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# Project Summary

# Transport of Pollutants in Plumes and PEPES: A Study of Transport of Pollutants in Power Plant Plumes, Urban and Industrial Plumes, and Persistent Elevated Pollution Episodes

William M. Vaughan

**Because of the increased concern for the regional nature of secondary air pollutants (e.g., sulfates, nitrates, oxidants, and aerosols) the U.S. Environmental Protection Agency (EPA) sponsored a major field program in the northeastern United States during the summer of 1980. Two EPA field programs were actually carried out simultaneously. One, an outgrowth of prior power plant plume studies, addressed persistent elevated pollution episodes, and the other continued the 1979 northeast regional oxidant study in developing part of the data base for the regional oxidant model. Field activities were based in Columbus, OH.**

**Ten research aircraft and several mobile and stationary surface monitoring platforms from three EPA contractors, seven Federal agencies, and four Universities participated in the intensive measurement program between 16 July and 15 August 1980. Pollutants measured included $SO_2$, NO, $NO_x$, $O_3$, sulfate, nitrate, and aerosols. This report describes the contractors' activities. Their aircraft logged over 350 flight hours in 100 missions ranging as far east as Laconia, NH, as far south as Montgomery, AL, as far west as Texarkana, AR, and as far north as Saginaw, MI.**

**Descriptive analyses are summarized for urban plume missions and regional missions. The quality assurance program is described, showing the efforts made to develop a well coordinated data base. Sources for reports and data are provided. Many subsets of the data base can be used in model development of transport, transformation, and removal processes.**

***This Project Summary was developed by EPA's Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).***

## Introduction

Increasing concern for the regional nature of formation and transport of secondary pollutants (e.g., sulfates, nitrates, oxidants, and aerosols) has led the EPA to conduct major field studies since the mid 1970's. The project report, here summarized, describes activities during the summer of 1980 that addressed the occurrence of Persistent Elevated Pollution Episodes (PEPES) and continued the Northeast Regional Oxidant Study (NEROS). These activities are known as The 1980 PEPE-NEROS study.

The PEPE-NEROS study involved two field programs coordinated from headquarters in Columbus, OH. PEPE opera-

tions involved regional-scale missions to characterize air masses transporting aged pollutant mixtures. NEROS operations involved regional characterization missions to provide parameterizations for the Regional Oxidant Model (ROM) as well as urban plume missions to describe inputs to the ROM. Common weather forecasting, communications, and data processing supported both studies. Platforms were deployed for PEPE or NEROS missions, dependent on forecast conditons.

The prime contractor for this study was Environmental Measurements, Inc. with strong sub-contract support from AeroVironment, Inc., SRI International, and Washington University Technology Associates. The project report focuses on the activities of this contractor team.

## Field Study

### *Participants and Platforms*

The organizations that participated in the PEPE-NEROS study are shown in Table 1. Table 2 shows the nature of their participation and the principal investigators involved.

### *Operations*

Depending on weather conditions, platform status, and study objectives, specific PEPE or NEROS missions were planned and executed. These missions involved various mixes of activities and geographic coverage.

The NEROS missions for urban and regional studies involved release of clusters of small tetroons at various altitudes (97 tetroons were released and tracked by NOAA-Idaho Falls), and release of a large EPA tetroon to be tracked by FAA centers. The position of the large tetroon could be phoned to field headquarters in Columbus from the FAA centers. Once the transport was marked be tetroons, the aircraft and surface platforms were deployed to document the air quality and mixing conditions in the air mass. CHOPPER and the NOAA turbulence aircraft were principally dedicated to urban plume surveys. The EPA Lidar plane mostly carried out plume-oriented studies, but occasionally conducted regional studies outside Ohio. Moving Lab conducted frequent ground-level surveys near Columbus, but was also deployed to West Virginia and Kentucky for PEPE-oriented regional surveys.

NEROS regional measurements were made between about 70 and 85° W longitude, and 38 and 45° N latitude to characterize the northeastern grid used in the ROM. SCOUT, CHEM-1, and CHEM-2 made frequent flights across various parts of this NEROS area. They were usually vectored to the location of the large EPA tetroon in order to measure the aging of the air mass in the vicinity of this specific marker.

