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A SUMMARY OF THE POLLUTION EVENTS DURING NE-OPS DEP 2002

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1. INTRODUCTION

The North East Oxidant and Particle Study conducted field measurements during the summers of 1998, 1999, 2001, and 2002. The summers of 1999 and 2002 had anomalously warm and dry periods compared to climatology, and each summer displayed a broad range of events. In this paper we will concentrate on the summer of 2002 since the events of 1999 have been reported elsewhere, see Investigations of Ozone and Particulate Matter Air Pollution in the Northeast, Philbrick et al. 2000**.** The research took place in Northeast Philadelphia, approximately 2.5 km southeast of the Northeast Philadelphia airport and 13 km NNE of the urban center. The site was bounded on the east by the Delaware River, on the west by Interstate 95 about 0.4 km from the site, to the north by suburban areas and the south by the urban Philadelphia. In addition to Millersville University, other institutions participating in the PA-DEP funded project included The Pennsylvania State University (Raman Lidar), University of Maryland (Aircraft), Clarkson University (surface particulates and trace gases), and Drexel University (long-chain carbons).

2. INSTRUMENTS AND DATA COLLECTION

Millersville University deployed a Tethered Atmospheric sounding system (TASS) for aloft measurements of conventional meteorological variables (T, p, Rh, wind), ozone concentration, and scattering as a proxy for PM2.5. A suite of instruments located at the surface included: a TSI 3-wavelength nephelometer, API analyzers for O_3, CO, SO_2, and $NO/NO_2/NO_x$, and complementary PM2.5 measurements for comparison with the aloft values.

The signals from sensors attached to the TASS were radio-transmitted to the surface for near-real time analysis and archiving. The laser diode scatterometer recorded 5-minutes average PM2.5 concentrations on a data-logger, which were downloaded periodically. The API trace gas analyzers recorded one-minute averages of gas concentrations, which were stored and retrieved once per day.

The TASS was used in a profiling mode, ascending to 300 m then descending to the surface at an approximate rate of 0.2 m/s. Measurements were transmitted to the data acquisition system about every 3 seconds. In this manner Millersville University was able to obtain a characterization of the atmospheric boundary layer to 300 meters with high vertical and temporal resolution. Approximately 540 profiles of the ABL were obtained over the 30-day project duration, which commenced on June 30, 2002.

3. CASE STUDIES

Seven air quality episodes were identified in summer 2002. Below is a listing of all the pollution episodes during the duration of the 2002 intensive. Although all events are interesting, the case studies included in this paper illustrate the transport mechanism the best.

Summer 2002 Air Quality Episodes

Date	Description of 2002 Episodes
July 1-3	"Cut-off" low; High O_3, particle, and haze event, strong nocturnal jet; many one hour exceedances.
July 6-7	Canadian wildfires; highest particulate matter event in four years, priming conditions for high O_3 on July 8-9.
July 8-9	Recirculation event; highest O_3 on July 8th, 150 ppbv; Haze and high O_3 on July 9th.
July 17-19	High O_3 and haze event; Code Orange spread northerly along I-95 corridor from Philadelphia to New York.
July 22-23	Hot and humid conditions but strong winds kept O_3 in moderate range in PA; CT and MA reported Code Red
July 28-29	Convergence along leeside trough brings moderate O_3 levels into PA; Temperatures in 80 F keep O_3 from reaching Code Red; Haze present due to high (70 F) dewpoints
July 31-Aug 5	Highest O_3 from IAD to NYC along I-95 corridor; Stagnation event and large areas of Code Red and Code Orange.

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3a. High Haze event of July 1-3, 2002

High haze was observed in the Philadelphia metro area beginning mid-day on July 2, 2002. Visibility dropped from 10 statute miles to 4 statute miles in under 5 hours. On July 1, 2002 haze was observed west of the Appalachian Mountains, and was then advected into the Philadelphia area the next day (Ryan et. al. 2002). The HYSPLIT back trajectory showed that the air was transported, at low levels from northwestern Pennsylvania. At 5000 m an upper level low was the principal driver for the transport of air from Quebec east then south through New York City, and finally in to the Philadelphia area.

