DIAL Ozone Measurement Capability Added to NASA's HSRL-2 Instrument Demonstrates Tropospheric Ozone Variability Over Houston Area

Marta Fenn[1][0000-0001-6088-6200], Johnathan Hair[2][0000-0002-9672-1237],
Taylor Shingler[3][0000-0003-4596-1027], Richard Ferrare[4][0000-0002-1005-9730]

[1] SSAI, 1 Enterprise Pkwy, Hampton, VA, 23666 USA, Marta.A.Fenn@nasa.gov

[2] NASA Langley Research Center, Hampton, VA 23681 USA, Johnathan.W.Hair@nasa.gov

[3] NASA Langley Research Center, Hampton, VA 23681 USA, Taylor.J.Shingler@nasa.gov

[4] NASA Langley Research Center, Hampton, VA 23681 USA, Richard.a.ferrare@nasa.gov

Abstract. NASA Langley Research Center (LaRC) fielded its second generation multiwavelength High Spectral Resolution Lidar (HSRL-2), which also includes wavelengths to enable Ozone Differential Absorption Lidar (DIAL) measurements, aboard the NASA Gulfstream-V (G-V) aircraft during September 2021. Flying at 9 km, the lidar provided nadir profiles of ozone and aerosol backscatter, extinction, and depolarization over the Houston metropolitan region, including Galveston Bay and the Houston Ship Channel. These observations were part of a larger air quality assessment of the region, TRACER-AQ (Tracking Aerosol Convection ExpeRiment – Air Quality), which is NASA mission conducted in collaboration with an effort led by the DOE (Department of Energy), TRACER (Tracking Aerosol Convection Interactions ExpeRiment). Additional participants including from academia and TCEQ (Texas Commission on Environmental Quality) provided meteorological and atmospheric constituent measurements from ground sites, mobile laboratories and from boats. Here we present a description of HSRL-2 measurement capabilities and examples of tropospheric ozone and aerosol measurements collected during TRACER-AQ. The flight tracks were overlapping raster patterns repeated three times throughout the day to measure the temporal and spatial variability in ozone and aerosols over the region. These measurements will help understand and evaluate space-based air quality observations from future satellite passive UV-VIS sensors such as the NASA TEMPO satellite.

Keywords: Aerosols, Ozone.

1 Introduction

1.1 Rationale

Air quality experts now have a bird's eye view of the complex atmospheric composition of the Houston metropolitan region during late summer conditions, when the surface ozone concentration most frequently exceeds regulatory limits. TRACER-AQ [1] was the most recent of a series of air quality studies conducted by NASA and TCEQ to inform changes in regulations as well as assess their results along with changes in industry and meteorology. Anticipating data products from the TEMPO satellite, these observations can help develop strategies to use space-based observations.

1.2 Instrument information

NASA Langley Research Center's HSRL-2 instrument can be configured to measure ozone profiles via the DIAL technique, in addition to the existing ability to measure profiles of aerosol backscatter and depolarization at three wavelengths (355, 532, 1064 nm) and aerosol extinction via the HSRL technique at two wavelengths (355, 532 nm). This ozone-measurement capability was first demonstrated in flights aboard NASA's ER2 and UC-12 aircraft during 2015 and 2016 [2]. Figure 1 shows HSRL-2 deployed on the NASA G-V aircraft for TRACER-AQ.

