J2.17 FUTURE OF AIRNOW AND THE AIR QUALITY INDEX: BEYOND OZONE MAPPING AND FORECASTING

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1. INTRODUCTION

In 2002, more than 146 million people across the United States lived in areas where monitored air quality levels were, at times, unhealthy because of high levels of ozone, particle pollution or other principal pollutants (U.S. Environmental Protection Agency, 2003a). For many—especially children, outdoor workers, people who suffer from asthma and other respiratory problems, the elderly, and people with heart conditions—knowing current and forecasted levels of air pollution can make a significant difference in the quality of their lives and planning their daily activities.

Since its inception in 1998, the U.S. Environmental Protection Agency's (EPA) AIRNow program has been the only public information tool for providing national real-time and forecasted ozone air quality information and its associated health effects. Now, five years after its beginning, the AIRNow program is expanding to include new pollutants and to bring in new partners as it continues to provide daily health protection for all people in the United States. This paper provides a brief background on the successes of the past five years and the future plans for AIRNow and air quality reporting, forecasting, and public health protection.

2. BACKGROUND

EPA's AIRNow program was developed as part of the Agency's Environmental Monitoring for Public Access and Community Tracking (EMPACT) initiative to provide time-relevant, environmental information to the public. Initially, the program focused on ground-level ozone as it was the most common air pollution problem and the most understood. The AIRNow program was built on the existing extensive network of ozone monitors throughout the country. These monitors have historically been used to provide quarterly reports to AIRS-AQS. While AIRS-AQS remains the most complete and comprehensive air quality database in the United States, it offers no real-time access and is relatively difficult for the general public to access and navigate. The AIRNow program was created to address this deficiency and to link the air quality concentrations to a health-based cautionary message utilizing EPA's Air Quality Index—AQI (U.S. Environmental Protection Agency, 1999).

The initial focus of AIRNow was to provide real-time ozone maps, as shown in Figure 1, to the public via the Internet on the AIRNow website (www.epa.gov/airnow). The graphic nature of the ozone maps and the inherent understanding of the AQI color categories enabled the public to easily comprehend current ozone concentrations. AIRNow collects air quality data on an hourly basis from over 100 state and local agencies through a voluntary partnership. State and local air quality forecasters quickly discovered the usefulness of having easy access to real-time ozone maps for daily forecasting and forecast verification. For example, a forecaster can help predict long-range transport of ozone by examining upwind ozone concentrations shown on various AIRNow ozone maps. With increased media exposure and available tools, state and local agencies have continually supplied AIRNow with more air quality information that EPA has made available to the public. Today, state and local agencies submit daily air quality forecasts to AIRNow for more than 300 cities.

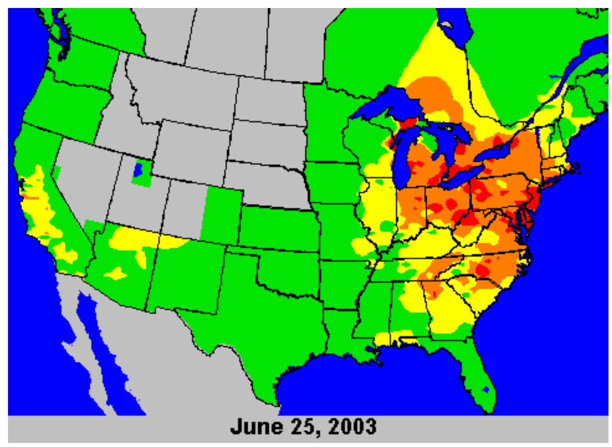

Figure 1. Peak AQI based on ozone concentrations for June 25, 2003, from the AIRNow Web site.

To prepare for the inundation of air quality information that was expected from state and local air quality agencies, AIRNow developed the infrastructure needed to collect, verify, and distribute the generated products in a timely and reliable manner. Distributing this information to the public in a reliable, user-friendly format is the key to providing the public health protection that the program was initially designed to deliver. The AIRNow program has unique partnerships with major weather service providers and national media to distribute this information to the public beyond EPA's AIRNow web site audience. As a result, air quality reports and forecasts show up on a regular basis in weather broadcasts and newspaper weather pages across the country. Now, the general public has access to current and forecasted air quality information as part of their daily news and weather information sources.

