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Status of PAMS Meteorological Monitoring Activities

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ABSTRACT

The Photochemical Assessment Monitoring Station (PAMS) requires surface and upper-air meteorological data to assist in the development and evaluation of new ozone control strategies, emissions tracking, trend analysis, exposure assessment, and numerical modeling. An emphasis is placed on the acquisition of upper-air meteorological data. Wind and temperature profiles can be obtained with *in situ* measurement systems such as expendable balloon systems (rawinsondes), tethered balloon sondes, or with ground-based remote sensors such as Doppler sodars, radar wind profilers, and radio acoustic sounding systems (RASS). This paper provides a summary of the meteorological monitoring activities in support of PAMS planned for the 1997 summer ozone season. The results of several air quality studies conducted in PAMS areas are cited as examples of the importance of meteorological data in assessing ozone and precursor transport and dispersion.

INTRODUCTION

On February 12, 1993, the United States Environmental Protection Agency (EPA) promulgated rules to establish enhanced ambient monitoring networks for ozone and ozone precursors as required by Section 182 (c)(1) of the 1990 Clean Air Act Amendments. These networks, known as Photochemical Assessment Monitoring Stations (PAMS), are required in ozone nonattainment areas designated as serious, severe, and extreme. The PAMS requirements are incorporated in the ambient air quality surveillance regulations (Title 40 Part 58 of the Code of Federal Regulations). In addition to provisions for enhanced monitoring of ozone and its precursors, surface and upper-air meteorological measurements must be made in each PAMS network.

The data gathered by PAMS are intended to enhance the ability of State and local air pollution control agencies to effectively evaluate ozone nonattainment conditions and identify cost-effective control strategies. The data will be used to evaluate, adjust, and provide input to the photochemical grid models utilized by the States to develop ozone control strategies and demonstrate their success; meteorological data of known accuracy are essential to this process.

A detailed knowledge of meteorological conditions is necessary to better understand the mechanisms that are responsible for nonattainment episodes. Surface and upper-air meteorological data can be used in statistical models to characterize distinct episode types and severity. Trajectory models can be used to elucidate source-receptor relationships. A carefully designed network of surface and upper-air meteorological sensors can provide information on the dynamical structure of

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localized mesoscale circulations (sea/lake breeze, mountain valley flows) which are mechanisms for mixing, transport, and dispersion. Upper-air meteorological data can be used to estimate the height of the mixed layer. These data can also be used to infer the magnitude of vertical and lateral mixing of the atmosphere which is a measure of pollutant dispersion. Hourly profiles of wind velocity and temperature from ground-based remote sensors will improve numerical simulations from the Urban Airshed Model (UAM) and other algorithms used to reproduce nonattainment episodes. This paper provides a summary of the meteorological monitoring activities in support of PAMS planned for the 1997 summer ozone season. In addition, the results of several air quality studies conducted in PAMS areas are cited as examples of the critical importance of utilizing meteorological data in assessing ozone and precursor transport and dispersion.

METEOROLOGICAL PROGRAMS

Meteorological monitoring requirements are discussed in detail in Appendix N of the *PAMS Implementation Manual* (U. S. Environmental Protection Agency, 1994). The required surface measurements at all sites in each PAMS area include 10-m horizontal wind speed and wind direction, air temperature, and relative humidity. Solar radiation, ultraviolet radiation, barometric pressure, and precipitation measurements are required at one site in each PAMS area. Measurement of these surface meteorological variables is normally accomplished with various types of *in situ* sensors (U. S. Environmental Protection Agency, 1995). The required upper-air measurements in the first several hundred meters of the boundary layer include horizontal wind speed and wind direction, and air temperature at a representative location in each PAMS area. Estimation of the mixed layer height is also recommended. As indicated in the *PAMS Implementation Manual*, "the design of the upper-air monitoring program will depend upon region specific factors such that the optimum design for a given PAMS region is expected to be some combination of remote sensing, and conventional atmospheric soundings."

