EPJ Web of Conferences **362**, 09018 (2026) https://doi.org/10.1051/epjconf/202636209018
ILRC31/CLRC22-2024

Ozone Transport and Distribution along the Northern Shore of the Long Island Sound observed with Ozone and Wind Lidars

C. J. Senff[(a)], A. O. Langford[(b)], R. J. Alvarez II[(b)], S. P. Sandberg[(b)], S. Baidar[(b)], Wm. A. Brewer[(b)]

[(a)]*University of Colorado CIRES at NOAA Chemical Sciences Laboratory*
325 Broadway, Boulder, CO 80305, USA
[(b)]*NOAA Chemical Sciences Laboratory, Boulder, CO, USA*
325 Broadway, Boulder, CO 80305, USA
christoph.senff@noaa.gov

Abstract: The NOAA CSL TOPAZ ozone lidar and an autonomous Doppler wind lidar were deployed to the Connecticut shore downwind of New York City in summer 2023 as part of the CUPiDS and AEROMMA air quality field campaigns. We used the lidar observations to characterize the effect of the complex transport and mixing patterns in this area on the vertical structure and temporal evolution of ozone along the northern shore of the Long Island Sound.

1. Introduction

Emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) from large urban areas in the northeastern US, including New York City (NYC), react in the presence of sunlight to form significant amounts of ozone (O_3), especially during the late spring through early fall "ozone season". O_3 is known to have adverse effects on human health and it is one of the "criteria" pollutants regulated under the U. S. Clean Air Act. The prevailing synoptic flow in the summer months in the greater NYC area is from the southwest, which often transports the NYC ozone plume across the Long Island Sound (LIS) to the Connecticut shore and then farther into New England. As the NYC pollution plume is advected towards Connecticut, it interacts with the complicated regional flow and mixing regimes, in particular the land-sea breeze, over the LIS and adjacent land areas. Some of the highest surface O_3 concentrations downwind of NYC are typically observed along the Connecticut coast. To better understand the causes of these high O_3 events and how they may be influenced by the unique transport and mixing processes in the area, we deployed the NOAA Chemical Sciences Laboratory (CSL) Tunable Optical Profiler for Aerosols and oZone (TOPAZ) lidar and an autonomous Doppler wind lidar (Vaisala, S200) at the Yale University Coastal Field Station (YCFS, 41.2592, -72.7311, 3 m MSL) on the central Connecticut coast near New Haven

Figure 1: NOAA TOPAZ lidar and three other TOLNet ozone lidars deployed along the LIS coast.

(Figure 1). This deployment was part of the NOAA Coastal Urban Plume Dynamics Study (CUPiDS) and Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA, [1]) air quality campaigns, which interacted closely with the NASA Synergistic TEMPO Air Quality Science (STAQS) study. These large campaigns brought together many instruments on a variety of observations platforms, including insitu and remote sensors on four different aircraft, mobile van and O_3 sonde observations, as well as many ground-based measurements. The NOAA TOPAZ lidar and three other Tropospheric Ozone Lidar Network (TOLNet) lidars formed a small regional network along the LIS coastline for the duration of the studies (Figure 1). The main scientific objectives of the NOAA TOPAZ and Doppler lidar deployment, in

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

concert with the many other observational assets, were to a) document the effect of the land-sea breeze circulation on the distribution of O_3 and aerosol concentrations in the urban outflow downwind of NYC, b) evaluate the capabilities of high-resolution air quality models to replicate observed O_3 concentrations in the NYC area, and c) validate O_3 observations from the satellite-borne geostationary Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument.

2. Instrumentation

The NOAA CSL trailer-based TOPAZ lidar [2,3] and the autonomous Doppler wind lidar were deployed at the YCFS site from 4 July – 14 August 2023 (Figure 2). TOPAZ emits three wavelengths in the near UV spectral region (~

Figure 2: NOAA Doppler lidar and TOPAZ trailer at the YCFS site.

286 – 294 nm), from which O_3 profiles along the lidar beam are retrieved using the Differential Absorption Lidar (DIAL) technique. Aerosol backscatter profiles are derived from the lidar signals at the ~294 nm offline wavelength [2]. A roof-mounted two-axis scanning mirror permits pointing of the laser beam at a series of elevation angles at different azimuth angles. Until 2023, the azimuth angle could be changed manually, but was left fixed for the duration of each field deployment. Recently, the scanner was programmed to alternate between two different azimuth angles, at which elevation scans over different sets of angles can be performed. The scanner control is fully automated based on a user defined list of elevation and azimuth angles. Zenith operation is achieved by moving the scanner mirror out of the laser beam path.