3. PARTICLE POLLUTION—A YEAR-ROUND CONCERN

Before 2003, the majority of AQI reporting throughout the United States happened only during the summer season because ozone is a significant problem for many areas and typically occurs in the summer months. Unfortunately, ozone forecasting in the summer alone created an unintentional media blackout of air quality information during the fall and winter. Unlike ozone, particle pollution is not limited by season or sunlight. In some parts of the country, high particle pollution levels occur during the winter months and, in other areas, concentrations may be high throughout the year. With more scientific studies showing that short- and long-term exposures to elevated levels of particle pollution are associated with serious health effects, the health benefits of informing the public of high particle levels are obvious and important. Therefore, particle pollution data gathering and forecasting are essential to expand AQI reporting year-round.

Over the past several years, EPA provided grants to state and local air quality agencies to supplement the existing particle pollution monitoring network infrastructure with continuous instruments in an effort to reduce the resource burden and encourage more public reporting of the AQI. Because a network of continuous $PM_{2.5}$ monitors is spreading throughout the nation, particle forecasting programs are now a reality.

EPA set a goal in 2002 to begin providing real-time and forecasted particle pollution information to the public by October 1, 2003. To accomplish that goal, many technical issues had to be resolved and appropriate outreach materials and cautionary health messages developed.

3.1 What Is Particle Pollution?

Particle pollution (also known as particulate matter or fine and course particles) includes a mixture of solids and liquid droplets in the air. Some particles are emitted directly; others are formed in the atmosphere when other pollutants react. Particles come in a wide range of sizes. Those less than 10 microns (µm) in diameter are so small that they can get into the lungs, potentially causing serious health problems. There are two types of particles:

- Fine particles. Particles less than 2.5 µm in diameter are called "fine" particles. Sources of fine particles include all types of combustion, including motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes.
- Coarse dust particles. Particles between 2.5 µm and 10 µm in diameter are referred to as “coarse.” Sources of coarse particles include crushing or grinding operations, wind-blown dust, and dust stirred up by vehicles traveling on roads.

3.2 Health Concerns

The size of particles is very important. The smaller-sized particles—those 10 µm or less in diameter—tend to pose the greatest health concern because they can get deep into the lungs. These particles include “fine” particles which are 2.5 µm or less in diameter (found in smoke and haze) and “coarse” dust particles between 2.5 µm and 10 µm in diameter. Larger particles—those greater than 10 µm in diameter—can irritate the eyes, nose, and throat. They are less likely to cause more serious problems because they usually do not penetrate as deeply into the lungs. When inhaled, small particles can be deposited in the airways or deep in the lungs (Figure 2). Once deposited, several things may happen: particles may be cleared out by the body's natural defense mechanisms, they may accumulate on the surface where they deposit, or they may be absorbed into the underlying tissues. The soluble components of fine particles, along with very small (“ultrafine”) particles, may enter the bloodstream. Some particles may react chemically in the body; others remain in their original form.

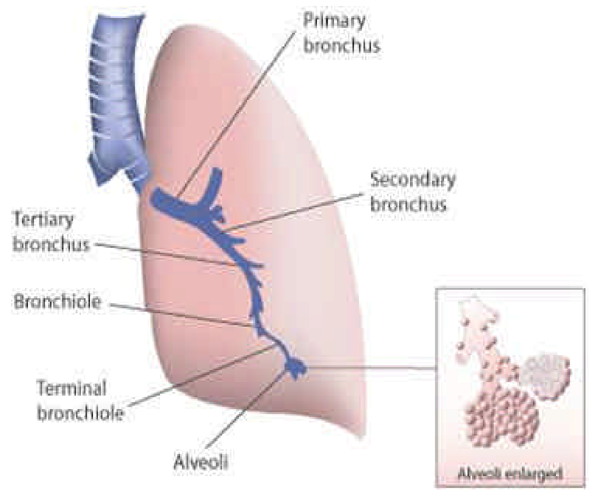

Figure 2. Schematic of the lung.

In addition, people with chronic obstructive pulmonary disease (COPD) have obstructed airflow which may cause more particles to deposit in their lungs. People with diabetes may be at increased risk of serious effects, possibly because of underlying cardiovascular disease. Older adults are at increased risk because they may have undiagnosed heart or lung disease or diabetes. Numerous studies show that when particle levels are high, older adults are more likely to be hospitalized, and some may die from aggravated heart or lung diseases. Children are at risk for a number of reasons: they are more vulnerable to particles because their lungs are still developing; they spend more time at higher activity levels, which can lead to more particles depositing in the lungs; and they are more likely to have asthma or acute respiratory diseases that can be aggravated by particles.

