6.8 EXAMINATION OF THE INFLUENCE OF A FRONTAL PASSAGE ON AIR POLLUTION EPISODES

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1. Introduction

The effects of meteorological fronts on air quality have been of great interest to researchers [1]. Knowledge of these effects assumes significant importance in the wake of studies correlating increased ozone and particulate matter with adverse health effects. Air quality and health experts believe that the health hazard is in the small particle component, $PM_{2.5}$, which is inhaled by humans and deposited in the bronchioles and alveolar sacs in the respiratory system, leading to adverse health effects [2]. Local air pollutants, such as nitrogen oxides (NO_x) and hydrocarbons, may control the complex ozone response. However, the regionally transported ozone and precursors provide most ground-level ozone in many of the largest episodes. Ozone is formed indirectly by the action of sunlight on volatile organic compounds and nitrogen oxides. In addition, about 10-15% of ground-level ozone is transported down from the stratosphere [3].

Frontal activity can be closely studied by using water vapor as a tracer of variations in the planetary boundary layer (PBL). Variations in the PBL thickness control the dilution volume for the chemical species injected into the atmosphere. Additionally, wind gusts (ahead of a front) and gravity waves (evident in the water vapor concentration) provide interesting evidence of the dynamical processes that rapidly change characteristics of the local air masses as the front moves through the region. The dynamics causes mixing of ozone, which results in ozone depletion due to oxidation loss from increased interaction with the surface.

2. Instrument/Analysis

Raman Lidar techniques have been used to provide remote sensing profiles of ozone, water vapor, temperature, and optical extinction from the particles. The LAPS (Lidar Atmospheric Profile Sensor) instrument, which was developed and demonstrated as an operational prototype for the U.S. Navy, is the primary instrument used to obtain the results presented in this paper [1].

LAPS has the capability of measuring meteorological conditions and atmospheric properties such as vertical profiles of water vapor, ozone and extinction during day and night [1]. Raman lidar techniques have been used to measure the ozone and water vapor characteristics as part of the NARSTO-NE-OPS (North East-Oxidant and Particle Study) during the summers of 1998, 1999, 2001 and 2002.

The LAPS system uses vibrational Raman scattering to measure profiles of water vapor, ozone and optical extinction. Ozone is obtained from a DIAL analysis of the Raman shift of nitrogen (285nm) and oxygen (276nm), which occur on the steep side of the Hartley absorption band of ozone. Integrated ozone density profiles are obtained by taking the ratio of the O_2 and N_2 Raman shifted signals and correcting for molecular scattering and absorption. The ozone density is calculated by differentiating the integrated ozone profile. The signal profiles from Raman scatter signals at wavelengths of 607, 530 and 284 nm are directly analyzed to determine the optical extinction profiles. The water vapor mixing ratio (or specific humidity) is determined by taking the ratio of the signals from the first Stokes vibrational Raman shifts for water vapor and nitrogen,

$$SH\ (g/kg) = K^*[H_2O]/[N_2].$$

3. Observations/Results

Several sets of lidar measurements from the NARSTO-NE-OPS investigations in Philadel-phia during the summer of 1998, 1999, 2001 and 2002 have been analyzed and compared with other instruments. Examples of the effects of frontal activity on ozone and water vapor concentrations are shown in Figures 1, 2 and 3. Figure 1 shows a set of plots obtained using LAPS, that depict time sequences of water vapor, optical extinction and ozone for a period of about twelve hours on July 9 and 10, 1999.