The guidance for acquisition of upper-air meteorological data provides considerable flexibility with regard to both selection of the measurement system and the siting of that equipment. In particular, the selection of a site for upper-air meteorological monitoring for PAMS is not constrained by the location of the nonattainment area. A PAMS upper-air site may be located in a different State and may serve multiple PAMS nonattainment areas. As described by Crescenti (1994), several different types of measurement platforms may used to acquire upper-air meteorological data. These include aircraft, tall towers (typically up to 500 to 600 m), expendable balloon systems (rawinsondes), tethered balloon sondes, and ground-based remote profilers such as Doppler sodars, radar wind profiler, and radio acoustic sounding systems (RASS). Wind speed, wind direction, air temperature, and relative humidity data can be easily measured by aircraft, tower-mounted sensors, and balloon sondes. Doppler sodars and radar wind profilers acquire wind speed and wind direction, while RASS collect profiles of temperature. The backscattered signal from either a sodar or radar wind profiler is also useful in tracking the height of the mixed layer. As with any measurement system, each has advantages and disadvantages. A detailed overview of these remote sensor technologies is given by Clifford et al. (1994).

A minimum of four soundings per day is recommended to monitor the growth of the convective boundary layer. These profiles should be acquired just prior to sunrise when the atmospheric boundary layer is most stable; in mid-morning when the growth of the boundary layer is most rapid; during mid-afternoon when surface temperatures are maximum; and in late-afternoon when the boundary layer depth is largest. In special cases, an upper-air monitoring plan may be augmented with data from a nearby National Weather Service (NWS) station which launches rawinsondes twice per day (00 and 12 GMT).

Table 1 summarizes the PAMS upper-air meteorological monitoring programs either in place or expected to be in place for the 1997 summer ozone season. Included in the table is the EPA Region, affected area, classification, the minimum number of surface sites required for that area, the type of upper-air measurement platform, owner and/or operator responsible for maintaining the platform, and the status of the monitoring program. Blank cells in the table mean that no information is currently available. Figure 1 shows the locations of these sites. As of this writing, fourteen radar/RASS systems, seven Doppler sodars, and two rawinsonde programs are expected to be in used in support of PAMS during the 1997 summer ozone season. The ground-based remote sensors are configured to acquire profiles of wind and temperature data as one-hour averages. A rawinsonde program is operated at Baton Rouge by the Louisiana Department of Environmental Quality (LDEQ); this program provides four rawinsonde releases per day on forecast episode days during the ozone season. All PAMS networks have access to the twice-per-day rawinsonde data provided by the NWS. The PAMS network for Atlanta, for example, makes use of the NWS rawinsonde data acquired at Peachtree City, Georgia.

PREVIOUS AIR QUALITY STUDIES IN PAMS AREAS

The use of upper-air data has lead to a better understanding of the mechanisms which lead to ozone exceedences. Ground-based remote sensors are especially valuable since they are capable of resolving the temporal variability of the atmosphere on time scales of less than an hour. When configured into a network, these sensors are capable of resolving spatial variability of the atmosphere on the order of several tens of kilometers. The following are examples of how these technologies have been used in urban areas which experience ozone exceedences.

The 1991 Lake Michigan Ozone Study (LMOS) included a comprehensive field measurement program to gather data to understand the complex meteorology and air quality of the Lake Michigan Air Quality Region (LMAQR) and to verify predictions from air quality models (Dye et al., 1995). The LMAQR, which encompasses parts of Wisconsin, Illinois, Indiana, and Michigan, experiences ozone concentrations that exceed the National Ambient Air Quality Standard (NAAQS) of 120 ppb in urban and rural areas primarily during the summer. Most of the local ozone precursor emissions originate in the urban and industrial areas of northern Indiana (i.e., Gary), northeastern Illinois (i.e., Chicago), and southeastern Wisconsin (i.e., Milwaukee) (Dye et al., 1995). The highest ozone concentrations typically occur along the Wisconsin and Michigan shorelines.

The LMOS measurement program included a sodar, seven radar wind profilers, seven rawinsonde sites, and research aircraft. Dye et al. (1995) were able to develop a five-stage conceptual model of ozone and precursor transport from this network of upper-air observations around and over Lake Michigan. First, the land breeze and general offshore flow (i.e., southerly to west-southwesterly winds) during the early morning transported emissions confined in the stable nocturnal boundary layer into the stable air (conduction layer) over Lake Michigan. Second, a sharp horizontal temperature gradient developed by 0900 CDT along the western shoreline and effectively cut off additional injections of shore-emitted precursors into the conduction layer over the lake. The strong stability of the conduction layer limited pollutant dispersion. Third, by midmorning, the developing convective boundary layer grew as convection vertically mixed ozone. Next, the prevailing winds transported polluted air to the downwind receptor regions which were either the Wisconsin or Michigan shorelines depending on the large-scale wind flow. Finally, when the ozoneladen air flowed onshore at the downwind receptor regions, air with the highest ozone concentrations located in approximately the first 300 m of the atmosphere mixed down (fumigated) to the surface first, causing the highest ozone concentrations along the shoreline. Eventually, air from higher altitudes mixed down to the surface farther inland, but ozone concentrations in these air masses had lower concentrations.

