25PC2 AIRBORNE UV-DIAL URBAN PLUME MEASUREMENTS

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INTRODUCTION

This paper presents and interprets continuous vertical profile measurements of ozone and particulate density of urban origin within the lower troposphere obtained remotely with the EPA airborne downward-looking ultra violet differential absorption lidar (UV-DIAL) from special studies conducted in southeastern Michigan (greater Detroit area) in May 1992 and in the Houston, Texas, Gulf Coast area in July and August 1993. Measurements document the development, regional transport, and fate of urban photochemical pollutant plumes in these specific areas. The UV-DIAL measurements in Michigan were collected as part of a system evaluation and demonstration of system capability while those in Texas were collected as part of an overall effort to provide a comprehensive data base for development of model-based strategies for achievement and maintenance of ambient air quality standards for ozone; the Houston area has the second most severe such air quality problem in the U.S.

EPA AIRBORNE DOWNWARD-LOOKING UV-DIAL SYSTEM

A compact airborne downward-looking UV-DIAL has been developed at EPA's Environmental Monitoring Systems Laboratory in Las Vegas, Nevada. This system has the capability of providing concurrent range-resolved remote measurements of gaseous ozone and sulfur dioxide and of particulate density in the lower two to three kilometers of the troposphere using a differential absorption concept. Specifically, measurements of absorption of laser beams are obtained at "on-wavelengths" (for which a gaseous constituent is strongly absorbing) and "off-wavelengths" (for which a gaseous constituent is not so strongly absorbing) to provide solutions to the lidar equation in ratio form in terms of these wavelengths. Adjustments to DIAL-derived constituent concentrations may be required because of interferences by other gases which may also absorb laser energy and/or by aerosols in the atmosphere which may differentially scatter or absorb laser energy at these wavelengths. Multiple laser wavelengths (five in all) for the EPA UV-DIAL measurements, including these adjustments, are obtained by using a pulsed krypton fluoride excimer laser to pump two Raman cells in parallel, one filled with deuterium gas and the other filled with hydrogen gas.[1] Laser signal return collection is via

a classical Newtonian telescope and detection via range-gated photomultiplier tubes in the focal plane of a custom Czerny-Turner spectrograph. Data acquisition is accomplished by a Microvax II and a hard disk, with permanent storage on 8-mm cartridge tape and on-board realtime display of transmitted and received laser signals for quality assurance. Navigational information for data collection is provided by a dedicated global positioning system. In addition, information on the viewing scene for the UV-DIAL is provided by a downward-looking video camera. The EPA UV-DIAL can be flown in a small- to medium-sized cargo aircraft. From such a platform, continuous vertical profiles of gaseous concentrations and on relative density (in terms of lidar backcatter) of aerosol distributions can be obtained in cells beneath the aircraft along the flight path. Cell resolution is a joint function of laser firing rate (20 Hz maximum), data digitization rate, data averaging and smoothing rate, and aircraft speed but should vary between about 30 and 150 m in the vertical and 500 and 1500 m in the horizontal.[2,3]

DATA PRESENTATION AND ANALYSIS

Two representative examples of ozone urban plume formation, transport, and fate in the vicinity of Detroit are shown here. Other measurements for the southern Michigan study and measurements for the Houston study will be shown in the paper presented at the meeting.