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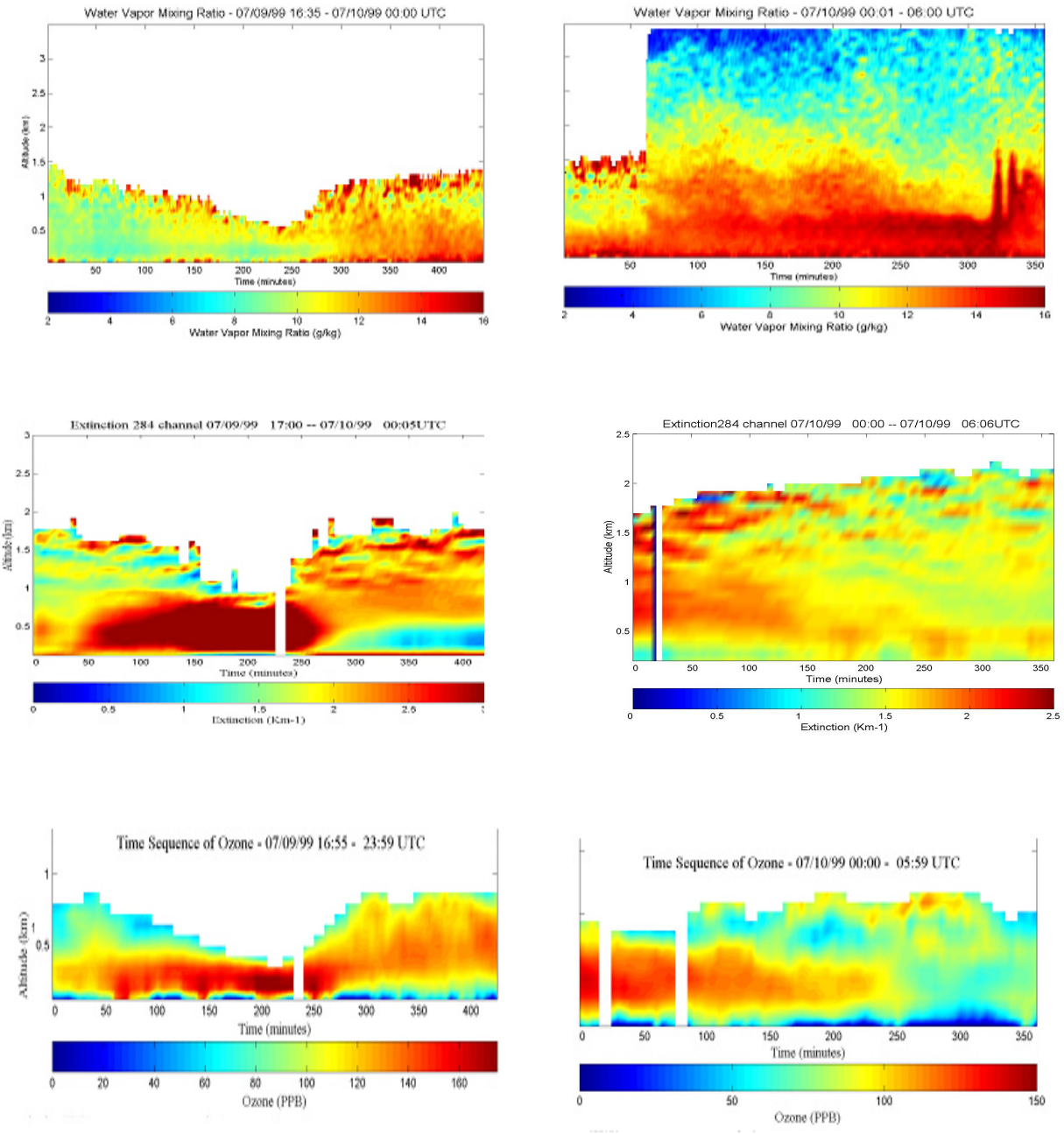

Figure 1. The water vapor, extinction and ozone profiles between 1635 UTC on July 9 and 0600 UTC on July 10 as the front moves into the region.

We observe an increase in the level of ozone at about 1700 UTC on July 9, and a corresponding increase in the extinction profile. A major reason for this increase in ozone and extinction is due to an accumulation of precursors, such as the observed high levels of Volatile Organic Compounds (VOC's) and $PM_{2.5}$ in the region [5]. Also, a very weak cold front passed south of Maryland on July 7. The frontal boundary then became stable and stalled over Maryland. On July 9, this frontal boundary moved north towards Philadelphia as a warm front, carrying with it a mass of pollutants. These pollutants serve as precursors for ozone formation. They are mixed in the planetary boundary layer and are photochemically transformed to ozone and particulate matter. This increase in the particulate matter results in an increase in the extinction profile. Surface analysis on the evening of July 9 depicted the warm front becoming better organized and moving north as shown in Figure 2. This process led to high concentrations of ozone, VOC's and particulates during the afternoon of July 9.

As the cold front approaches from the northwest, the ozone concentration and extinction fall gradually, and at about 0410 UTC on July 10, the ozone drops to about 90 ppb. The decrease in the ozone concentration is accompanied by a gradual increase in the water vapor concentration (Figure 1). This is because the strong winds accompanying the front, near the ground, lead to the formation of turbulent eddies. These eddies are responsible for the efficient mixing and exchanges of mass, heat and momentum through the planetary boundary layer, which cause an increase in the water vapor concentration. At about 0515 UTC on July 10, oscillations in the water vapor profile, which represent gravity waves, are observed at the onset of a period of wind gusts and rain.

