EVOLUTION OF AIR POLLUTION EVENTS DETERMINED FROM RAMAN LIDAR

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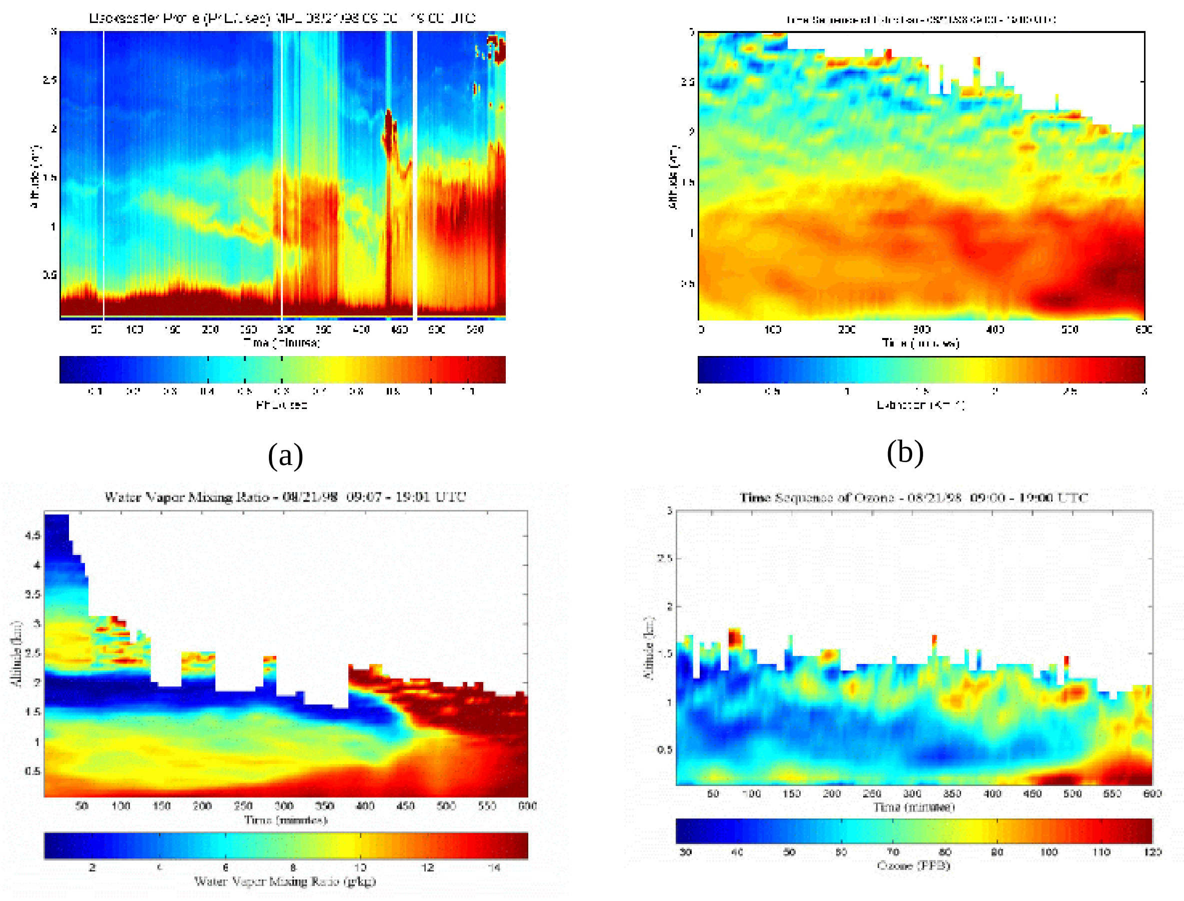
Introduction. Analyzing data obtained during atmospheric pollution episodes, which generally result in increases in both ozone and fine particle matter, provides a means of describing the evolution of pollution events and the influence of the local meteorology in changing the particle and chemistry distributions in the lower atmosphere. Vertical profiles of atmospheric constituents were obtained using a multi-wavelength Raman lidar to describe pollution events in the lower atmosphere. The signal profiles from Raman scatter wavelengths at 607, 530, and 285 nm, and the lidar backscatter at 532 nm were used to measure optical extinction, while at the same time Raman lidar measurements were used to obtain profiles of water vapor, temperature, and ozone. Correlation between backscatter and extinction measurements provides a means of describing variations in atmospheric aerosol and particulate matter in the lower atmosphere. It is important to obtain improved ways of measuring the distribution of airborne particulate matter, which has been shown to have a strong correlation with health and respiratory problems. Investigations of the relationships of profiles of optical extinction with profiles of water vapor and ozone are useful in understanding the evolution of pollution events. Water vapor time sequences provides a most useful description of the boundary layer dynamics. Examination of atmospheric pollution episodes shows strong correlation between ozone and aerosol concentrations within the planetary boundary layer. The correlation could be due to common meteorological conditions, such as stagnant air mass, or to common formation processes from chemical and photochemical production paths. Several pollution events have been used to study variations in extinction, backscatter, water vapor, and ozone measurements from the NARSTO-NE-OPS investigations in Philadelphia during summer 1998 and 1999.[1] These measurements demonstrate a strong correlation between ozone and aerosol during air pollution events.