The 1992 Atlanta Field Intensive was designed to investigate the various chemical and meteorological factors leading to the continued exceedences of the NAAQS for ozone in and around the city of Atlanta, Georgia (Marsik et al., 1995). Intensive chemical and meteorological measurements were made on a series of eight ozone exceedence days from mid-July to late-August. The upper-air meteorological systems used in this study included three wind profiling radars with RASS, two aerosol lidars, and a rawinsonde system. These data were used to determine the mixing height of the planetary boundary layer. This parameter is of particular importance to air pollution modelers. The ability of photochemical and dispersion models to accurately predict surface pollutant concentrations is dependent upon the accurate representation of the time-varying mixing height. This is because the mixing height determines the effective volume in which chemical reactions take place. Overall, the rawinsonde appeared to give the most accurate mixing height estimates. The radar wind profiler estimates were found to be erroneously high during the early morning hours due mainly to the use of a setup configuration that precluded detection on the newly developing mixed layer below 400 to 600 m. However, during the day under convective conditions, estimates of the mixing height from the radar wind profiler were comparable to that of the rawinsonde.

Two regional air quality studies were conducted in southeast Texas and Louisiana during the summer of 1993 to collect meteorological and air quality data to analyze conditions that lead to exceedences of Federal and State ozone standards and to support meteorological and photochemical modeling studies of these ozone episodes (Lindsey et al., 1994, 1995). The Gulf of Mexico Air Quality Study (GMAQS) and the Coastal Oxidant Assessment in Southeast Texas (COAST) project employed a network of seven radar/RASS systems. Lindsey et al. (1994, 1995) found that every ozone exceedence was associated with a reversal of the sea breeze/land breeze circulation. Days on which the flow reversal did not occur were generally non-exceedence days. Normally, the weak land breeze (offshore flow) during the early morning hours is nonexistent since the local thermal gradients set up by the land/sea temperature difference is not large enough to overcome the large-scale, synoptically forced southwesterly flow of the Bermuda high pressure system. However, they speculated that when the Bermuda high moved westward, the synoptic scale gradients weaken allowing for the formation of the land breeze during the evenings. When this happened, the land breeze would push the polluted air from the Houston airshed offshore. This polluted air would be pushed back onshore during the next day with the onset of the sea breeze, thereby adding to the locally-generated ozone in the Houston area. It is clear from the analysis by Lindsey et al. (1995) that without the hourly-averaged radar wind profiles, it would have been difficult to assess what mechanisms were responsible for the ozone exceedences.

An array of four radar/RASS systems were deployed in the northeastern United States in the summer of 1994 to acquire upper-air data (Lindsey et al., 1996). These sensors were located in New Brunswick, New Jersey, Bermudian Valley, Pennsylvania, Schenectady, New York, and Bridgeport, Connecticut. The profiles of wind, temperature, and backscatter intensity were used to examine the mesoscale and synoptic scale processes that influence ozone and precursor transport. Analyses showed that on ozone exceedence days, growth of the convective mixed layer was slower than on prior days. This slower growth confined morning emissions to a shallower layer. Consequently, photochemistry likely occured in the presence of higher precursor concentrations. During the evening, the surface-based nocturnal boundary layer would develop to a depth of about 200 m. Between the top of the nocturnal boundary layer and the top of the previous day's convective boundary layer, a residual layer developed. This decoupled layer, which contained high concentrations of ozone and precursors, was effectively cut off from surface processes that might have titrated ozone concentrations. The moderate stability of this layer probably limited further diffusion until vigorous convective mixing to the surface (fumigation) during the next day. Within this decoupled layer, a low-level jet was observed at the profiler sites on all nights preceding an exceedence day. The core of the jet was usually centered between 400 and 800 m above the ground with velocities ranging between 5 to 15 m s^{-1} from the southwest to west-southwest. Lindsey et al. (1996) speculated that this low-level jet was capable of transporting ozone and its precursors over long distances during the evening. Once again, with out the aid of hourly wind and temperature data from the radar/RASS, it would have been difficult to determine the exact nature of this decoupled layer and low-level jet.