Accompanying this drop in visibility was a rise in the ß-Scattering coefficient to levels that were four times the levels seen on other high pollution days (Fig. 1). In fact the back scattering alone exceeded the values seen in total scattering on a "normal" high pollution event. This was a significant haze event for the Northeast. One possible explanation for the high scattering coefficients is small Canadian wildfires in the northern Great Lakes region. The wildfires were smaller in size than the wildfires that influence the region later in the week.

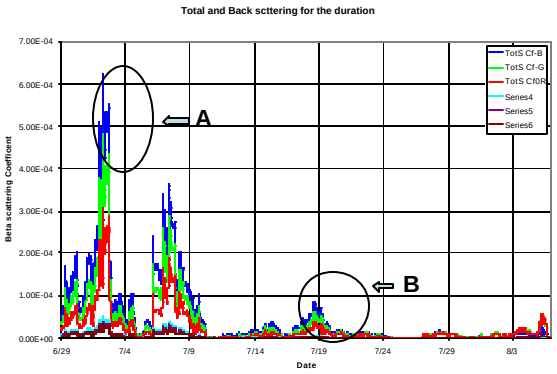


Figure 1. (A) shows the scattering coefficient during the high haze event. (B) represents a separate high pollution event. The trace gas concentrations where in the moderate range during July 1-3.

In conjunction with the high scattering coefficients for this episode, $PM_{2.5}$ values were also well above their norms, with values in the range from 0.10 to 0.25 with an average of 0.13mg m^{-1}.

Also during this period relatively high ozone values were observed reaching 120 ppbv on July 2, 2002. During the early morning hours of July 3, nighttime values were measured over 80 ppbv, while the previous night at the same time values never exceeded 30 ppbv.

The end of this hazy period was marked by a drastic and rapid reduction in the scattering coefficient, a decrease in relative humidity, and an increase in visibility. This occurred between 0600 and 1200 EDT July 3, 2002. Scattering coefficients remained near normal until the next event of NEOPS-DEP, the Canadian smoke event.

3b. The Canadian Smoke Event of July 6-8, 2002

A low pressure system located to the northeast of Maine brought smoke from Canadian wild fires into the mid-Atlantic region beginning on July 6. Air in the region was smoky and had the faint smell of pine. Deterioration of the air quality was first seen during the twilight hours of July 6. During the afternoon of July 6, the first evidence of smoke could be seen at the site in the form of high thin overcast at an altitude of about 4000 m. With afternoon temperatures around 25-27 C, and a brisk wind driven by synoptic gradients, the smoke began to mix down to the surface where is could be readily detected by deteriorating visibility, the faint smell of pine, and high values of scattering coefficient and PM2.5. By sunset on July 6, the media coverage was extensive.

HYSPLIT back trajectories show that the smoke in the Philadelphia area was advected rapidly from the area of the Canadian wildfires (Fig. 2). Nephelometer data showed the initial "wave" of the smoke reached Philadelphia at approximately 1600 EDT. DustTrak and nephelometer data (see Fig. 1) show a wave like pattern of rises and falls, as smoke plumes moved through the site.

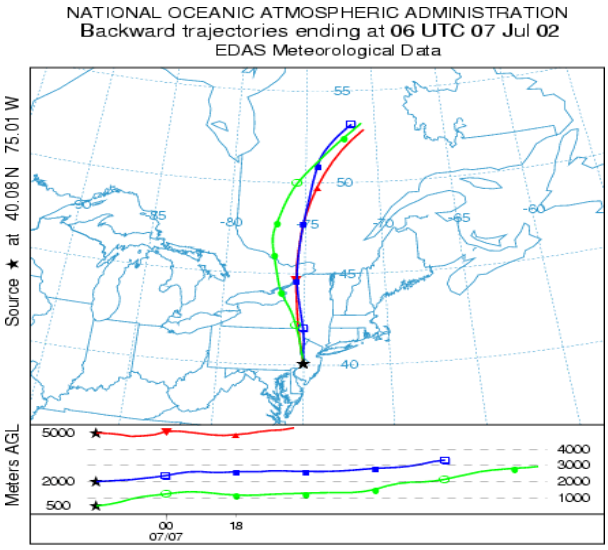


Figure 2: A HYSPLIT back trajectory initialized on July 7th at 0600 UTC going back 48 hours.