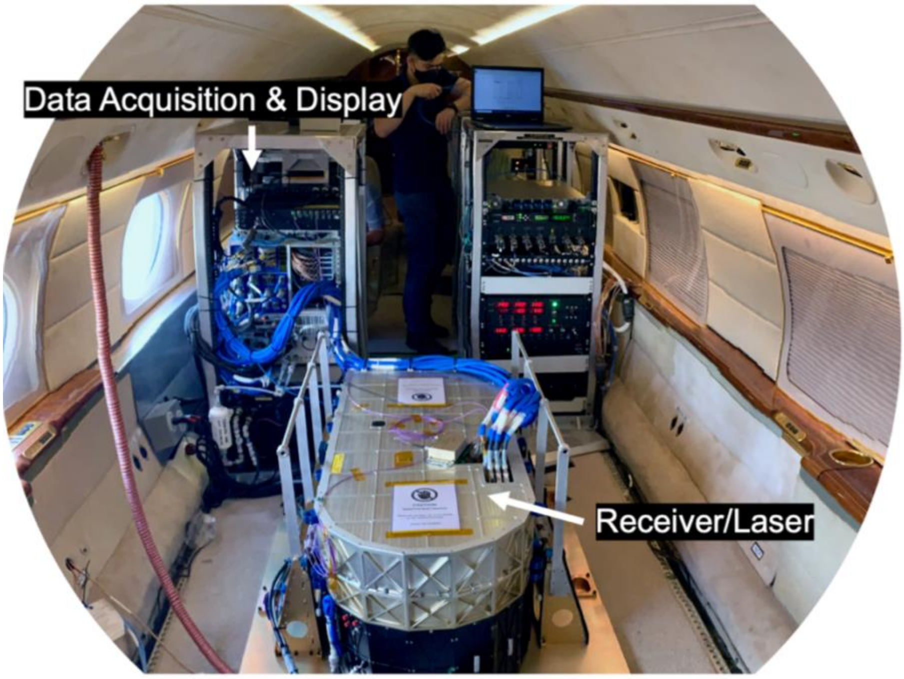

Fig. 1. HSRL-2 on board the NASA G-V during TRACER-AQ.

1.3 Sampling strategy

The HSRL-2 instrument provided three a dimensional picture of the aerosol and ozone distributions from the surface up to about 8 km above the Houston metropolitan region (the source of urban emissions), as well as Galveston Bay and the Houston Ship Channel (the source of petrochemical industry emissions) while the G-V flew a raster pattern over the entire region (figure 2a). A fourth dimension, time, was addressed by repeating the entire raster three times during each flight (morning (0900-1130 local time), midday (1130-1400 local time), and afternoon (1400-1630 local time)) to observe the changes in the ozone and aerosol distributions caused by boundary layer dynamics, the interaction of sea/bay breezes in this coastal environment, as well as synoptic weather events. The NASA G-V platform flew over 90 hours during 11 flights from September 1 through September 27, 2021.

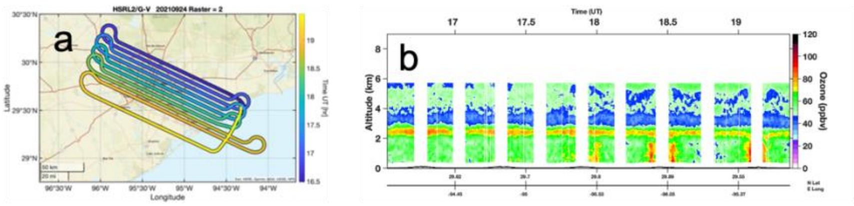

Fig. 2. a) Typical flight track of the G-V aircraft with nadir viewing HSRL-2 on board. This pattern was flown up to three times per day at an altitude of 9 km. The color scale indicates that each pattern took approximately three hours. **b)** Ozone curtain collected from the mid-day raster (raster #2) on September 24, 2021.

2 Data Products

2.1 Ozone

Ozone mixing ratio profiles were measured using the HSRL-2 Differential Absorption Lidar (DIAL) wavelengths of 290 nm (on-line) and 300 nm (off-line) at 13 km horizontal and 300 m vertical resolution from 350 m to 5750 m above ground level (figure 2b). These curtains of ozone inform transport contributions to ground level ozone. Additional ozone products include average ozone mixing ratios in near-surface layers (0.35 - 0.5 km, 0.35 - 1 km, and 0.35 - 2 km) useful for comparison with ground-based monitoring stations (figure 3).

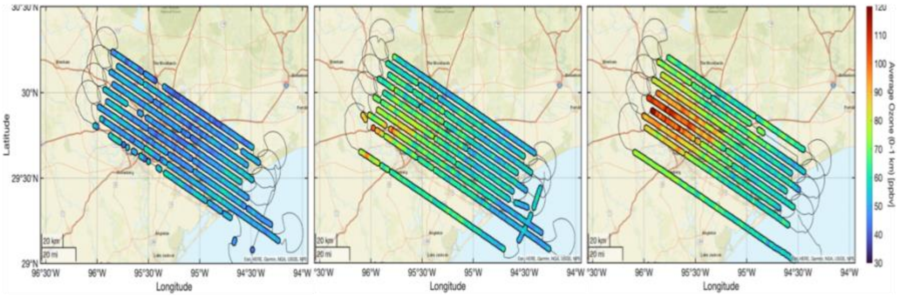

Fig. 3. Average ozone mixing ratios in the layer between 0.35 - 1 km measured during the (left) morning, (middle) midday, and (right) afternoon at a higher horizontal resolution (2 km) on Sept. 24, 2021.