Ozone distributions are shown in Figure 1 for a portion of a transect over lower Lake Huron on the U.S. side of the international border with Canada from just north of Port Huron about 50 km downwind of Detroit to about 150 km downwind of Detroit during the early afternoon on May 11, 1992. On this date, southeastern Michigan was situated in a moderate pressure gradient ahead of a slowly moving cold front situated over the Western Great Lakes. Surface winds over the study area varied between southeast and south while those within the mixed layer (which reached between 1800 and 2100 m above ground in the afternoon) varied between south and south southwest. The DIAL measurements in Figure 1 and in other transects (not shown here) indicate that the overall background for ozone in the Detroit vicinity within the mixed layer to be rather uniform at 75-90 ppb. Previous investigations have also found high ozone background to exist throughout the boundary layer during periods of high photochemical production and regional transport.[4] Short excursions in the ozone concentration field to substantially below 75 ppb, especially in range cells near the ground, are likely due at least partially to destruction by oxides of nitrogen or to deposition.[5] In Figure 1 a layer of ozone to 100-125 (or more) ppb persists between about 800 and 1400 m above ground. The layer appears to rise in altitude 200-300 m and deepen slightly over the lake. This layer with excesses of ozone over background up to 50 ppb or more and also higher aerosol concentrations (determined from backscatter of aerosol from the lidar signal return) likely represents the current Detroit "urban plume." This result is in line with previous in situ measurements of ozone concentrations in plumes from other large metropolitan areas, which have been reported to be typically elevated 30-70 ppb over background.[6] The result is also consistent with previous measurements in the Detroit area made at ground stations within the urban plume and at rural sites outside the extent of the urban plume for the upper quartile of peak ozone concentrations; peak values in the plume were reported at 30 to 57 ppb higher than corresponding values outside of the plume.[7] The increase in height of the layer over Lake Huron may be due to airflow convergence and attendant lifting or to spatial variability in the depth of the mixed layer or to both.

Ozone distributions are shown in Figure 2 for the east-west portion of a perimeter flight on May 14 south of Detroit and north of Toledo, Ohio. The cold front had passed though the

Detroit area the morning of May 13 with winds shifting at the ground from southwest to north and north northeast and within the mixed layer from southwest to northwest. A small transitory high behind the front was over southeastern Michigan on May 14 causing surface winds to shift from northeast to east and to southeast by evening and winds within the mixed layer (which reached a maximum of 1000-1250 m in the afternoon) to shift from northwest to northeast and to southeast by evening. The UV-DIAL measurements indicate that the regional background had dropped to 50-70 ppb by time of the flight. Lower values which generally reached 25-50 ppb but sometimes less than 25 ppb (with the lower values likely due to deposition and destruction by nitrogen oxides) were found in the lowest 400-600 m above ground. Higher values representing the regional background appeared to extend to lower altitudes later in the flight, perhaps indicative of fumigation downward as the depth of the mixed layer increased. Since afternoon temperatures were 10-15 degrees Celsius colder than earlier in the week and considerable cloudiness occurred, little photochemical activity was expected as in apparent in the DIAL measurements. Rather, high values near the ground appear to be the result of downward mixing into the surface-based mixed layer of the higher values present in the regional background aloft. Such downward mixing of carryover pollutants has been observed during field programs encompassing in situ measurements in the vertical dimension.[8] Finally, a layer of elevated ozone concentrations above 1800 m and over 200 m thick with values of 75-100 ppb is found in the figure. Simple trajectory analysis indicated that the layer could have originated near Detroit as part of its urban plume on May 12. The height of the layer is consistent with such a origin (maximum mixed layer depth of 1600-1800 m), especially if the upper limit of the mixed layer depth and lifting of the layer with frontal passage are considered.

REFERENCES

1. D. Diebel, M.P. Bristow, and R. Zimmermann, "Stokes shifted laser lines in KrF-pumped hydrogen: reduction of beam divergence by addition of helium," *Appl. Opt.*, 30: 626-628 (1991).

2. H. Moosmüller, R.J Alvarez, R.M. Jorgensen et al, "An airborne lidar system for tropospheric ozone measurement," Paper 93-390, Annual Meeting of the Air and Waste Management Association, Denver, 1993.

3. M.P. Bristow, D. Diebel, D.H. Bundy et al, "Development of an airborne excimer-based UV-DIAL for monitoring ozone and sulfur dioxide in the lower atmosphere," in *Remote Sensing of Atmospheric Chemistry*, J.L. McElroy and R.J. McNeal, Editors, Proc SPIE 1491, pp. 68-74 (1991).