Trace gas data clearly shows the onset of the smoke event with rapid rises in the CO and SO_2 concentrations. During July 6-7, ozone levels did not exceed 80 ppbv because brisk winds kept local concentrations from accumulating. But on July 8 ozone levels reached its highest concentration for the 30-day project at 140 ppbv.

Forest fire emissions can contain large quantities of enhanced ozone concentrations (Wotowa and Trainor, 2000;Peppler et al., 2000; Wotawa et al., 2001). Levels of CO were measured above 1.4 ppmv. Average CO levels on July 7 were above 1.2 ppmv, while a non-smoky day is typically below 0.6 ppmv.

Although ß-scattering coefficient was not as high as the haze event of July 1-3, the $PM_{2.5}$ at the surface was 3-4 times higher than a "normal" polluted summer day (Fig. 3). Values reaching 0.7 mg/m^{-1} were seen, which is the highest value recorded during the three years of NE-OPS field studies. This PM2.5 concentration measured aloft through 300m AGL using the laser-diode scatterometer onboard the TASS is shown in Fig. 4. While the July 6-7 smoke event was interesting from a scientific point of view, its pervasiveness and the fact that is was solely due to a natural condition, albeit extreme, did not elicit much ramification from the regulatory side.

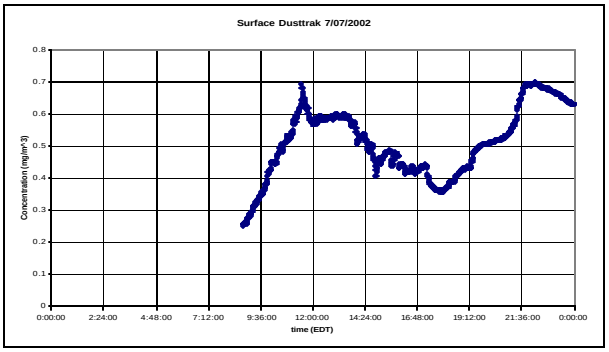


Figure 3: This illustrates the extreme values of $PM_{2.5}$ on July 7, 2002. Normal values are 3-4 times lower.

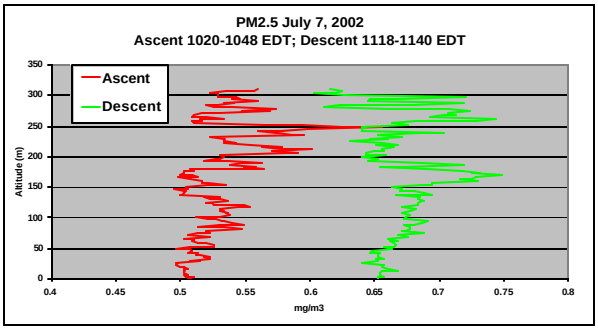


Figure 4: This shows the vertical distribution of $PM_{2.5}$ obtained by the laser-diode scatterometer on the TASS.

3c. July 17-19, 2002 High Pollution Event

The upper level pattern was remarkably similar to the one that was seen during the smoke event with a low over eastern Canada, but in the lowest levels a back-door cold front passed the site July 17 bringing with it drier air. Later in the day the front recirculated back towards the north bringing with it moist maritime air with enhanced pollutant concentrations. This provided a synoptic setting for a Code-Orange pollution event (Ryan et al. 2002).

NOx and CO levels rose quickly during the morning rush hour, reaching a maximum at approximately 0830 EDT. A rapid rise in O_3 followed as NO and NO_2 were oxidized. Fig. 5 very clearly shows the morning rush hour.