2.2 Aerosol Products

A suite of aerosol products retrieved at three wavelengths, 1064 nm, 532 nm, and 355 nm, were calculated beneath the aircraft along the flight track. These include particulate backscatter profiles and depolarization profiles at all three wavelengths at a horizontal resolution of about 2 km and a vertical resolution of 15 m, reported between 60 m above ground level to 8500 m, and aerosol extinction and aerosol extinction/backscatter ratio ("lidar ratio") profiles at 355 nm and 532 nm calculated at about 13 km horizontal and 300 m vertical resolution from 350 m to 7300 m above ground level. Also provided are aerosol optical thickness profiles, and aerosol backscatter Angström exponents (355 nm-532 nm, 532 nm -1064 nm), and an aerosol extinction Angström exponent (355 nm-532 nm). A sample of selected data products is provided in figure 4, and instrument details are provided in [3] and [4].

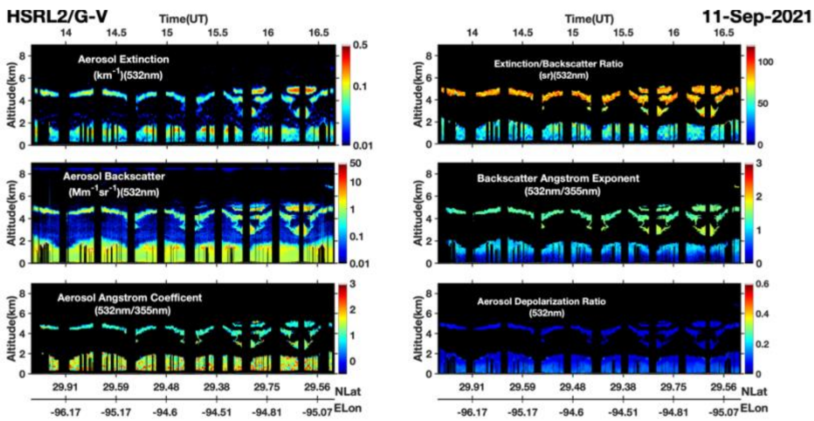

Fig. 4. Selected HSRL-2 aerosol products from Sept. 11, 2021.

Additional aerosol products include average aerosol extinction within near-surface layers (0.3 - 0.5 km, 0.3 - 1 km, and 0.3 - 2 km) useful for comparison with ground-based monitoring stations (figure 5).

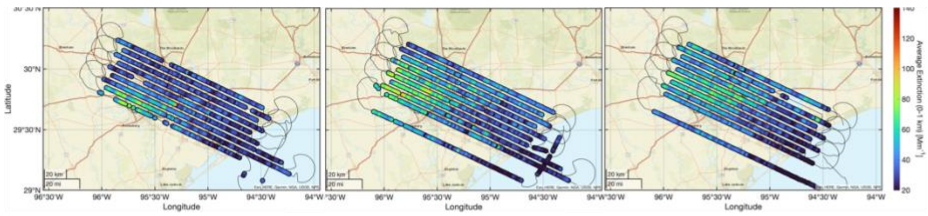

Fig. 5. Same as Figure 3 except for average aerosol extinction.

3. Aerosol corrections for DIAL Ozone measurements

The HSRL-2 wavelengths used for DIAL ozone retrievals (290, 300 nm) are close enough together to reduce anomalous effects caused by differences in the scattering and extinction behavior of aerosols. However, sharp aerosol gradients benefit from additional correction. NASA's Airborne UV_DIAL system utilized a Bernoulli correction scheme that assumed constant aerosol backscatter and extinction Angström coefficients for the entire flight [5]. Since HSRL-2 measures aerosol backscatter and extinction profiles at 355 nm and 532 nm, the ozone retrieval uses these measurements to derive the aerosol Angström coefficients needed for such correction on a profile-by-profile basis, leading to improved accuracy in the derived ozone profiles. TRACER-AQ provided the opportunity for comparing HSRL-2 retrievals of ozone profiles with those from other instruments, such as ground-based lidars and ozone sondes. Comparisons of the resulting aerosol corrected ozone profiles with ozone measurements from these will be shown in the poster.

References

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