4. F.M Vukovich, J. Fishman, and E.V. Browell, "The reservoir of ozone in the boundary layer of the eastern United States and its potential impact on the global tropospheric ozone budget," *J. Geophy. Res.*, 90: 5687-5698 (1985).

5. D.M. Leahey and M.C. Hansen, "Observational evidence of ozone depletion by nitric oxide at 40 km downwind of a medium size city," *Atmos. Environ.*, 24A: 2533-2540 (1990).

6. T.L. Clark and J.F. Clarke, "A Lagrangian study of the boundary layer transport of pollutants in the northeastern United States," *Atmos. Environ.*, 18: 287-297 (1984).

7. N.A. Kelly, M.A. Ferman, and G.T. Wolff," The chemical and meteorological conditions associated with high and low ozone concentrations in Southeastern Michigan," *JAPCA*, 36: 150-158 (1986).

8. S. Wakamutsu, I. Uno, and M. Suzuki, "A field study of photochemical smog formation under stagnant meteorological conditions," *Atmos. Environ.*, 24A: 1037-1050 (1990).

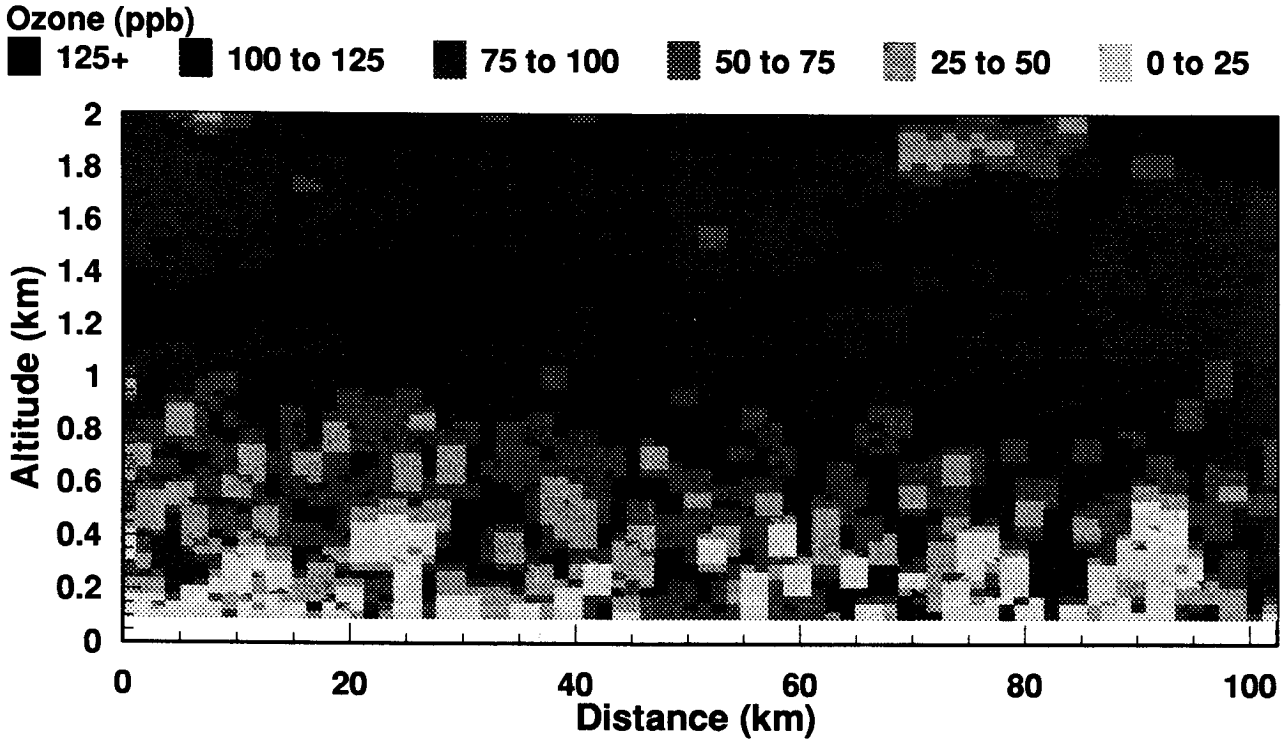

Figure 1. Ozone distribution (ppb) for Transect 3, 1417-1437 EDT, May 11, 1992 (over Lake Huron from just above Port Huron to as far north as the beginning of the Huron National Forest).