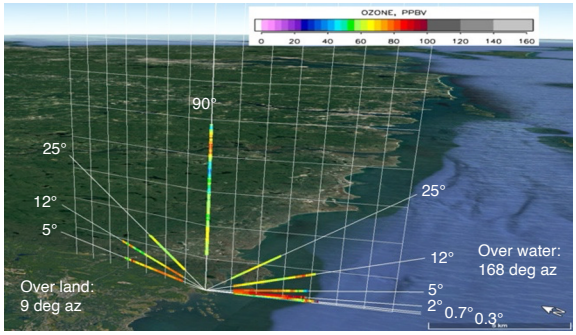

Figure 3: TOPAZ lidar scan pattern (data from 12 July 2023, 9:55 – 10:15 EST)

For the CUPIDS deployment, we used a scan pattern that included a zenith measurement followed by a set of slant path observations at shallow elevations angles (25, 12, 5, 2, 0.7, and 0.3 degrees) with the laser beam pointed in a southerly direction over the LIS (Figure 3). After another zenith observation, a similar elevation angle scan sequence (25, 12, and 5 degrees) to the north over land was performed, which excluded the lowest three elevation angles because of laser beam obstructions. A full scan cycle was completed in about 20 minutes. This scan pattern allowed us to map out the O_3 and aerosol structure within a few kilometers of either side of the shoreline. We created separate composite vertical O_3 and aerosol profiles over the land and water sides by projecting onto the vertical and then blending the individual slant path observations. The over-water vertical profiles cover an altitude range from 5 m AGL up to about 7 km AGL, while the over-land profiles started at about 100 m AGL and reached the same maximum altitude as the over-water profiles.

The co-located, autonomous Doppler lidar continuously repeated a scan sequence that consisted of vertical stares to observe atmospheric turbulence and sets of conical, vertical slice, and sector scans to measure horizontal wind speed and direction profiles. The Doppler lidar vertical slice scans were performed along the same planes as the northerly and southerly TOPAZ scans. We used a combination of the vertical velocity turbulence measurements, horizontal wind speed and direction profiles, as well as Doppler lidar relative backscatter measurements to derive mixing heights [4].