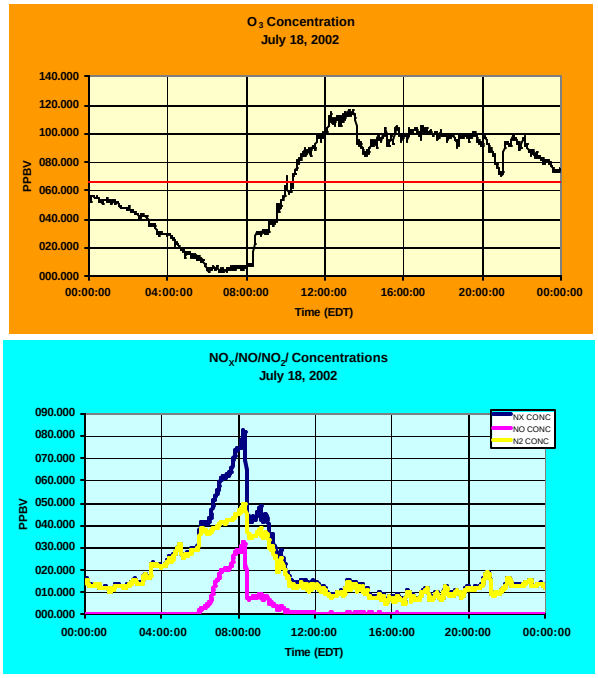


Figure 5: The ozone chart (top) shows a rapid increase in ozone levels just after 8:00 EDT. While the NO/NO2/NOx chart (bottom) show the rapid rise up to 8:00 EDT then a rapid fall.

High haze also occurred on these days due to the high humidity, relatively high aerosol concentration, and subsequent deliquescence of aerosols to form haze droplets. ß-scattering coefficients were the third highest seen during the project (Refer to Fig. 1). Along with this rise in β-scattering coefficient was an accompanying rise in the concentration of $PM_{2.5}$.

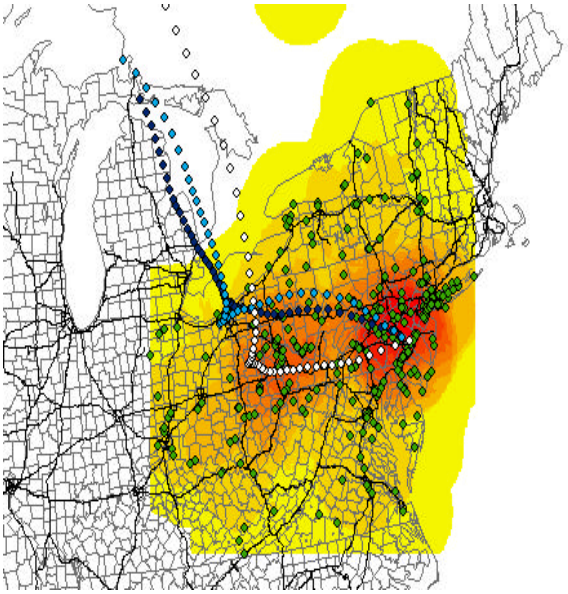


Figure 6: July 18 back trajectories overlaid upon EPA emissions data. White dots indicate the 5000m height, blue is 2000m and purple is 500m. The warmer colors indicate areas of high NOx concentrations.

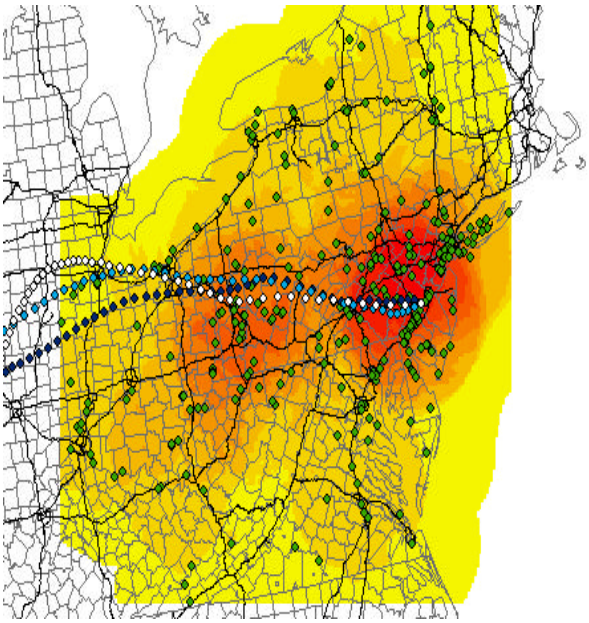


Figure 7: Same as fig. 6 except for July 19, 2002.