In people with heart disease, particles have been linked to heart attacks and cardiac arrhythmias (irregular heart rhythms). Recent evidence suggests that some of these effects may result from very short-term exposures, possibly as short as an hour. In healthy children and adults, exposure to elevated particle levels for short periods of time may cause minor irritation (U.S. Environmental Protection Agency, 2003b). Most healthy people will recover quickly from these effects and are unlikely to experience long-term health problems. Long-term exposure to particles has also been associated with reduction in lung function and the development of chronic bronchitis.

3.3. Real-Time Reporting Of Particle Pollution Data

EPA and state and local agencies face difficult challenges in presenting particle data to the public. The fundamental issue is that the AQI is based on 24-hr average $PM_{2.5}$ measurements, yet AIRNow (and the public) desire hourly air quality information.

The 24-hr measurement has historically been obtained using a $PM_{2.5}$ Federal Reference Method (FRM) or an equivalent. Past health effects studies and EPA's AQI were based on this 24-hr averaged data. Unfortunately, FRM $PM_{2.5}$ measurements require laboratory analysis (taking several weeks) and are not available in real time to compute a current AQI value for the AIRNow program. There are, however, a number of alternative methods that provide continuous $PM_{2.5}$ measurements.

Several technical hurdles had to be addressed: (1) correlating continuous data to the FRM, (2) resolving the issue of using hourly data to estimate a 24 hr average, and (3) dealing with network monitor density and spatial representativeness concerns.

FRM Correlation

EPA assembled a team of EPA and state and local agencies to address the issue of correlating continuous monitoring data to the FRM. The workgroup produced a guidance document to help agencies make their continuous data "match" FRM data (U.S. Environmental Protection Agency, 2001). Typically, for demonstrating the statistical relationship between continuous measurement techniques and FRM measurements, daily FRM measurements are regressed onto the daily average of hourly $PM_{2.5}$ measurements. If a suitable relationship can be demonstrated, the daily average of hourly measurements is used to compute the AQI. AIRNow receives hourly measurements of $PM_{2.5}$ from state and local air quality agencies that have been converted to FRM-like measurements using the regression relationship established or are already FRM-like. Transformation of hourly measurements to FRM-like measurements is the responsibility of each monitoring agency.

Averaging Time

The AQI for particles was developed to assess air quality conditions over a 24-hr period. The difficulty lay in presenting current particle pollution conditions at any given time during the day via the AQI. Real-time air quality assessment is the goal of AIRNow; thus methods were developed to estimate the AQI (based on a 24-hr average) given the current hour and previous data. This approach is called the surrogate, where hourly data are used as a surrogate for 24-hr averaged data. EPA formed a workgroup with state and local agencies to evaluate methods for estimating the 24-hr AQI from hourly data. The approaches differed in several ways but essentially used a variety of short-term averaging techniques of data from previous hours.

EPA had statistical analyses performed on these methods to ascertain which method would best predict the 24-hr average while demonstrating responsiveness to shorter-term particle conditions. The criteria for evaluating each method include the following:

- Works for all geographic areas.
- Is within 80% of the value of the 24-hr average 80% of the time.
- Identifies spikes in $PM_{2.5}$ rapidly (within two to three hours) and recovers rapidly (within two or three hours) when concentrations fall.
- Is not overly sensitive to outliers caused by local sources.

EPA chose cities to represent each of the following regions of the United States: the South, West, East, and Midwest. For each city, all available hourly $PM_{2.5}$ data from April 2002 to April 2003 was obtained.

Results of this analysis showed that a weighted average performed best using hourly data to estimate the 24-hr average on which the AQI is based. The surrogate method being used by AIRNow combines both the 4-hr and 12-hr averages in the following manner as a predictor of future values:

1. Calculate the average of the previous 12 hours (75% of the values are required).
2. Calculate the ratio of the most recent hour to the average of the previous 12 hours.
3. Calculate an "adjusted" hourly value:
   - If the actual hourly value is $<30\ \mu g/m^3$, the adjusted hourly value is equal to the actual hourly value.
   - If the actual hourly value is $>30\ \mu g/m^3$ and the ratio of the most recent hourly value to the average of the previous 12 hours is <0.9 or >1.74, the adjusted hourly value is equal to the actual hourly value.
   - If neither of the above conditions is met, the adjusted hourly value is equal to 0.75 times the actual hourly value.