ELECTRA was deployed for its regional surveys from Wallops Island, VA in support of NEROS and PEPE regional measurements. CHEM-3 provided correlative *in situ* measurements at selected locations beneath ELECTRA's flight path as it had done earlier in the program for LAS-Queenair flights.

PEPE regional surveys were less restricted, involving flights into stagnant air masses (two to five days old) or into moving air masses characterized by regional visibility degradation, as reported by FAA and National Weather Service wire services and as detected by satellite imagery. These regional surveys extended into New York and New England during the first week of August 1980, following development of wide-spread haziness in the area. In the middle of the second week of August, several flights into Tennessee, Alabama, and Arkansas were carried out to characterize a maritime tropical air mass associated with an extension of the Bermuda high that had been stationary over Georgia and Tennessee for four days. Measurements were also made as this aged air mass moved out to the Atlantic.

Both internal and external quality assurance activities were carried out throughout the field measurement program. The contractor team referenced its platform measurements to a master calibrator separate from each contractor's internal quality assurance program. The team addressed the altitude and time response of various instruments and developed a uniform approach to data processing. Aircraft flybys were conducted to provide *in situ* platform comparisons. In addition, EPA provided an external audit of most of the project platforms through the services of Research Triangle Institute and PEDCO.

### *Data Base*

The Project Report gives a summary description of the data base that was created at the Special Studies Data Center at Washington University. This data base is also available at EPA's Meteorology and Assessment Division. These

***Table 1.*** *Participants in the PEPE NEROS Study*

| |
|---|
| Agencies |
| *U.S. Environmental Protection Agency* |
| *ESRL - Research Triangle Park* |
| *EMSL - Research Triangle Park* |
| *EMSL - Las Vegas* |
| *National Oceanic and Atmospheric Administration (NOAA)* |
| *Boulder Laboratories (BL)* |
| *Idaho National Engineering Laboratory (INEL)* |
| *National Science Foundation* |
| *National Center for Atmospheric Research (NCAR)* |
| *National Aeronautics and Space Administration (NASA)* |
| *Langley Research Center (LRC)* |
| *Jet Propulsion Laboratory (JPL)* |
| *Wallops Island* |
| *Department of Energy* |
| *Argonne National Laboratory (ANL)* |
| *Federal Aviation Administration (FAA)* |
| *Tennessee Valley Authority (TVA)* |
| *Ohio Environmental Protection Agency* |
| Contractors |
| *Environmental Measurements, Inc. (EMI)* |
| *AeroVironment, Inc. (AV)* |
| *SRI International* |
| *Washington University Technology Associates (WUTA)* |
| *MESOMET, Inc.* |
| *Battelle Columbus Laboratories (BCL)* |
| *Research Triangle Institute* |
| *PEDCO Environmental* |
| Universities |
| *Washington University* |
| *Harvey Mudd College* |
| *Ohio State University* |
| *Others, supported by the Agencies* |
| International |
| *Atmospheric Environment Service of Canada* |
| *Millan M. Millan of Barringer Research* |
| *N.D. van Egmond, Rijks Instituut voor de Voksgezondheid* |
| *Bertin & Cie* |