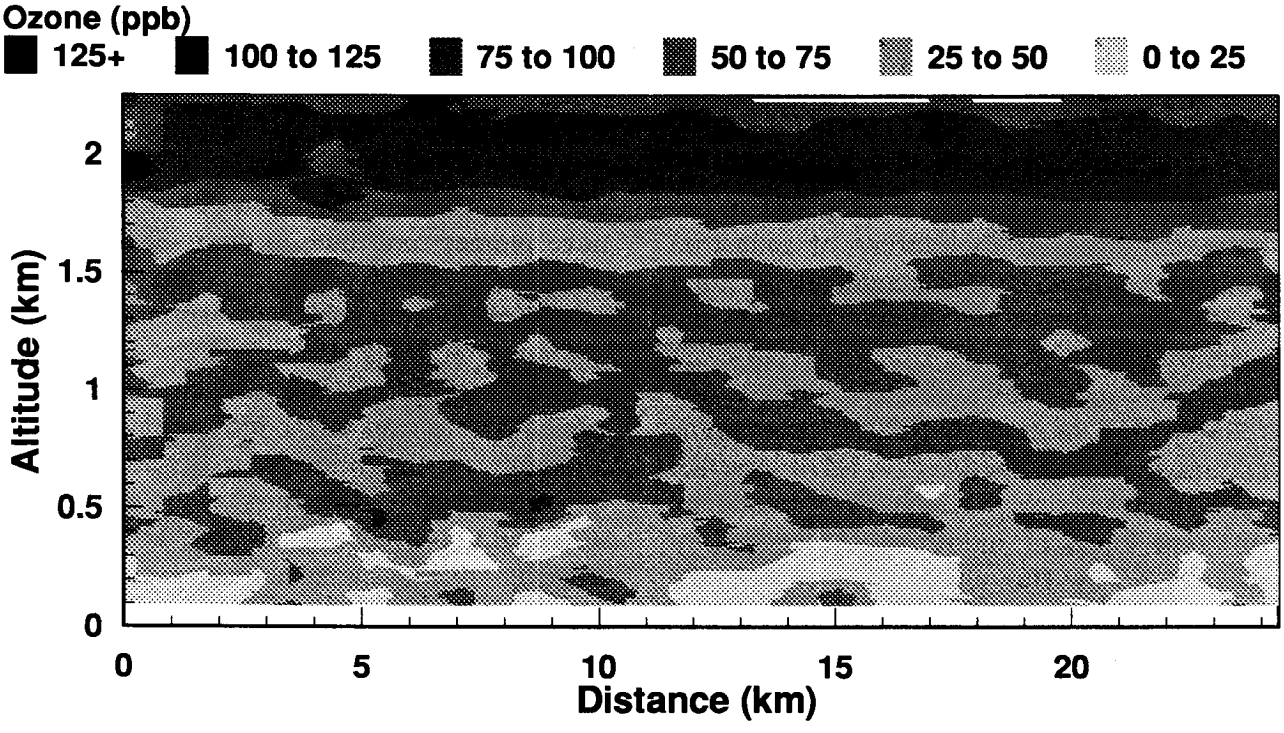

Figure 2. Ozone distribution (ppb) for Transect 5, 1107-113 EDT, May 14, 1992 (from Rockwood about 20 km south of the Detroit metropolitan area west northwest to a point about due south of Ann Arbor).