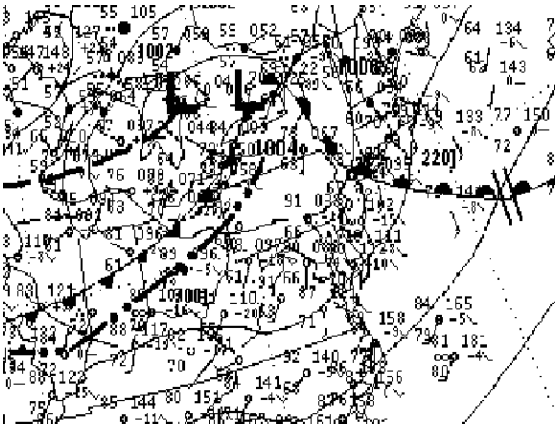

Figure 2. Evening surface analysis on July 9, showing the warm front becoming better organized and moving north from Maryland through Philadelphia.

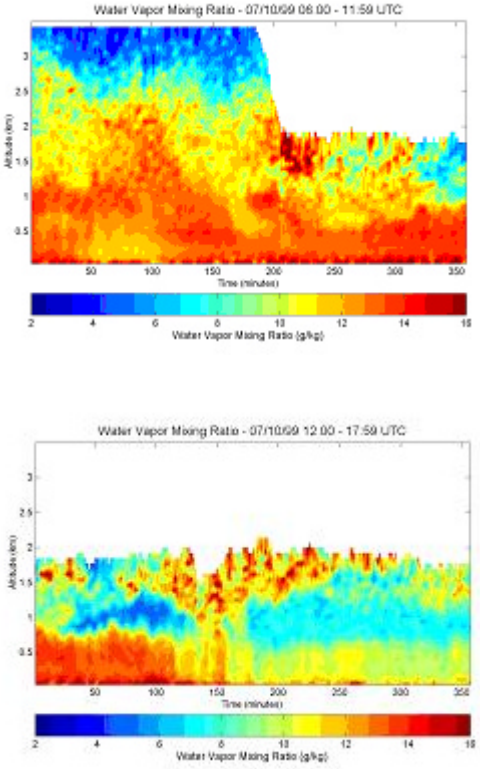

Figure 3. Water vapor during the gusty rain period is shown in the upper panel and a drop in the water vapor concentration at about 1440 UTC due to the arrival of a cool, dry mass of air behind the front is shown in the lower panel.

At about 1440 UTC on July 10, we observe that the water vapor concentration drops to about half of its original value (Figure 3). This is attributed to the arrival of a cold dry mass of air behind the fairly strong cold front which approached the region on July 10, as shown below.

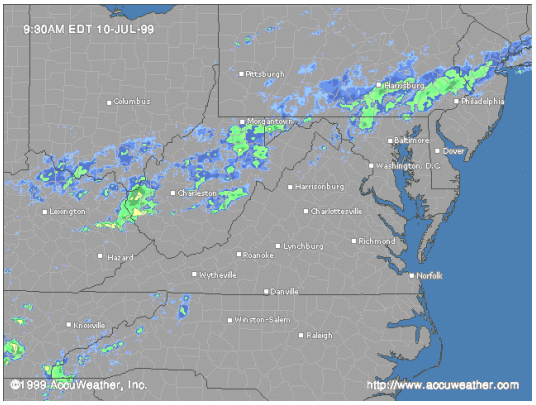

Figure 3. Cold front passing over southern Pennsylvania on July 10,1999.

The episode of July 9-10, 1999 is one of a number of episodes of frontal activity that have been studied and analyzed using LAPS. Other episodes of interest have occurred on July 10, 2001 and July 31-Aug 5, 2002.

4. Conclusion

Lidar has the capability of measuring time sequence profiles of meteorological conditions and events which provides a more useful measure of atmospheric behavior than conventional techniques. Data obtained from LAPS during the summer of 1998, 1999, 2001 and 2002 provide additional insight into the effect of frontal passage on air pollution episodes. The results obtained corroborate the fact that a warm front, on July 9, carrying pollutants left behind by an earlier region of stagnation, causes an increase in the ozone concentration. The arrival of wind gusts and rain, in the early morning hours of July 10, results in an increase in the water vapor concentration, with a corresponding decrease in ozone. One factor is thought to be due to the increase in water vapor, producing larger aerosol particles, which provide loss surfaces for ozone oxidation. A second reason for the decrease in ozone is due to the increase in dynamic mixing down to the surface, where ozone is lost by oxidation processes. The arrival of a cold, dry mass of air behind the front over central and south-east Pennsylvania causes the water vapor to drop to about half of its original value at 1440 UTC on July 10. The observations made by LAPS demonstrate the Raman lidar as a tool for understanding the influence of frontal passages on air quality.

5. Acknowledgements

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