NEW CAPABILITY FOR OZONE DIAL PROFILING MEASUREMENTS IN THE TROPOSPHERE AND LOWER STRATOSPHERE FROM AIRCRAFT

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ABSTRACT

Recently, we successfully demonstrated a new compact and robust ozone DIAL lidar for smaller aircraft such as the NASA B200 and the ER-2 high-altitude aircraft. This is the first NASA airborne lidar to incorporate advanced solid-state lasers to produce the required power at the required ultraviolet wavelengths, and is compact and robust enough to operate nearly autonomously on the high-altitude ER-2 aircraft. This technology development resulted in the first new NASA airborne ozone DIAL instrument in more than 15 years. The combined ozone, aerosol, and clouds measurements provide valuable information on the chemistry, radiation, and dynamics of the atmosphere. In particular, from the ER-2 it offers a unique capability to study the upper troposphere and lower stratosphere.

1 INTRODUCTION

NASA Langley's current airborne lidar Ozone and Aerosol Lidar instrument provide profiles of ozone via the Differential Absorption Lidar (DIAL) technique and aerosol and cloud optical properties via the High Spectral Resolution Lidar (HSRL) technique. This lidar has been a much relied-upon facility-class instrument for deployment on the larger aircraft platforms (i.e., DC-8) over the last three decades, having been deployed on 33 major field experiments focused on investigation of regional- and global-scale processes within tropospheric and stratospheric, satellite validation, and model assessments [1]. Ozone lidar measurements continue to be a requirement on many NASA-sponsored airborne process studies and validation campaigns such as the recent and successful SEAC4RS and KORUS campaigns and will be important for future satellite (e.g. TEMPO and SAGE-ISS) validation campaigns.

This abstract provides a technical overview of major subsystems of this new instrument, an overview of potential new investigations, and highlight a few examples of ozone and aerosol profiles acquired during flights in January 2016 and April 2016 from the B200 and ER-2 aircraft platforms, respectively. In addition, the ozone profiles measured by the lidar are compared with profiles from ozonesondes and ground-based TOLNet ozone lidar systems.

2 METHODOLOGY

This new system is designed to combine aerosol/cloud and the trace gas ozone measurements into a single integrated instrument. The driving requirement was to develop a lidar system that is much smaller, lighter, and uses less power compared to previous generations. In addition, to fly on the ER-2 aircraft the system had to operate autonomously or with very limited remote control.

2.1 Laser Subsystem

A critical development was the laser systems. The laser system consists of a Nd:YAG pump laser built by Fibertek Inc. and a nonlinear optics module (NLO) that was built by IIT Industries with modifications by NASA LaRC and Welch Mechanical Designs, LLC. The NLO consists of two Optical Parametric Oscillators (OPOs) and two crystals for Sum Frequency Generation (SFG). The pump laser is a seeded single frequency 1064nm laser that has a single oscillator and a single preamplifier. The light from the pump laser is then split to two amplifier paths. This results in two output beams with 100mJ per pulse at 200Hz (20W) in each output. One of the amplifier outputs is frequency doubled (SHG) and then frequency tripled (THG). The other amplifier output is used to pump the two OPOs that generate 1608nm and 1945nm which are then mixed with 355nm in two SFG crystals to produce the 290nm and 300nm ozone DIAL wavelengths.

Nd:YAG Laser (bottom in *Figure 1*)
(Fibertek Inc.)

- 40W laser, 200Hz pulse rate, seeded single frequency
- 20W leg to pump dual Optical Parametric Oscillators (OPO)
- 20W leg to generate 355nm, 532nm, 1064nm
- Aerosol and cloud measurements are conducted at 355, 532, 1064nm

Nonlinear Optics Module (top in *Figure 1*)
(ITT Industries, Welch Mechanical Designs, NASA LaRC)

- 1W @ 290nm and 0.5W @ 300 nm, 200Hz
- Dual OPOs: 1608nm and 1945nm
- Sum frequency generation (SFG): mix OPO and 355nm to generate Ozone DIAL wavelengths

Summary of Transmitted Wavelengths

- Transmit single frequency 3.6W @ 1064nm, 2.5W @532nm, and 3.5W @ 355nm wavelengths required for HSRL measurements.
- Transmit 1W @ 290nm and 0.5W @ 300nm

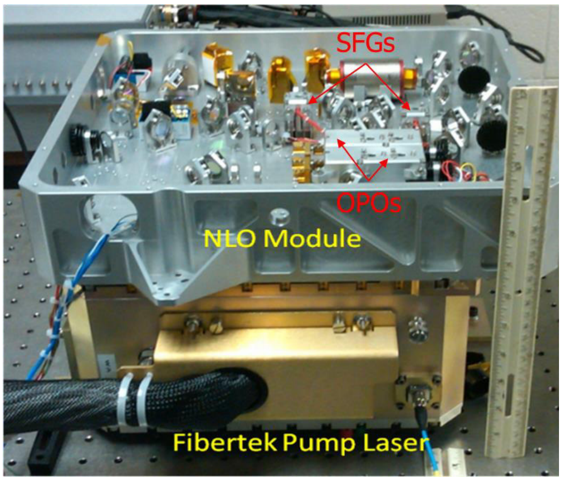

Figure 1. Picture of the Nd:YAG laser (bottom) and the nonlinear optics module (top) that contain dual OPOs and SFG mixers.