Method. Remote sensing using Raman lidar techniques provides a means of effectively measuring the aerosol extinction, as well as profiles of water vapor, temperature, and ozone. Lidar also measures the signal backscattered from particles. Measurements were taken using the Penn State University lidar, referred to as LAPS (Lidar Atmospheric Profile Sensor)[2], and the Science and Engineering Services, Inc. Micro Pulse Lidar.[3] The LAPS system uses rotational Raman scatter to measure temperature, and vibrational Raman scattering to measure profiles of water vapor, ozone, and optical extinction. Analysis of extinction profiles during periods of atmospheric pollution events provides an understanding of the characteristics and distribution of airborne particulate matter (PM). The measured Raman signals of the primary molecular species are directly analyzed to determine the optical extinction profiles in the far field (800-5000 m). Special care is given to the analysis of the near field data (<800 m) because of overfilling of the detector, which is located at the far field focal plane. Water vapor profiles provide information about short-term dynamical processes in the atmosphere, serve as a tracer of transport, and provide a continuous monitor of the height of the planetary boundary layer. Ozone is obtained from a DIAL (DIfferential Absorption Lidar) analysis of the Raman shift of N_2 (285 nm) and O_2 (276 nm), which occur on the steep side of the Hartley absorption band of ozone.[4] Backscatter profiles from airborne particles were measured by the LAPS instrument detection of 532 nm return photons during the 1999 summer campaign and were also measured using a Micro Pulse Lidar (MPL) Model 1000 prepared by Science and Engineering Services, Inc. during the 1998 summer pilot study.

Results. An air pollution event that occurred during the NE-OPS pilot study on 21 and 22 August 1998 was examined. The first of a sequence of plots in Figure 1 shows the backscatter signal from the MPL. An increase in the backscatter occurs where a plume collides with the boundary layer. The next plot of extinction (b) measured by LAPS shows the increase of aerosol scattering during that same period. Plots of water vapor (c) and ozone (d) from the LAPS instrument also show increases when the transported air mass from aloft is mixed with the rising boundary layer. There is a dramatic increase of ozone as the mixing occurs. The increase is so sudden that it has been proposed that the plume transported ozone precursors which mixed down to quickly produce the ozone observed from one of several rapid chemical processes. The ozone profile does not indicate high levels of ozone in the elevated water vapor plume, so the direct transport of ozone is unlikely. The plot of extinction shows a simultaneous increase of particulate matter just before the ozone event occurred. In order to be detected with lidar, most of the particle sizes must be within the accumulation mode, which is formed by growth of smaller particles (<0.1 μm) to produce larger particles.[5] One way to increase



(a) (b) (c) (d)

Figure 1. Time Sequence Vertical Profiles measured by lidar on 21 Aug. 1998 09:00 –19:00 UTC (a) MPL Backscatter (b) LAPS Extinction (c) LAPS Water Vapor (d) LAPS Ozone

particle size, thus increasing extinction, is to coalesce water vapor onto particles, which occurs when the relative humidity is high or above the critical saturation ratio.[5] However, in this case, the temperature increased, and the relative humidity decreased during the period when airborne particulate matter extinction increased; thus, conglomeration and chemical processes lead to increased particle size and number density.

Conclusions. Measurements of the variations in the profiles of optical extinction, water vapor, and ozone are needed to understand the evolution of pollution events. Profiles of backscatter, extinction, water vapor, and ozone were measured and compared using two different lidar systems, the PSU Raman lidar, LAPS, and the SESI Micro Pulse Lidar. Data taken on August 21st showed a sudden increase of ozone in the planetary boundary layer when a plume, which was transported aloft, was mixed into the PBL. Since low level ozone was observed inside the plume, it was determined that this rise was due to the presence of ozone precursors transported inside the plume. Extinction and backscatter measurements support the hypothesis that mixing down of precursors for ozone and particle formation were directly involved in the increase. The water vapor profiles show the exact timing of the pollution event, which occurred when the thickening boundary layer mixed with the plume. These measurements help describe the dynamical processes that occur in the lower atmosphere, especially during pollution events and have shown the importance of vertical mixing, horizontal transport, and storage of precursor materials in the residual boundary layer overnight. A clear case of transport of ozone precursors was observed during 21 August 1998 in Northeastern Philadelphia, PA. This example of an atmospheric episode, which depicts increases in both ozone and aerosol levels, was used to investigate conditions for meteorological control of the ground level exposure to both ozone and aerosol/particulate matter. Data from the 1999 summer intensive program includes seven events and also demonstrates the importance of vertical profiles in understanding the meteorological and dynamical control factors during pollution episodes.

References.

1. Philbrick, C. Russell, "Investigations of Factors Determining the Occurrence of Ozone and Fine Particles in Northeastern USA", Measurement of Toxic and Related Air Pollutants - Proceedings of a Specialty Conference Cosponsored by the Air and Waste Management Association and the U.S. EPA's National Exposure Research Lab, Volume 1, Cary, North Carolina, pp. 248-260, 1998.
2. Philbrick, C. Russell, "Raman Lidar Capability to Measure Tropospheric Properties", Proceedings of the Nineteenth International Laser Radar Conference, NASA Langley Research Center, Hampton, VA, NASA Conf. Publ. 207671, pp. 289 - 292, 1998.
3. Lee, H.S., I.H. Hwang, J.D. Spinhirne, and V.S. Scott, "Micro Pulse Lidar for Aerosol and Cloud Measurement", Selected Papers of the 18th International Laser Radar Conference (ILRC), pp. 7-10, Berlin, 1996.
4. Esposito, Steven T. and C. Russell Philbrick, "Raman/DIAL Technique for Ozone Measurements", Proceedings of the Nineteenth International Laser Radar Conference, NASA Langley Research Center, Hampton, VA, NASA Conf. Publ. 207671, pp. 407 - 410, 1998.
5. Rogers, R.R., and M.K. Yau, A Short Course in Cloud Physics , Pergamon Press, Oxford, Chapter 6, pp. 81-98, 1989.