**Table 2.** *Platforms and Operations During PEPE-NEROS*

| *Airborne Platforms* | *Source* | *Principal Investigator* |
|---|---|---|
| *CHEM-1 (Chemistry Aircraft)* | *EMI* | *Willian Vaughan* |
| *CHEM-2 (Chemistry Aircraft)* | *AV* | *Ivar Tombach* |
| *SCOUT (Chemistry Aircraft)* | *SRI* | *Bruce Cantrell* |
| *ELECTRA (Lidar Aircraft)* | *NASA/LRC-Wallops Island* | *Ed Browell (UV-DIAL)[a] Jeffrey Scroga (HSRL)[b]* |
| *CHEM-3 (Chemistry Aircraft)* | *NASA/LRC* | *Gerald Gregory* |
| *LAS[c] Queenair* | *NASA/JPL* | *Mike Schumate* |
| *EPA Lidar* | *EMSL Las Vegas* | *Jim McElroy* |
| *Turbulence Aircraft* | *NOAA/BL* | *Brad Bean* |
| *Cloud Chemistry Aircraft* | *NCAR* | *Al Lazrus* |
| *CHOPPER (Chemistry Aircraft)* | *EPA-TVA-EMI* | *Willian Vaughan* |
| Surface Platforms | | |
| *Moving Laboratory* | *EMI* | *Gary Klauber* |
| *Doppler Sodar 1 and 2* | *AV* | *Michael Chan* |
| *Aerosol Laboratory* | *U. of Minnesota* | *Peter McMurry* |
| *Lidar Van* | *SRI* | *Ed Uthe* |
| *Tethered Balloon* | *NASA/LRC* | *Otto Youngbluth* |
| *Bertin Sodar* | *Bertin & Cie* | *Pierre Huguet* |
| *MARS[d]* | *NASA/JPL* | *Bruce Gary* |
| Other Operations | | |
| *Small Tetroon Tracking* | *NOAA/INEL* | *Gene Start* |
| *Large Tetroon Tracking* | *SRI* | *Walt Dabberdt* |
| *GC Laboratory* | *ESRL* | *William Lonneman* |
| *Photochemistry Precursors* | *Harvey Mudd* | *Gregory Kok* |
| *$NO_x$ Ozone Network* | *EMI-BCL* | *William Vaughan* |
| *Dry Deposition Experiment* | *ANL* | *Marvin Wesley* |
| *Sun Photometer Network* | *NASA/LRC-U. of Miami* | *Joe Prospero* |
| *Data Center* | *WUTA* | *Noor Gillani* |
| *Weather Center* | *SRI* | *William Viezee* |

[a] *UV-DIAL Ultraviolet Differential Absorption Lidar*
[b] *HSRL High Spectral Resolution Lidar*
[c] *LAS Laser Absorption Spectrometer*
[d] *MARS Microwave Atmospheric Remote Sensor*

magnetic tape data are in standard format and are available by individual platform or by day with all measurements linked by time.

The magnetic tape data base has a companion hard copy data base with data volumes for contractor platforms and for special study measurements. An overview volume summarizes meteorological conditions and measurement activities for each day.

## Observations

As noted above, both urban plume and regional missions were carried out. These collections of data were reviewed and assigned a priority based on apparent quantity and quality of data. Descriptive analyses were then prepared.

AeroVironment prepared a descriptive analysis report for the urban plume surveys on 30-31 July and on 4, 12, and 13 August 1980. Because of budget constraints, these analyses were focussed on the flights of CHEM-2. SRI International prepared regional descriptive analyses for the regional missions on 1 August and on 7-11 August 1980.

### Urban Plume Descriptive Analysis

The data from CHEM-2 were closely reviewed for chemistry information, and the data from Lidar Van, Sodar-1 and -2, NWS soundings from Dayton, and from tetroon releases were used to evaluate the meteorological data. Air parcel trajectories were constructed for the five urban plume days noted above. The air quality parameters measured by CHEM-2 were summarized for the times when CHEM-2 was considered to be in the urban plume from Columbus.

The vertical extent of the plume was determined from aircraft soundings and was used to select the altitude range of winds for trajectory calculations. The width of the urban plume was graphically presented to show plume maximum and average concentrations as well as background values to either side of the plume and upwind of Columbus. Seven air quality parameters were tabulated for each traverse of the plume. Values for the plume were sometimes difficult to determine because of small gradients, and often required subjective judgements. Ozone served as the best indicator of the urban plume.

On several occasions, trajectory evaluation indicated that measurements may have been made to the side of the urban plume. Measurements within the urban plume indicated that higher ozone levels tend to occur in the lower portion of the plume, and that the plume width, defined by elevated ozone values, does not vary greatly, averaging 20 to 30 km. Some transects at greater distances showed apparently narrower ozone plumes, probably because only the core of the plume was distinguishable from background values. Data from other platforms may improve the overall plume resolution.

The Columbus plume was much easier to detect and track with a flow of clean continental air from the northwest than with a southwesterly flow when the plumes from Cincinnati and Dayton, OH made up the background air mass.