- If 75% of the hourly values needed to calculate the 12-hr average are not available, the adjusted hourly value is equal to 0.75 times the actual hourly value.

4. Calculate the "adjusted" 4-hr average, which is the average of the 4 most recent “adjusted” hourly values (75% of the values are required).
5. Calculate the "estimated mid-point 24-hr average" where concentration = ((12-hr average) + (adjusted 4-hr average))/2

These estimated concentrations are used until 18 of 24 values or more are available for calculating a “real” mid-point 24-hr average for each hour of the day.

Spatial Representativeness

Unlike the ozone mapping program initially developed under AIRNow where there were over 1300 ozone monitors across the United States, there are currently about 350 continuous $PM_{2.5}$ monitors across the United States. Therefore, the ability to develop smooth contour maps on a national or even regional scale is limited. EPA chose to provide particle data to the public in terms of “bubble” or point maps (Figure 3) where each monitor is simply represented by AQI color-coded circles. In areas of the country where there appears to be sufficient network monitor density, contour maps will be generated (Figure 4). In addition, research efforts are underway to examine other data sources such as ASOS visibility data and the use of existing FRM sites to supplement the $PM_{2.5}$ monitoring network and enhance the capability to provide contour maps.

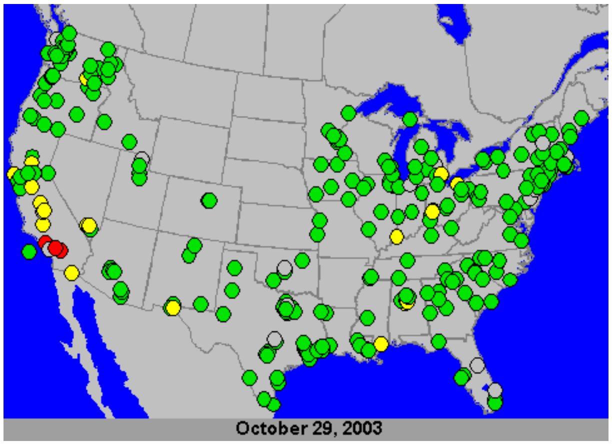

Figure 3. Map showing AQI based on 24-hr average $PM_{2.5}$ data from October 29, 2003. Note the unhealthy air (red dots) in southern California due to smoke from wildfires.

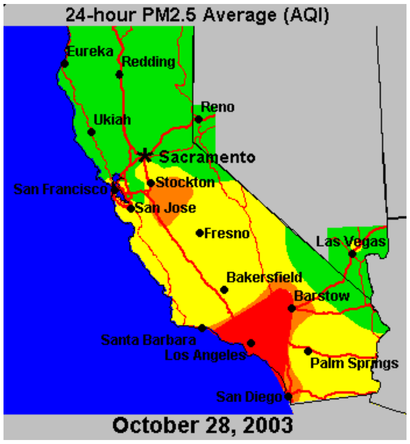

Figure 4. Contour map showing $PM_{2.5}$ AQI from October 28, 2003. Note the unhealthy air in southern California due to smoke from wildfires.

4. PARTICLE POLLUTION FORECASTING

Reporting current real-time air quality information via maps or the AQI is a very useful tool. However, AQI forecasting provides the ultimate health protection as it allows individuals to plan and make lifestyle changes that may reduce their exposure on poor air quality days. Ozone forecasting has been around for a few years, and skill and accuracy are constantly improving. However, particle pollution forecasting is a relatively new science and many state and local agencies do not have either existing programs or the necessary infrastructure in place. Particles are more complex than ozone, and the meteorological conditions affecting particle concentrations differ from those that affect ozone.

EPA recognized that new forecasting tools and applicable experience would have to be developed to assist state and local agencies. EPA developed a series of forecasting tools to aid state and local forecasters in predicting $PM_{2.5}$. These tools consist of phenomenological tables and statistical methods. In addition, EPA developed regional workshops and a $PM_{2.5}$ forecasting guidance document (U.S. Environmental Protection Agency, 2003c). The statistical forecasting tools were developed using Classification and Regression Tree (CART) analysis. CARTs are decision trees derived by systematically splitting historical peak pollutant concentration data into two groups based on a single value of a selected predictor variable. For air quality forecasting, a decision tree can be used to predict future pollutant concentrations based on the values of forecasted weather variables. Figure 5 shows an example decision tree for Columbus, Ohio.