To further elucidate the characteristics of this July 18-19 event, we employed ArcGIS v.8 to combine HYSPLIT parcel trajectories and hourly industrial plant emission obtained from the EPA archives (Figs 6-7). The trajectory path of the air over the Pittsburgh urban area is clearly seen. Darker colors on the map indicate areas of higher concentrations of nitrous oxides. The air moved into the Philadelphia region over a 12-hour period contributing to the degradation of the air quality in the Philadelphia region. Air on July 17 originated over the Great Lakes then moved south into Ohio and finally made an eastward turn through Pittsburgh and into the Philadelphia region. Air on July 18 (Fig. 6.) showed a very similar track as July 17 again starting over the Great Lakes. July 19 (Fig. 7.) indicated that the air originated over the mid-west then followed a similar path as the air on July 18. It is apparent that the deleterious air quality in Philadelphia is, in part, due to the influx and advection of precursors and pollutants from the western urban areas and the Ohio River Valley. The focus of ongoing research is to quantify these numbers using box models and ArcGIS.

3d. Sea Breeze Front of July 20, 2002

A cold front passed over the research site early in the morning, followed by weak easterly winds behind the front. This weak easterly flow combined with clear sky conditions and seasonal temperatures provided a setting that produced coastal gradients and established a sea breeze front. Aided by the easterly synoptic flow, the sea breeze was able to propagate across NJ and into eastern PA at approximately 2030 EDT. Following the passage of the sea breeze front wind direction changed abruptly to southeasterly (Clark et al. 2002).

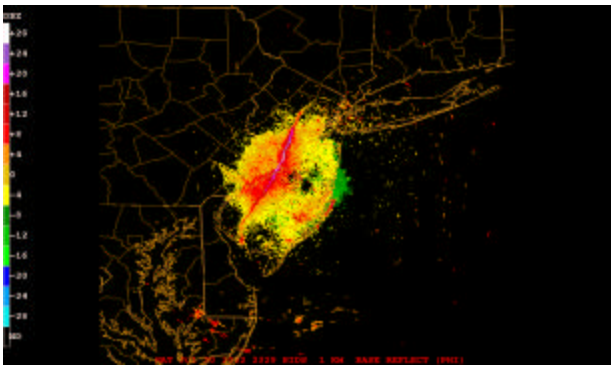
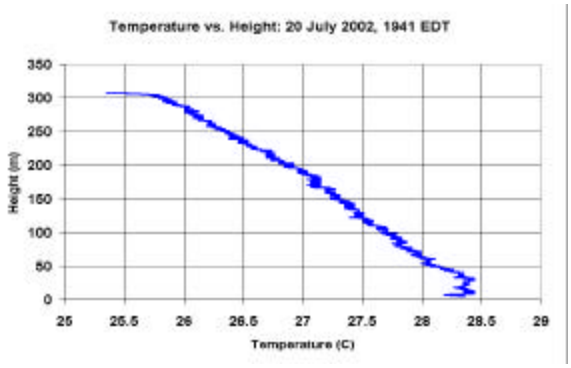
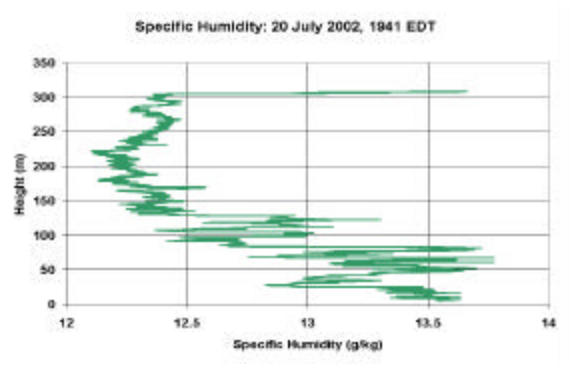