3. Preliminary Results

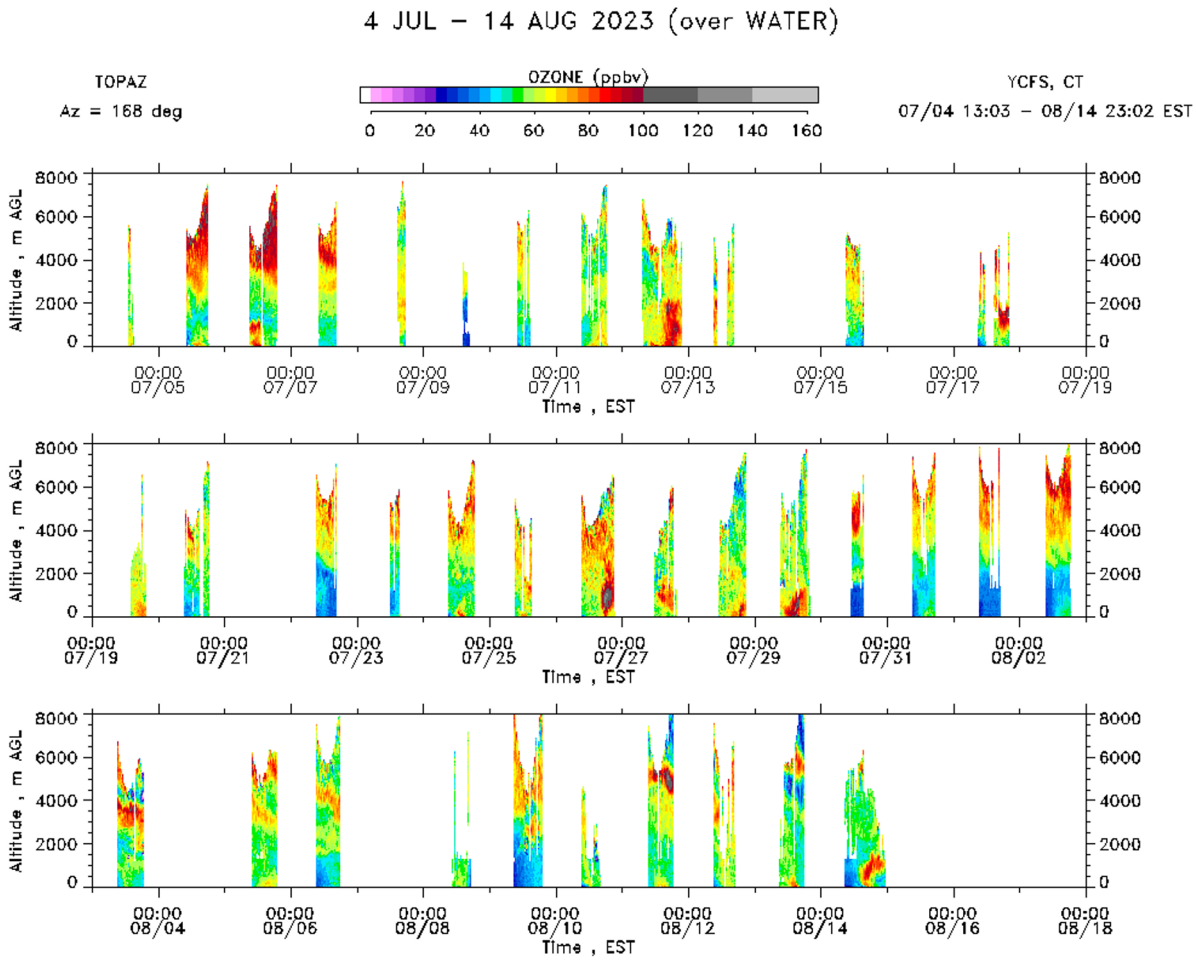

Figure 4: Over-water O_3 profiles observed with the TOPAZ lidar during the CUPiDS campaign.

The TOPAZ lidar collected O_3 profile data on 36 of the 42 days that it was on station at the YCFS site (Figure 4). On the remaining six days, rain and low clouds prevented TOPAZ operation. Figure 4 reveals a very complex vertical structure and temporal evolution of O_3 at the YCFS site. High O_3 concentrations in the lowest 1-2 km (e.g., 7/12, 7/26, 7/29, and 8/14) were caused by the NYC O_3 plume being transported in southwesterly flow across the LIS to the central Connecticut coast. In contrast, observed O_3 levels in the boundary layer were very low on several days when the winds switched to a northerly direction with no significant upwind emissions sources (e.g., 7/22, 7/30 – 8/2). We also observed high O_3 concentrations in the middle troposphere above 3 km AGL on almost half the measurements days (e.g., 7/5 – 7/7). These elevated O_3 layers were either associated with stratospheric intrusions or wildfire plumes. They never descended into the lower part of the troposphere where they could have been entrained by the boundary layer and mixed down to the surface and, consequently, surface air quality was not impacted by these transported layers.

Figure 5 shows the O_3 time height cross sections observed with TOPAZ for two days (7/29 and 8/14) when the NYC O_3 plume impinged on the Connecticut coastal area around the YCFS site. On 7/29, the highest surface O_3 concentrations of the entire study were observed at YCFS, exceeding 100 ppbv over a 2-hour period. The TOPAZ O_3 profile observations reveal that the O_3 plume was only 500 - 1200 m deep and quite well mixed, especially in the lowest 500 m (Figure 5, upper right). In contrast, on 8/14, the O_3 plume was very inhomogeneous and was mostly confined to altitudes between 500 and 1500 m AGL, except during a few hours at the