2.2 Receiver Subsystem

The receiver consists of multiple channels for the aerosol/cloud and ozone measurements. The system incorporates the HSRL technique at both 532nm and 355nm using an iodine vapor filter and Michelson Interferometer, respectively. The 1064nm channels are detected using the standard backscatter approach with calibration from the 532nm channel. The 532nm and 1064nm retrievals are implemented similar to Hair et al. (2010) [2]. The system also measures the linear depolarization ratio for all three wavelengths [3]. The system has flown on multiple campaigns with the aerosol/cloud measurement channels since 2012. Here we report additional channels that are included in the system to enable ozone profiling through the Differential Absorption Lidar (DIAL) technique focused on measurements in the lower stratosphere and troposphere. These ozone wavelengths are transmitted simultaneously and are split in the receiver with a dichroic filter where each channel has 1nm wide interference filter before the photomultiplier detectors.

2.3 Overall System Design

As noted above, a main objective was to reduce the overall size, weight, and power requirements of this new instrument compared to the current airborne ozone DIAL system that Langley has flown over the past 3 decades. This was accomplished mainly by the laser system approach and design along with the supporting custom electronics and chillers. In addition, considerable effort was put forth in the design of the receiver and instrument structure. The telescope incorporates a 40cm diameter all-metal telescope and a dual-sided aft-optics breadboard. A comparison of the two system sizes is provided in Figure 2 and Table 2. The new system is configured to view downward (e.g. from ER-2) in contrast to the current DIAL system, which simultaneously views in the nadir and zenith directions (e.g. from DC-8).

Table 2. Comparison of size, weight, and power of the new system compared to the current system.

	UV DIAL	HSRL/ DIAL	Change
Volume(m^3)	3.7	0.34	11x
Weight(kg)	907	135	7x
Power(kW)	9.75	1.7	6x

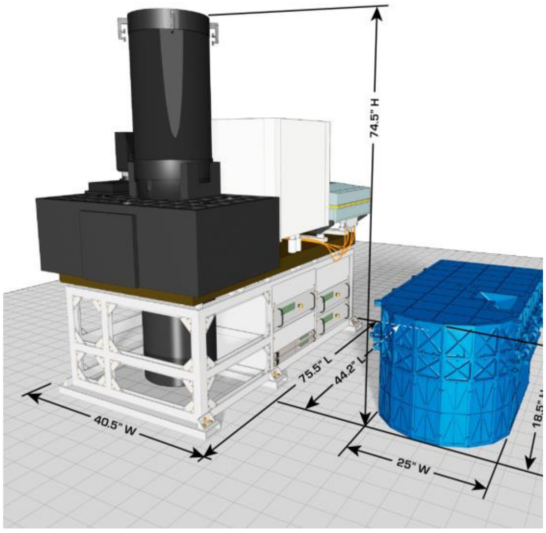

Figure 2. Comparison of the size of the current (left) and the new (right) lidar transceivers.

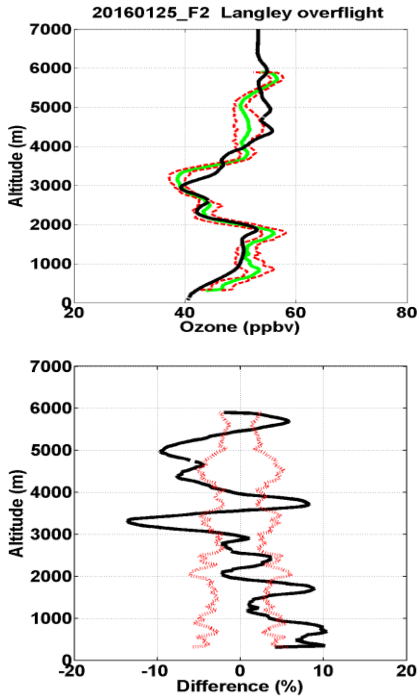

Figure 3. Comparison of lidar and ozonesonde profiles measured 25 January 2016. The top plot shows the sonde (black) and the lidar (green) ozone mixing ratio. The red lines show the ozone standard deviation over the measured interval for the lidar. The bottom plot shows the difference (black) in the ozone profile and the standard deviation over the averaging interval of the lidar.

