Design of a Mobile Tropospheric Ozone Lidar and Ozone Profiling in New York during Summer 2023

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Introduction

Ozone (O_3) is one of the primary pollutants in the New York City Area and during high ozone episodes can exceed the 70 ppb National Ambient Air Quality Standards (NAAQS) for surface ozone [1]. Emissions from transportation and industrial activities generate abundant ozone precursors such as nitrogen oxides and volatile organic compounds (VOCs) [2]. It is critical to observe the vertical distribution of ozone and other pollutants over time to understand the processes that lead to poor air quality, but there is a lack of such ongoing observation of vertical ozone distribution in NYC.

A mobile tropospheric Ozone (O_3) Differential Absorption Lidar (DIAL) system was recently developed at the City College of New York (CCNY) as part of the Tropospheric Ozone Lidar Network (TOLNET). As part of the summer 2023 NOAA CUPiDS and NASA STAQS campaigns, the mobile O_3 lidar was deployed to Columbia University Lamont-Doherty Earth Observatory (LDEO) in Palisades, New York, and took measurements there from August to September 2023.

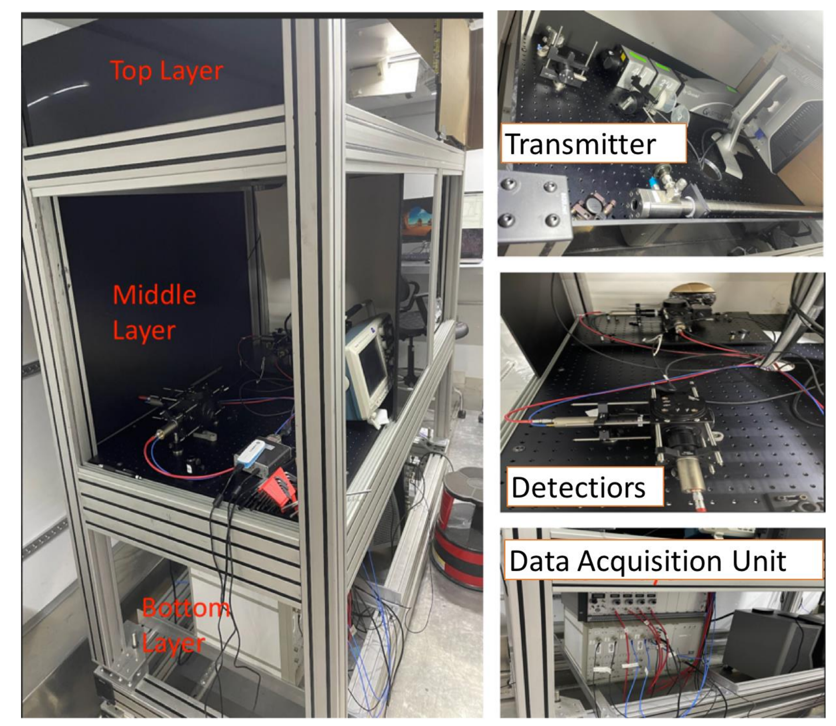

Figure 1. The main components of the CCNY Trailer O_3-DIAL system.

Methodology

Differential Absorption Lidar (DIAL) is a Lidar remote sensing technique that is used to retrieve vertical profiles of trace gas concentrations in the atmosphere. Ozone DIAL utilizes two close by wavelengths in the ozone Hartley band (200 – 310 nm) with different amounts of ozone absorption. The wavelength with stronger ozone absorption is referred to as λ_{on}, and the less absorbed wavelength is λ_{off}. By comparing the returned signal power from each wavelength, the range-resolved ozone number density, N_{O_3} can be determined [3].