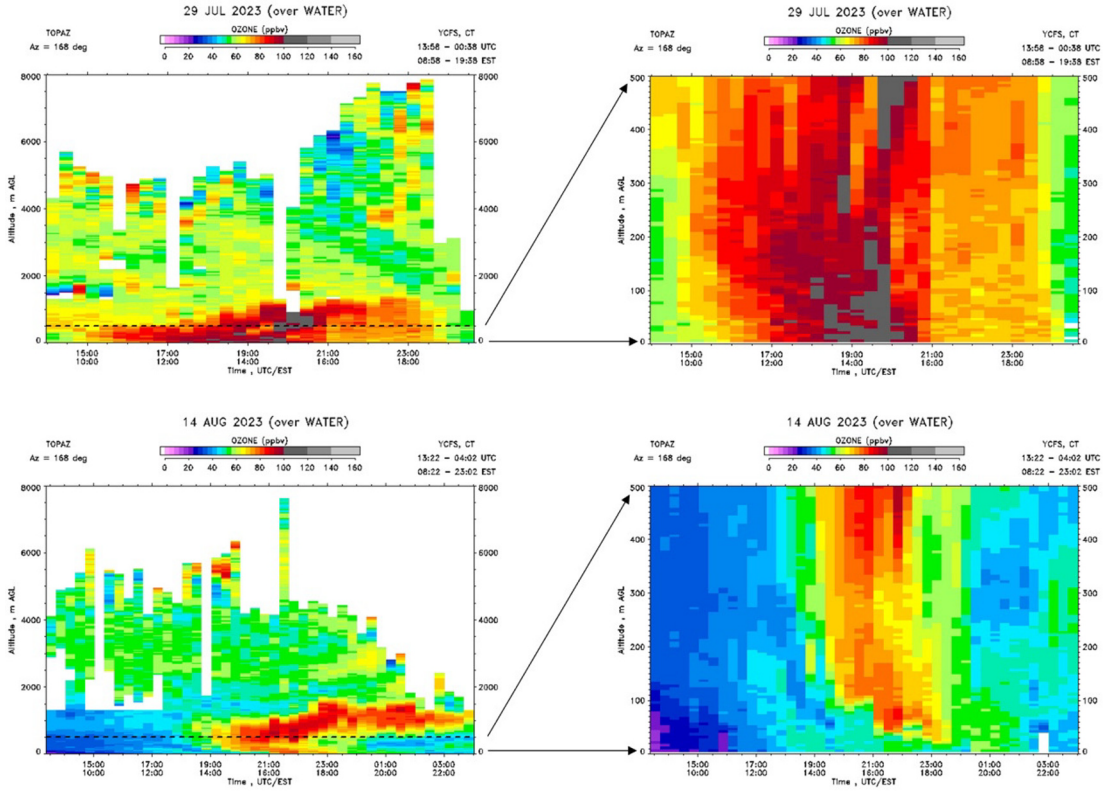

Figure 5: Over-water O_3 profiles observed with TOPAZ on 7/29 (top) and 8/14 (bottom). Plots in the right-hand column show O_3 profiles in the lowest 500 m for the same days.

beginning of the event when the plume, containing up to 80 ppbv of O_3, extended down to an altitude of about 30 m AGL. At the same time, surface O_3 concentrations only peaked in the 50s ppbv, resulting in a very sharp vertical gradient (Figure 5, lower right). This points towards a shallow stable surface layer with weak turbulence that was insufficient to mix the high O_3 concentrations down to the surface. This case also illustrates the extraordinary capabilities of the scanning TOPAZ lidar that permit vertical profiling of O_3 in the surface layer at very fine vertical resolution.

In our continuing analysis of the CUPiDS data set, we will incorporate the observations from the collocated Doppler wind lidar as well as in situ and remote sensing observations from other instruments and platforms to characterize the impact of the complex wind flow and mixing regimes along the northern LIS shore on the vertical structure and duration of the high ozone events observed with the TOPAZ lidar.

4. Acknowledgements

This work was supported by the NOAA Climate Program Office, Atmospheric Chemistry, Carbon Cycle, and Climate (AC4) Program, the NASA-sponsored Tropospheric Ozone Lidar Network (TOLNet), and the NOAA cooperative agreement NA22OAR4320151.

5. References

[1] AEROMMA 2023 white paper: https://csl.noaa.gov/projects/aeromma/whitepaper.pdf.

[2] Alvarez, R. J., et al., "Development and application of a compact, tunable, solid-state airborne ozone lidar system for boundary layer profiling", J. Atmos. Ocean. Technol., doi: 10.1175/JTECH-D-10-05044.1, (2011).

[3] Alvarez, R. J., Senff, C. J., A. M. Weickmann, S. P. Sandberg, A. O. Langford, R. D. Marchbanks, W. A. Brewer, and R. M. Hardesty, "Reconfiguration of the NOAA TOPAZ Lidar for Ground-based Measurement of Ozone and Aerosol Backscatter", Proceedings of the 26th International Laser Radar Conference, Porto Heli, Greece, 25-29 June 2012, 249-252 (2012).

[4] Bonin, T. A., B. J. Carroll, R. M. Hardesty, W. A. Brewer, K. Hajny, O. E. Salmon, and P. B. Shepson, "Doppler Lidar Observations of the Mixing Height in Indianapolis Using an Automated Composite Fuzzy Logic Approach", J. Atmos. Ocean. Technol., doi: 10.1175/JTECH-D-17-0159.1, (2018).