SUMMARY

This paper has presented a brief overview of the various PAMS meteorological monitoring activities with an emphasis placed on the upper-air monitoring components. Most of the implementing agencies are using ground-based remote sensors such as Doppler sodars, radar wind profilers, and radio acoustic sounding systems to acquire upper-air information necessary to better understand the mechanisms that are responsible for nonattainment episodes. The results of several air quality studies conducted in PAMS areas have been cited as examples of the critical importance of upper-air meteorological data in assessing ozone and precursor transport and dispersion.

DISCLAIMER

This document has been reviewed in accordance with U. S. Environmental Protection Agency policy and approval for publication. Mention of trade names or commercial products does not constitute EPA endorsement or recommendation for use.

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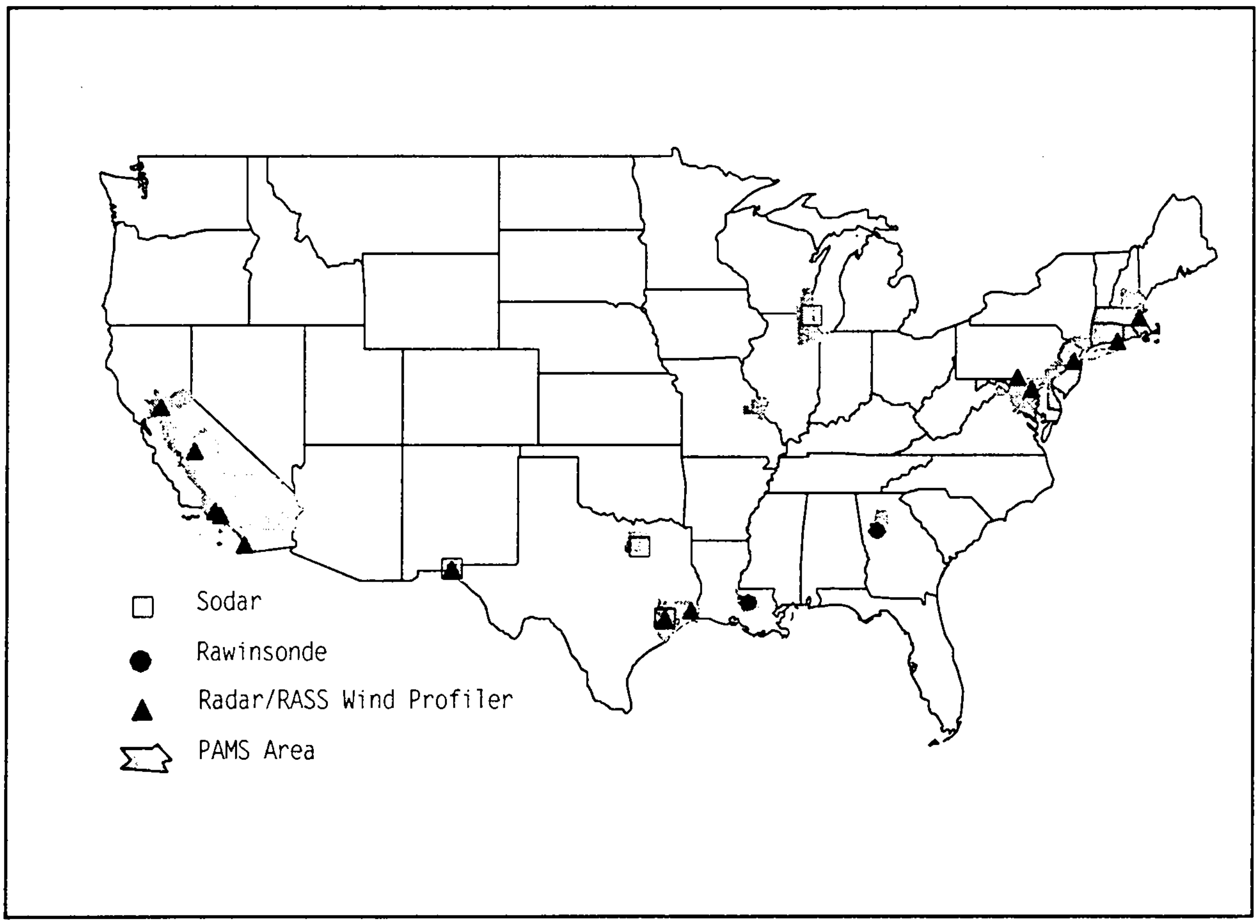

Figure 1. PAMS upper-air meteorological monitoring locations.