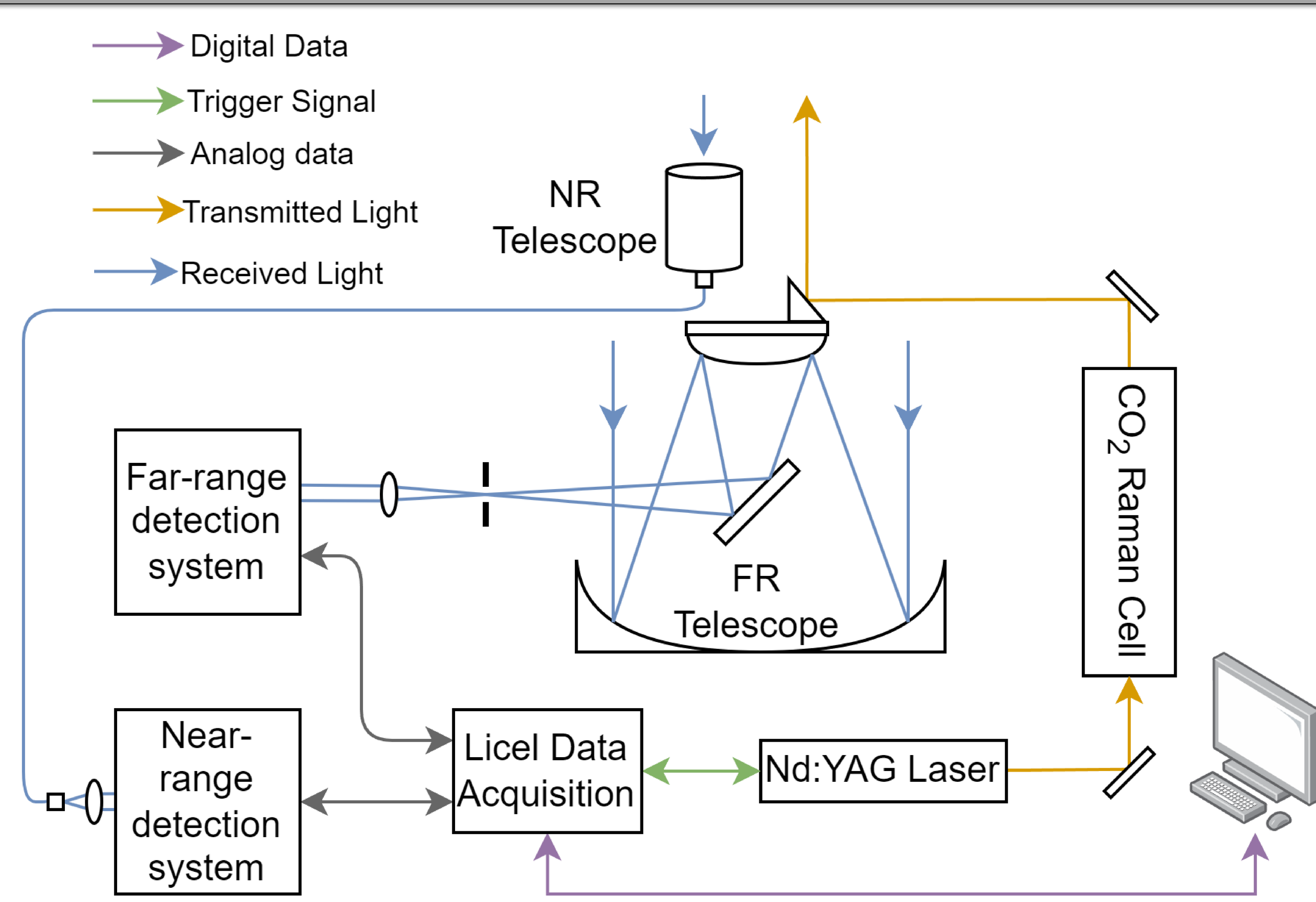

Figure 2. Schematic of the CCNY Trailer O_3-DIAL system

The CCNY Trailer O_3-DIAL system uses a Nd:YAG laser (266-nm, 20 Hz) to pump a CO_2 Raman cell to generate the "on" and "off" wavelengths at 287.2 nm and 299.1 nm by the Stimulated Raman Scattering (SRS) effect. The transmitted laser light is sent vertically into the atmosphere and backscattered light is collected by a 2-inch refractive telescope and a 20-inch Cassegrain telescope for near-range and far-range signal detection, respectively. Photomultiplier tubes (PMTs) convert the optical energy into analog electrical signals, which are then digitized and sent to a computer for analysis by a Licel Data Acquisition unit.

