical constituents of the atmosphere is analogous to the meteorological observing system that supports the current weather forecasting system. Information on atmospheric pollution is needed to both initialize and evaluate the forecast. For example, today's ozone levels will have a strong influence on tomorrow's levels. Specific research needs include the following:

Data to initialize models and perform operational evaluation: Most air quality forecast models use some form of dynamic initialization, assimilating observed chemical data in a manner akin to the way weather forecast models are initialized using meteorological observations. This process requires near real-time access to air quality data. The United States has a reasonably dense network of ozone monitors that are operated for both regulatory and other purposes. With this network it is possible to quantify both urban and rural levels in most parts of the country. However there are areas of interest, most notably National Parks and Wilderness Areas, where there are no monitors and therefore no way to evaluate forecast skill. The situation for other pollutants is not nearly as good. If short-term (1-3 day) forecasts of these pollutants are needed, fast-response (1-hr or less) near real time data will be needed for model initialization and evaluation. For some pollutants (e.g., particulate matter) there are currently no reliable fast-response measurements, while for others (e.g. carbon monoxide and sulfur dioxide) reliable data are available only for urban or industrial areas. New monitoring systems will have to be developed if forecasts for these pollutants are needed. In some cases satellite data may be able to fill in some of the gaps through integration data from sparse surface networks. In other instances useful surrogates may be found that can substitute for the desired data. For example, visibility data from the 900+ airport meteorology network (ASOS) may serve as a surrogate for fine particle mass [Richards *et al*, 1996].

Data for diagnostic evaluation of complex grid models: A diagnostic evaluation of model performance requires information on the fundamental physical and chemical processes responsible for the formation and distribution of air pollution. While much of this information is available at research sites located throughout the United States, these stations are few and far between and access to the data is difficult. An integrated network of research monitoring stations that are capable of characterizing the atmosphere both in terms of meteorologically and chemically important parameters (including chemical precursors and key intermediates) is needed to support a national forecasting effort. Such a network could build on the existing efforts by augmenting measurements at existing sites and adding stations in key areas where such data are currently not available.

Information on the vertical distribution of pollution: The formation and collapse of daytime and nocturnal inversion layers serves to isolate the surface from the residual mixed layer and the free troposphere. Transport of pollution above the daytime mixed layer and the stable nocturnal layer can have a strong influence on next day pollution levels. Current monitoring networks are blind to this pollution, and vertical pollution distributions are made only infrequently and usually only during intensive field campaigns. New remote sensing instruments (i.e., DIAL lidars) and advances in sonde technology offer the opportunity to characterize the vertical pollution distribution on a more frequent basis and over a wider area of the country. The development of reliable air quality forecasts will require access to such data. By way of comparison, imagine the difficulty of performing weather forecasts while denied access to the daily soundings and profiler data.

Access to data in a timely manner: Most of the air quality data in the United States are collected for regulatory purposes. In most cases, these data are not available for several months after they are collected. Access to this data in near real-time would facilitate and improve the air quality forecasting process. Some states and the EPA's AIRNOW program are providing limited access to data from part of the ozone network in real time. This capability needs to be extended to other pollutants for which forecast information is needed.

4.0 Conclusions and Next Steps

The need for air quality forecasts is clear. A growing number of State and Local Air Agencies (currently 35 states and 135 cities) are using summertime ozone forecasts to alert sensitive populations and reduce precursor emissions through reduced vehicular traffic on "ozone action days". A similar approach is being used to reduce carbon monoxide levels in Denver. Plans are being developed to extend these forecasts to include other pollutants (e.g. particulate matter). The National Park Service uses ozone forecasts to protect their workforce and inform park visitors. Air quality forecasts are also an important part of the Federal process for dealing with natural disasters (wildfires and volcanic eruptions). All indications are that uses for air quality forecasts will continue to grow as reliability and coverage improves and new applications are identified.

Federal activities related to air quality forecasting are currently limited to 1) EPA efforts to facilitate the collection and dissemination of real time data and the posting of locally-produced ozone forecasts and 2) efforts by NOAA to develop and evaluate a number of experimental forecasting techniques and 3) the National Park Service's program to use ozone forecasting as a proactive approach to resource management. To date, these efforts are largely uncoordinated with only model resources available to improve and extend air quality forecasting methodologies and supporting infrastructure (i.e., observing systems, data ingest, etc.). The Subcommittee has identified a number of activities to improve air quality forecasts:

Improved coordination – A number of Federal agencies are currently engaged in some aspect of air quality forecasting; others have related activities that could contribute to a national effort. A more formal process for coordinating Federal activities would ensure that limited resources are used to maximum advantage. The Air Quality Research Subcommittee could facilitate such coordination and NARSTO, the tri-national (Mexico, United States, and Canada) research consortium focused on ozone and fine particles, could serve as a connection to the private sector.

Identification of customer needs – This is a rapidly evolving area with a need for ongoing communication between the user and research communities. EPA has close contact with the State and Local Air Programs that are the core of the AIRNOW program; NOAA has conducted a number of workshops to identify current and future needs. These efforts need to continue and be integrated to improve communication. A coordinated Federal program must be responsive to the needs of the user community.

Evaluate existing technology – Current approaches to air quality forecasting vary from the simple to the complex. Some have been carefully evaluated, while others have not. There is a lot to be learned from the work that has already been done. A systematic and objective evaluation of the methods that are currently in place is the first step in identifying areas for improvement and opportunities for extension to other pollutants.

Program development – A forecasting system (Section 1.3) is needed to support operational air quality forecasting. The system must include a method to continuously evaluate and improve the forecast consistent with the needs of the users. A program plan should be put in place that identifies operational, research, and developmental needs and, where possible, agency resources that can be used to address these needs. The information provided in Section 3 of this report is intended as a first step at identifying the key elements of the research portion of such a program.

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Committee on Environment and Natural Resources (CENR)
Subcommittee on Air Quality Research

The CENR is charged with improving coordination among Federal agencies involved in environmental and natural resources research and development, establishing a strong information-transfer link between science and policy, and developing a Federal environmental and natural resources research and development strategy that responds to national and international issues. There are five research subcommittees under the CENR:

- Air Quality
- Ecological Systems
- Global Change
- Natural Disaster Reduction
- Toxics and Risk

The Air Quality Research Subcommittee has articulated two major goals in its Strategic Plan:

- to enhance the effectiveness and productivity of U.S. air quality research, and
- to improve information exchange between research and policy on air quality issues, including the scientific knowledge base for air quality standards and assessing compliance

Dan Albritton of NOAA chairs the Subcommittee, which includes representatives from the following departments and agencies:

Department of Agriculture - Agricultural Research Service
Department of Agriculture - Cooperative State Research, Education, and Extension Service
Department of Agriculture - Natural Resources Conservation Service
Department of Agriculture - U.S. Forest Service
Department of Commerce - National Institutes of Science and Technology
Department of Commerce - National Oceanic and Atmospheric Administration
Department of Defense
Department of Energy
Department of Health and Human Services - Center for Disease Control and Prevention
Department of Health and Human Services - National Institutes of Health
Department of Housing and Urban Development
Department of State
Department of the Interior - National Park Service
Department of the Interior - U.S. Geological Survey
Department of Transportation - Federal Aviation Administration
Department of Transportation - Federal Highway Administration
Environmental Protection Agency
National Aeronautics and Space Administration
National Science Foundation
Office of Management and Budget
Office of Science and Technology Policy
Tennessee Valley Authority