### Regional Descriptive Analysis

Separate meteorological descriptions were prepared for the time periods examined by SRI International. An extensive array of meteorological data was evaluated for each period, including probabilistic treatment of trajectories that were transporting the air.

The general measurement activities of the surface and airborne platforms were summarized in graphic form. Tables were prepared summarizing the average, maximum, and minimum values of up to six air quality parameters ($O_3$, $NO_x$, $SO_2$, $b_{scat}$, sulfate, and nitrate) along various segments of the traverses.

The 1 August 1980 measurements, primarily by CHEM-2, involved following an air mass of low visibility that was exiting the east coast. It did not linger over the Ohio Valley long enough to become a major PEPE over that region. Sampling proceeded eastward from cleaner air over Ohio into the dirtier trailing edge of the air mass. Because the flight was approximately parallel to the transport wind, measurements in the eastern portion of the flight were

made in older air parcels that had been over Ohio 6-12 hours earlier. Definite trends of increasing ozone, sulfate, nitrate, and light scattering show the penetration of aged air parcels. Ozone, in units of ppb, increased from about 90 in eastern Ohio to about 115 in eastern Pennsylvania and New Jersey, light scattering, in units of $10^{-4}$ $m^{-1}$, increased from 1 to 5; 2;'s aerosol sulfate, in units of $\mu g\ m^{-3}$, increased from 23 to a peak of 50, then dropped to about 32; and nitrate, in units of ppb, increased from 3 to 8. Vertical profiles showed little stratification within the mixed layer. The return flight documented the cleaner air to the west, but also showed dirtier air toward the surface as the air stabilized after sunset. Aerosol sulfate, in units of $\mu g\ m^{-3}$ dropped from about 35 in New Jersey to about 15 in central Pennsylvania, but increased to about 31 below 900 m elevation in eastern Ohio.

Meteorological conditions of 7-11 August led to a broad region over the southeast of relatively stagnant air that was strongly influenced by the diurnal heating cycle, with daytime convection distributing the low visibility air near the surface into a deep layer. This mixing prevented the buildup of aerosols in a layer near the surface that would have led to even lower visibilities. In addition, thunderstorms and associated washout led to a patchy pattern, in both the horizontal and vertical, of low visibility and increased pollutant levels.

The northern part of the stagnation region was initially monitored on 7-8 August following a Regional Air Mass Characterization scenario, with a shift to regional PEPE missions as the stagnant air mass developed. The PEPE missions were conducted through 11 August, when an approaching cold front terminated the episode. During the episode, three regions of low visibility and high ozone were characterized by measurements. NEROS platforms obtained measurements in one of these areas, over the Washington, D.C. to New York, NY corridor. Contractor platforms characterized areas over the southeast portion of the Ohio River valley, and then over northern Alabama. Ozone values in the main PEPE area to the west of the Appalachians were generally above 90 ppb and reached 150 ppb in some areas. Light scattering coefficients up to $5 \times 10^{-4}$ $m^{-1}$ were measured.

## Recommendations

The extensive, relatively homogeneous, and accessible data base that now exists as a result of the PEPE-NEROS field program is primed for further use. It is a valuable data base because great care was taken to integrate it into a coherent whole, from design concept through field implementation. This data base is a singular collection of atmospheric measurements that address:

- Transformation processes associated with acid rain issues
- Transport processes associated with regional oxidant and visibility issues
- Mixing and removal mechanisms
- Aerosol growth by heterogeneous and homogeneous mechanisms
- The interaction of forecasts and realtime trajectories with field sampling strategies
- Other topics to be defined as atmospheric process investigators and modelers become aware of this resource.

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*The complete report, entitled "Transport of Pollutants in Plumes and PEPES: A Study of Transport of Pollutants in Power Plant Plumes, Urban and Industrial Plumes, and Persistent Elevated Pollution Episodes," (Order No. PB 85-191 666/AS; Cost: $10.00, subject to change) will be available only from:*
*National Technical Information Service*
*5285 Port Royal Road*
*Springfield, VA 22161*
*Telephone: 703-487-4650*
*The EPA Project Officer can be contacted at:*
*Atmospheric Sciences Research Laboratory*
*U.S. Environmental Protection Agency*
*Research Triangle Park, NC 27711*

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