Table 1. PAMS Upper-Air Meteorological Sites and Systems.

Re-gion	Affected Area	Class-ification	Min. Sites	Location	Upper-air System	Owner/Operator	Status
I	Portsmouth	Serious	2				
I	Springfield	Serious	3				
I	Providence	Serious	4				
I	Boston	Serious	5	Boston	radar/RASS	State of Massachusetts	pending 97
I	Greater Connecticut	Serious	5	Millstone Point	radar/RASS	Northeast Utilities	inactive
II	New York	Severe	5	New Brunswick Redhook	radar/RASS radar/RASS	Rutgers University NARSTO-NE	active ended Aug. 96
III	Washington, D. C.	Serious	5				
III	Baltimore	Severe	5	Balitimore	radar/RASS	University of Maryland	pending 97
III	Philadelphia	Severe	5	Gettysburg Holbrook	radar/RASS radar/RASS	NARSTO-NE NARSTO-NE	ended Aug. 96 ended Aug. 96
IV	Atlanta	Serious	5	Peachtree City	rawinsonde[1]	NWS	
V	Milwaukee	Severe	4				
V	Chicago	Severe	5	Waukegan	sodar	IL Dept. Nuclear Safety	active
VI	Beaumont[2]	Serious	2	Jefferson County Airport	radar/RASS	TNRCC	active
VI	Baton Rouge	Serious	3	Baton Rouge	rawinsonde[3]	LDEQ	active
VI	El Paso	Serious	3	Univ. Texas - El Paso Lower Valley Sun Metro NW site	radar/RASS sodar sodar sodar	UTEP TNRCC TNRCC TNRCC	active active active pending 98

Table 1. (continued)

Re-gion	Affected Area	Class-ification	Min. Sites	Location	Upper-air System	Owner/Operator	Status
VI	Houston	Severe	5	Clear Lake City Galveston Airport Wharton Power Plant Ship channel	radar/RASS sodar sodar sodar	TNRCC TNRCC TNRCC TNRCC	pending 97 active active pending 98
VI	Dallas[4]			Dallas/Fort Worth Airport Upwind rural site Hinton Denton Airport	radar/RASS sodar sodar sodar	TNRCC TNRCC TNRCC TNRCC	pending 98 pending 98 active active
VII	St. Louis[4]						
IX	Southeast Desert Air Basin	Severe	2				
IX	Ventura County	Severe	3	Simi Valley Landfill	radar/RASS	VCAPCD	active
IX	Sacramento	Serious	4	Franklin Field	radar/RASS	SMAQMD	pending 96
IX	San Joaquin Valley	Serious	5	Hanford/Lemoore	radar/RASS	SJVAPCD	pending 97
IX	San Diego	Severe	5	Point Loma NAS	radar/RASS	SDAPCD	active
IX	Los Angeles	Extreme	5	Los Angeles Int. Airport Ontario County Airport	radar/RASS radar/RASS	SCAQMD SCAQMD	active active

[1]Rawinsondes launched two times per day by NWS.
[2]Reclassified on June 1, 1996 to moderate nonattainment status and therefore not required to implement PAMS program.
[3]Rawinsondes launched four times per day by LDEQ on nonattainment days during ozone season.
[4]Pending classification to nonattainment status.

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16. ABSTRACT

The Photochemical Assessment Monitoring Station (PAMS) requires surface and upper-air meteorological data to assist in the development and evaluation of new ozone control strategies, emissions tracking, trend analysis, exposure assessment, and numerical modeling. An emphasis is placed on the acquisition of upper-air meteorological data. Wind and temperature profiles can be obtained with *in situ* measurement systems such as expendable balloon systems (rawinsondes), tethered balloon sondes, or with ground-based remote sensors such as Doppler sodars, radar wind profilers, and radio acoustic sounding systems (RASS). This paper provides a summary of the meteorological monitoring activities in support of PAMS planned for the 1997 summer ozone season. The results of several air quality studies conducted in PAMS areas are cited as examples of the importance of meteorological data in assessing ozone and precursor transport and dispersion.

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