EPA also developed phenomenological tables relating weather conditions and expected particle pollution levels. These tables use forecasts of important weather features to estimate future air quality conditions.

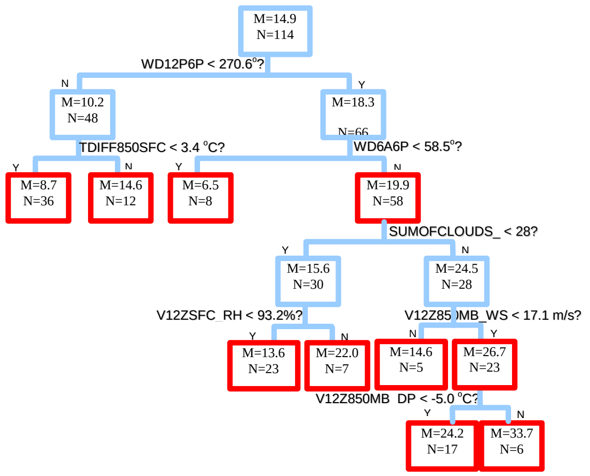

Figure 5. CART for predicting 24-hr average $PM_{2.5}$ concentrations in Columbus, Ohio. Variables include wind direction, cloud cover, v-component of the wind, and vertical temperature difference. "Y" and "N" indicate which branch of the tree to proceed down given the condition. M = 24-hr average $PM_{2.5}$ concentration in the node, and N = number of cases in the node. The correlation (r^2) for this decision tree is 0.72.

The particle forecasting effort initially focused on 36 major U.S. cities. However on October 1, 2003, over 140 cities across the United States provided particle pollution forecasts to AIRNow. These forecasts and real-time particle pollution reporting proved to be extremely valuable during the late October fires in California. Thousands of people in southern California were subjected to very unhealthy air quality during these fires, and having the capability to display these data and forecasts to the public during this crisis was invaluable.

5. THE FUTURE

With the success of the October 1, 2003, rollout of year-round reporting and forecasting of particle pollution, the AIRNow program is now the U.S. public's air quality resource. The future holds many opportunities to advance the science and communications of air quality and health information. In 2003, EPA and the National Oceanic and Atmospheric Administration (NOAA) signed an official Memorandum of Agreement to work together on the development of a numerical air quality forecast model. This significant agreement will provide state and local air quality forecasters with nationally consistent forecast guidance that they can use to develop their local air quality forecasts. The initial operating version for ozone is scheduled to be available in late summer 2004 and within the next five or six years will include particle pollution as well. A tool of this caliber represents a significant step forward in the field of air quality forecasting.

In addition, work continues in the deployment of continuous $PM_{2.5}$ monitors throughout the United States. Research underway will continue to explore ways to better use other data sources to supplement the existing network and enable better spatial coverage for particle pollution. There will also be numerous opportunities for the development of new forecasting tools using improved statistical approaches as well as satellite imagery. Preliminary work is already underway to ascertain if the Aerosol Optical Depth (AOD) product from the NASA MODIS system can be a viable operational particle forecasting tool.

Other areas that the AIRNow plans to address include

- increasing awareness of air quality data and forecasts among the television broadcaster community by giving short courses;
- incorporating visibility (data, cameras, and forecasts) into the AIRNow program to help establish a link between particle pollution and haze; and
- educating state and local air quality forecasters about new tools and techniques.

In December 2003, EPA conducted a strategic planning meeting to develop long-term goals for the AIRNow program. This meeting helped identify important areas of research, forecasting, operations, communication, and outreach to ensure the continued success of the AIRNow program.

It is important to remember the reason for all these forecasting and reporting efforts: to educate and inform the public about current and forecasted air quality conditions. The health effects of particle pollution on individuals are still being evaluated to ensure that cautionary health statements and levels of concern are accurate. As new information becomes available, the AQI and associated forecasting and reporting tools in AIRNow will be revised and updated to protect public health. The goal of AIRNow has always been to provide air quality information that can be used to protect public health and the environment. That goal will not change in the future; the air quality community will simply have better tools that can provide that protection.

6. REFERENCES

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