- The ozone number density, N_{O_3} can be calculated from [3]:

$$N_{O_3}(r) = \frac{1}{2\Delta\sigma_{O_3}\Delta r}\left[\ln\left(\frac{P_{off}(r+\Delta r)}{P_{off}(r)}\frac{P_{on}(r)}{P_{on}(r+\Delta r)}\right) - \ln\left(\frac{\beta_{off}(r+\Delta r)}{\beta_{off}(r)}\frac{\beta_{on}(r)}{\beta_{on}(r+\Delta r)}\right)\right] - \frac{\Delta\alpha_{mol}}{\Delta\sigma_{O_3}} - \frac{\Delta\alpha_{aer}}{\Delta\sigma_{O_3}}$$

- $\Delta\sigma_{O_3}$ is the differential ozone absorption cross section of the on and off wavelengths. $P_{on,off}$ and $\beta_{on,off}$ are the returned lidar power and backscatter coefficient for either the on or off wavelength. $\Delta\alpha_{mol}$ and $\Delta\alpha_{aer}$ are the differences in absorption by molecules and aerosols of the "on" and "off" wavelengths.

Results

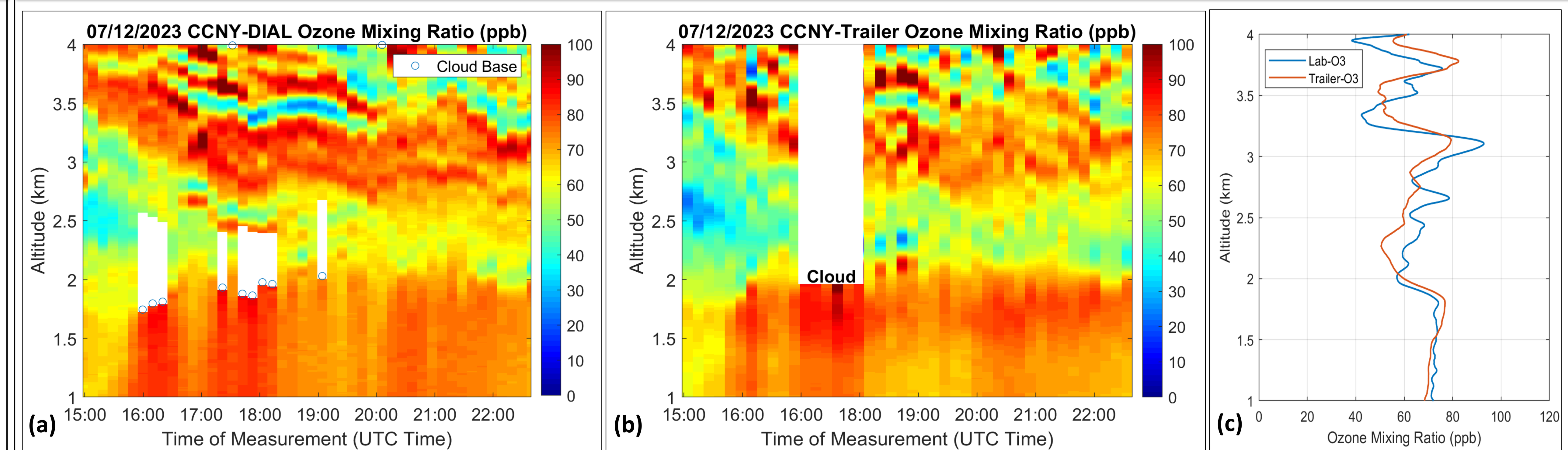

Figure 3. (above) **(a)** Time-altitude plot of O_3 mixing ratio observed by the Lab CCNY O_3-DIAL. **(b)** Time-altitude plot of O_3 mixing ratio observed by the CCNY Trailer O_3–DIAL. **(c)** Comparison of O_3 mixing ratio profiles of the CCNY Lab and Trailer O_3 DIAL on July 12th, 2023, at 20:08 UTC.