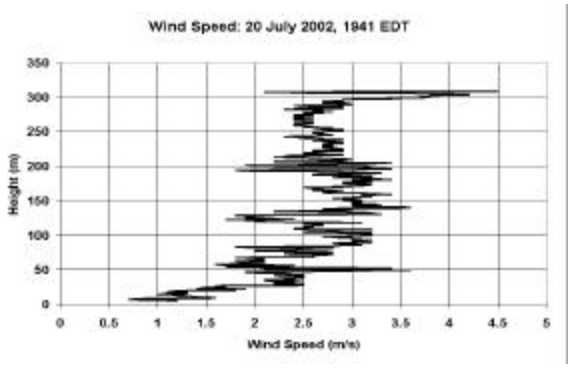
Figure. 8. Sea breeze front approaching Philadelphia at 2329 UTC (1929 EDT) on 20 July 2002.

Using the Ft. Dix WSR-88D radar (see Fig. 8) we were able to anticipate the approach of the sea breeze, which allowed us to deploy the TASS and produce the profiles shown in Fig. 9. In just a few minutes the profiles of humidity, temperature, wind speed and direction change a very noticeable amount as the sea breeze front moves over the area. Specific humidity increased from 13 – 22 g kg^{-1}, wind speed from 2-3 ms^{-1} to 6-7 ms^{-1}, and wind direction from east-northeasterly to southeasterly. Similar changes are observed in the surface trace gas time series, with uncommon rises in SO_2, NO_X, and O_3 on the bow wave of the sea breeze front as it passed over the site (Fig. 10).

Normally after the passage of a sea breeze front there is a sudden rise in humidity and a decrease in trace gas concentration as cleaner air advects into the region at low levels. Most sea breeze intrusions replace westerly winds with cleaner easterly flow. With the passage of this front we observed the increase in humidity due to the marine air mass, but we also recorded an atypical rise in trace gas concentrations. We believe that this rise in all four trace gas concentrations was due to the wind shift from east-northeasterly to southeasterly, replacing air that received little or no influx from upstream urban areas as it moved across the pine barren regions of NJ, with air whose quality had been significantly deteriorated by the weekend beach traffic. The sea breeze brought air from the Atlantic City area. Combustion products had a chance to “cook” in the afternoon sun and ultimately made their way into the Philadelphia region on the sea breeze front. Although the air quality was not a major threat to the health on this Saturday, it does illustrate how an air mass can be replaced in a very short time, as well as how small changes in wind direction along the Northeast corridor can have a major impact on the local air quality.







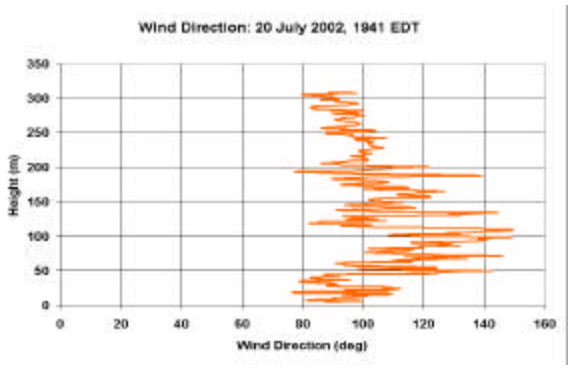
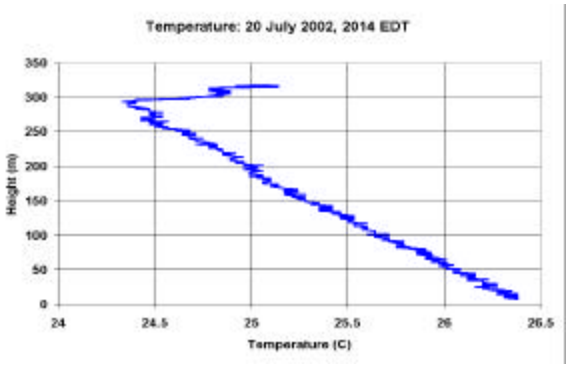
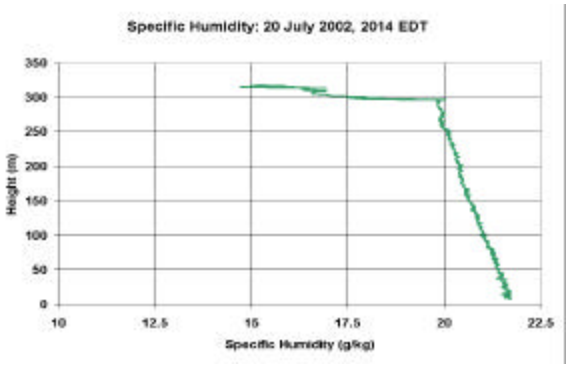
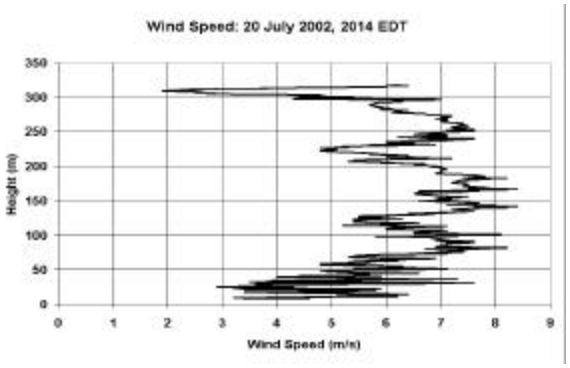