3 RESULTS

Two series of test flights were conducted on the NASA B200 aircraft from Hampton, VA in January 2016 (5 flights) and on the ER-2 aircraft from Palmdale CA in April 2016 (7 flights). The flights conducted from the B200 focused on evaluating the measurement performance of the ozone measurement and included overpasses of three TOLNet ground-based lidar systems: LMOL in Hampton VA, TropOz in Greenbelt MD, and RO_3QET in Huntsville AL. Ozonesondes were launched at three locations (Hampton and Wallops Island VA and Huntsville AL) during overpasses of the B200 aircraft. Airborne lidar measurements from 25 January 2016 are compared to measurements from an ozonesonde launched in Hampton, VA (Figure 3) showing a typical ozone profile. The lidar profile (green) compared favorably with the sonde profile (black) with a maximum and minimum difference of -13.5% and 10% and the mean standard deviation over the profile of 5.9%. There was no mean bias over the profile for this particular sonde comparison. The average of all six ozonesonde comparisons resulted in a mean profile bias of -1.2% and a mean profile standard deviation of 5.7%.

The seven ER-2 flights focused mainly on operational performance of the instrument, including flying at altitudes up to ~20km to assess the quality of the measurements within the lower stratosphere and near the tropopause. A flight conducted on 13 April 2016 flew from Southern California (lat=34.6N) south to 15N over the Pacific Ocean. The ozone curtain measured during the transit to this southern point is shown in Figure 4. The profiles extended down to the cloud tops near 2km altitude after the ER-2 descended to 18km. The unique capability of the lidar clearly observes the large-scale features in the ozone horizontal and vertical distribution. The lidar ozone profiles revealed a large tropopause fold that extended nearly over the entire flight track. The small aerosol layers, shown in Figure 4 (bottom) correlated with the increased ozone in the mid-troposphere. A sudden decrease in ozone is observed while crossing the Inter-Tropical Convergence Zone (ITCZ). The data also highlights the transport of lower ozone due to the large-scale dynamics related to convection in the tropics and the Brewer-Dobson circulation.

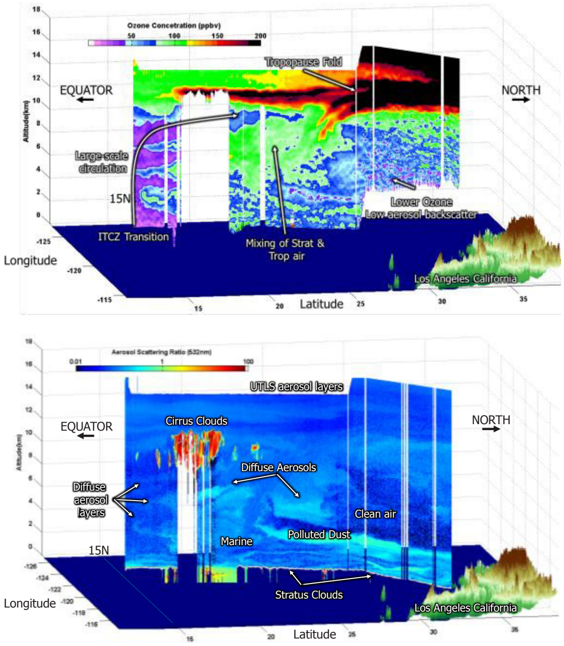

Figure 4. Ozone distribution (top) and the 532nm aerosol to molecular backscatter ratio (bottom) measured on flight from 13 April 2016.

4 CONCLUSIONS

The first NASA airborne ozone lidar developed to fly on both small aircraft (B-200) and high-altitude aircraft (ER-2) has successfully demonstrated. The instrument performed well on all the 12 flights conducted to date and demonstrated reliable and hands-off performance of dual OPO-based UV lasers at 290nm and 300nm. These flights provided the first opportunity to assess the measurement performance. The lidar ozone profiles compared well with profiles from coincident ozonesonde launches to within 1.2% with a variation of 5.7% on average. The airborne lidar profiles also compared well with profiles from the ground-based TOLNet DIAL lidar at University of Alabama in Huntsville. Comparisons to the other TOLNet sites have yet to be analyzed. The flights from the ER-2 demonstrated the lidar performance in a near autonomous operation and provided unique profiles of the lower stratosphere and upper troposphere ozone and aerosol distributions. In addition, current plans are to implement a recently developed Fibertek Inc. OPO laser system that operates at 304 and 316nm. This laser system is currently being integrated with the same pump laser described above and will enable profiling from 20km to the surface at all latitudes.

ACKNOWLEDGEMENTS

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