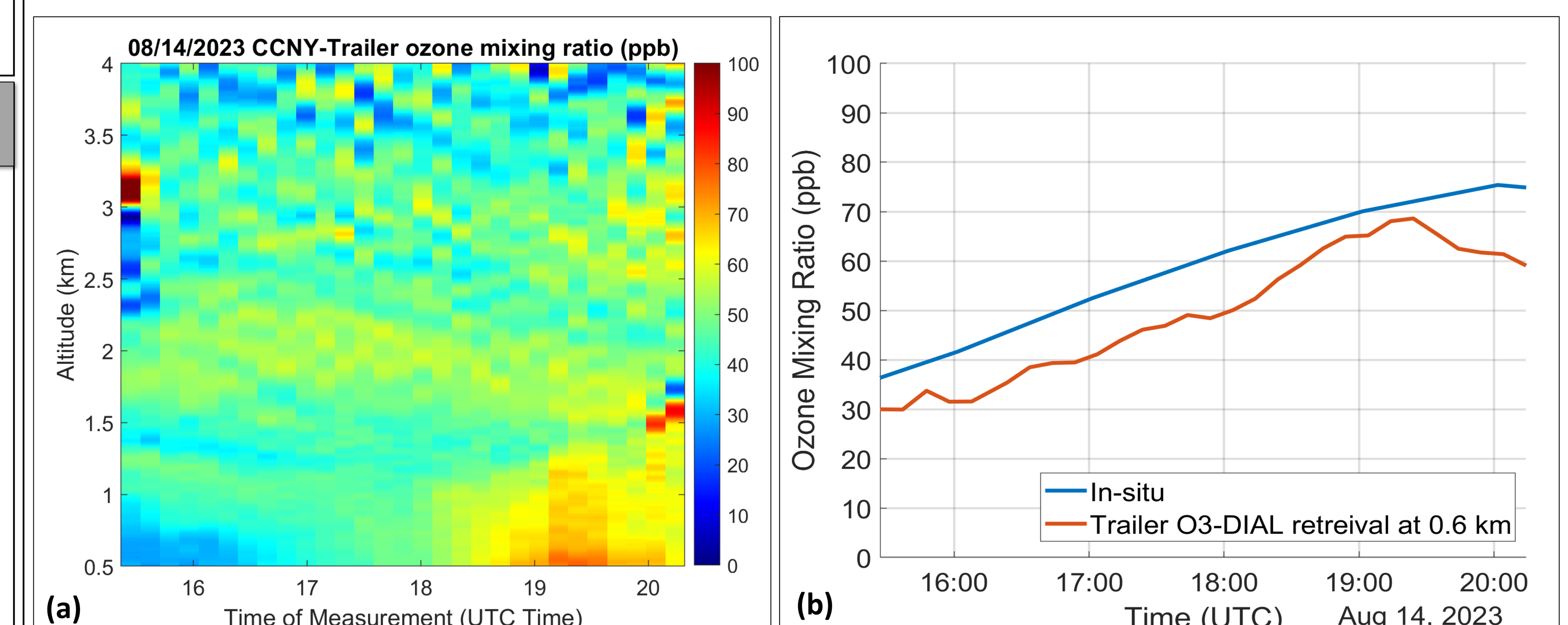

Figure 4. (left) **(a)** Time-altitude plot of O_3 mixing ratio observed by the CCNY Trailer O_3-DIAL at Lamont Doherty Earth Observatory on August 14th, 2023.
(b) Comparison of the O_3 mixing ratio measurements over time of in-situ ozone sampler and the CCNY Trailer O_3-DIAL at 0.6 km on August 14th, 2023.

- High O_3 exceeding 70 ppb observed from 1 to 2 km after ~15:00 UTC. The CCNY Trailer O_3-DIAL shows similar temporal variation with the Lab O_3-DIAL results in Figs. 3 (a) and (b).
- Fig. 3 (c) shows that the O_3 profiles from the Lab and Trailer O_3-DIAL are generally consistent from 1 km to 4 km. Overestimation of O_3 around 1.5-2 km and underestimation of O_3 around 2-3.2 km are observed by the trailer system
- Fig. 4 (b) displays consistent temporal variation of O_3 measured by the co-located in-situ O_3 sampler and the O_3 measured by the CCNY Trailer O_3-DIAL at 0.6 km.

Conclusions

- The CCNY Trailer O_3-DIAL was validated against the CCNY Lab O_3-DIAL. In the range of 1 to 4 km, the O_3 retrievals between the systems agree well with each other. Further optimization of the far-range receiver system could result in a better signal to noise ratio, which will allow us to retrieve ozone at altitudes higher than 4 km more consistently.
- The near-range channel requires more experimentation and tuning to retrieve ozone closer to the ground. The ozone retrieval from the near and far-range channels will be stitched together in the range where they are consistent, to achieve a single ozone profile.
- This mobile lidar system brings new ozone profiling capabilities to the New York City Metropolitan Area. It made valuable observations of ozone concentration profiles in during the 2023 Summer Air Quality Campaign and will be deployed at more sites of interest in the future.

References

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Acknowledgment

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