Fig. 9a. Vertical profiles obtained in the ascent mode using the TASS on July 20, 2002. Time is 1941 EDT; Top to bottom: Temperature (C), specific humidity (g/kg), wind speed (m/s), and wind direction (deg).







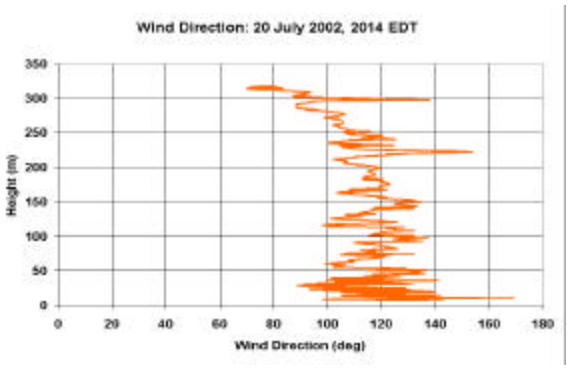


Fig. 9b. Vertical profiles obtained in the descent mode using the TASS on July 20, 2002. Time is 2014 EDT. Top to bottom: Temperature (C), specific humidity (g/kg), wind speed (m/s), and wind direction (deg).

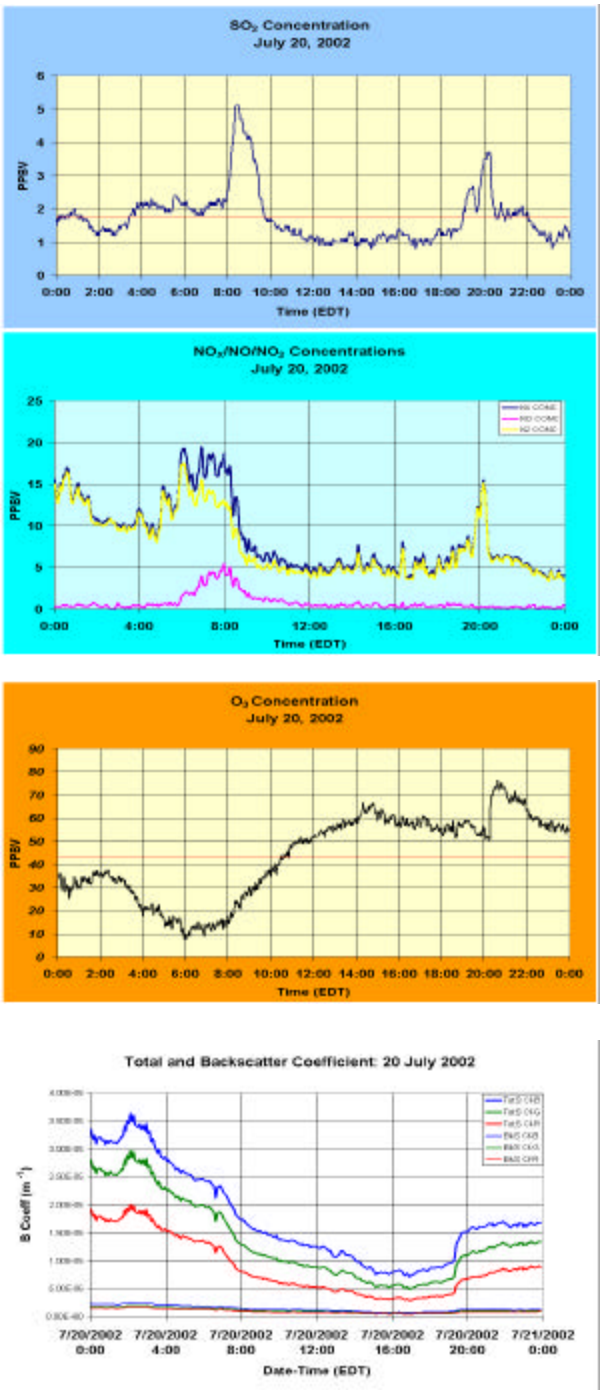


Fig. 10. Time traces of SO_2, $NO/NO_2/NO_X$, O_3 and β-scattering coefficient for July 20, 2002. Note the jump in concentration and scattering around 2000 EDT corresponding to the passage of the sea breeze front.

4. Summary

Urban pollution is not a problem that is bounded by the urban limits. On many occasions, the air quality that a location experiences on any given day is a function of the background concentrations, local production, and the amount of precursor and pollutant transport into the area by the wind. The effect of transport was the focus of this study. Presently, the results are only semi-quantitative, and the influence of transport can be clearly seen in the cases described in this paper. However, through funding from the PA-DEP, we are actively employing ArcGIS to quantitatively estimate the amount of trace gases emitted into urban plumes and carried into other areas along the parcel trajectory. Using model-based back trajectories, emission data, and conceptual models, air quality researchers are realizing the importance of transport, and this knowledge may help forecasters better predict pollution events.

High haze can be contributed to not only humidity but also to the advection of pollutants into an urban area, as seen in the Haze event of July 1-3. It is also clear that Haze can move into an area quite rapidly and affect the quality of air. Not all haze events are alike some contain higher ß-scattering values than others. The clearest example of pollutants being advected into an area is the Canadian smoke event, even though this was not considered a regulatory infraction because of its natural origin. It was very clear that high concentrations of smoke can be carried a very large distance. This smoke imports precursors that can drastically increase the levels of ozone and other trace gases, as it did on July 8-9 when the air mass, laden with pollutants, recirculated back toward the north.

Back trajectories overlaid on the emission data give us a very good idea of where the air that affects the region originates and also lets us know what pollutants and how much enters the plume. July 18-19 shows this very well. The path of the air through the Pittsburgh area "loads" the parcel with pollutants, and those parcels then move into the Philadelphia area and can mix down in the daytime boundary layer.

Finally, this analysis shows that sea breeze fronts that originate in the cleaner coastal regions do not always replace dirty air with clean air. Depending on their origin and the influences of human activity, small changes in wind direction can have profound effects on the local air quality, and in some cases, a sea breeze can actually bring air with higher trace gas concentrations. An understanding of the mesoscale features on a regional perspective is essential if we are to better predict the onset of a pollution (or clean air) event. Transport of pollutants plays a major role in the magnitude of pollution events in the major population centers.

5. Acknowledgments

The author would like to thank Dr. Richard Clark for allowing undergraduates such as myself to participate in this meritorious research. The author also wished to thank the PA-Department of Environmental Protection. Also acknowledged for its support of the NE-OPS study is the U.S. EPA under EPA grant R826373.The author also acknowledges the work of fellow students, Evan Lowery, Dan Rabatin, and Dan Brewer, who contributed to the GIS work, and other analyses. A special note of thanks goes to all the students and scientists from the

institutions involved in this research. Finally, my appreciation is extended to the Millersville University for providing partial support for the submission of this manuscript.

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