DIAL MEASUREMENTS OF FREE-TROPOSPHERIC OZONE PROFILES IN HUNTSVILLE, AL

Mike Newchurch[1], Shi Kuang[1], John Burris[2], Steve Johnson[3], Stephanie Long[1]

[1]*University of Alabama in Huntsville, 320 Sparkman Dr., Huntsville, 35805, mike@nsstc.uah.edu*

[2]*NASA Goddard Space Flight Center, Code 694, Greenbelt, Maryland 20771, burris@aeolus.gsfc.nasa.gov*

[3]*NASA Marshall Space Flight Center, Office Code VP61, Huntsville, Alabama 35812, Steven.C.Johnson@nasa.gov*

ABSTRACT

A tropospheric ozone DIfferential Absorption Lidar (DIAL) system has been developed jointly by NASA and the University of Alabama at Huntsville (UAH). Two separated Nd:YAG pumped dye laser systems produce the laser pulses with wavelengths of 285 and 291 nm at 20 Hz frequency. The receiver is a Newtonian telescope with a 40 cm primary and a two-channel aft optics unit. The detection system currently uses photon counting to facilitate operations at the maximum achievable altitude. This lidar measures free-tropospheric ozone profiles between 4-10 km at Regional Atmospheric Profiling Laboratory for Discovery (RAPCD) in UAH campus (ASL 206 m) under both daytime and nighttime conditions. Frequent coincident ozonesonde flights and theoretical calculations provide evidence to indicate the retrieval accuracy ranges from ~5% at 4 km to ~60% at 10 km with 750-m vertical resolution and 30-minute integration. Three Hamamatsu 7400 PMTs and analog detection technique will be added on the current system to extend the measurement to ~100 m above ground to monitor the PBL and lower tropospheric ozone variations.

1. INTRODUCTION

Measuring ozone variability at high spatial and temporal resolution increases our understanding of Planetary Boundary Layer (PBL), PBL and free tropospheric exchange, stratosphere and troposphere exchange (STE), and the impact of lightning generated NOx on tropospheric ozone. Within the troposphere, ozone is partially derived from transport processes that move ozone from the stratosphere into the troposphere and by the oxidation of hydrocarbons originating from anthropogenic activity [1]. Ozone, a powerful oxidant, is harmful to both plant and animal life; it is a strong greenhouse gas and an important component of photochemical smog. However, it is also a key component of the atmospheric oxidizing cycle that cleans the air of harmful pollutants.

The RAPCD-DIAL currently has two altitude channels. The high-altitude channel measures ozone between 4 and 10 km under both daytime and nighttime conditions. The low-altitude channel, which measures ozone between ~100m and 4 km, will be upgraded in the near future. Because of UAH's location, heavy aerosol pollution sometimes arises from sources such as forests, agriculture, and a number of large, coal fired, power plants. Compared with the clean free-troposphere, these aerosols require a larger dynamic range for the detection system because of their larger optical depth. Moreover, the rapid change of aerosols (e.g., due to convective activity) increases the measurement uncertainty for DIAL in the PBL and lower troposphere. Therefore the Huntsville system is configured somewhat differently from instruments designed to measure stratospheric ozone or those that, while designed for tropospheric measurements, have been located at relatively high altitudes. The location of the RAPCD-DIAL in the southeastern United States provides a unique observational site within an interesting scientific area to study ozone in the mid-latitudes that are affected by a variety of processes such as STE, in situ production, lightning NO_X and horizontal transport. Its low altitude facilitates the study of ozone within both the polluted PBL and the free troposphere.

2. SYSTEM DESCRIPTION

Our optimum laser wavelengths result from the following four considerations: 1) The maximum measurable altitude determines the shortest wavelength; 2) The ability to reduce solar radiation in daytime operation determines the longest wavelength; 3) Minimizing the aerosol interference; 4) Avoiding SO_2 interference helps select among potential wavelength pairs.

Table 1. Characteristics of RAPCD-DIAL system

System	Specification
Transmitter	
Lasers	Nd:YAG, 20 Hz repetition rate, ~300 mJ pulse^{-1} at 1064 nm, 80 mJ pulse^{-1} at 532 nm
Dye	Rhodamine 590 and 610
Emitted energy	4-5 mJ pulse^{-1} at 285/291 nm
Receiver	
Telescope	Newtonian, 40.6-cm diameter, f/4.5, 1.5-mrad FOV
Filter	Barr band-pass filter (286.4/11nm) and neutral density filters
Detector	Electron Tubes 9813QA, 20-30% quantum efficiency
Discriminator	Phillips Scientific 300 MHz
Signal Processing	Tennelec/nucleus MCS-II cards, 200 MHz, 24 bit

All lidar systems consist of three major components: the transmitter, receiver, and detection subsystems. The Huntsville transmitter consists of two identical dye lasers pumped by separate Nd:YAG lasers. The characteristics of the DIAL system are listed in Table 1. The receiver is a Newtonian telescope with a 40-cm primary and a two-channel aft optics unit. Its current location is in the RAPCD lidar laboratory where it views the atmosphere through a roof hatch with a 1-m by 1-m opening. The system currently operates with two altitude channels. The signal is split, so the high-altitude channel receives ~90% of the light, and the low-altitude channel receives ~10%. This division effectively restricts the lower-altitude channel to no higher that ~4 km; the high-altitude channel routinely covers 4-10 km and on occasion has reached 12 km. RAPCD's detection system currently uses photon counting to facilitate operations at the maximum achievable altitude. Two EMI 9813 QA PMTs, which have been used extensively for many years on a number of Goddard Space Flight Center lidar systems, are used – one for each channel. Data files are stored in a small microcomputer and processed immediately after acquisition ceases.

3. HARDWARE DIAGNOSIS

The fundamental issue for lidar measurement is the signal nonlinearity problem. Issues arising from the nonlinear operation of the receiver and detection system can adversely impact the quality of the retrieved data by ensuring that the signal is no longer proportional to the constituent being measured. Specific problem areas in photon counting involve the non-linear performance of the photomultiplier tube (PMT), discriminator, and multi-channel scalar (MCS) boards. An LED-based lidar simulator has been developed to characterize the individual components of a tropospheric ozone lidar, and both quantify and understand systematic error sources associated with measurements made by this instrument. Fig. 1 shows the block diagram of the LED experimental setup. The telescope's entrance is covered with an opaque to block the room light. The pulse generator #1 is used to trigger a Wavetek function generator, which drives the LED, the gate circuit, and the pulse generator #2 that controls the clock and bin width pulses for MCS boards. The oscilloscope monitors the driving voltage and the forward current of the LED. Neutral density (ND) filters reduce the luminous intensity of the LED to avoid saturating the PMTs. Using a series of waveforms, one can easily characterize the timing, range gate clock, dead-time, and signal-induced bias (SIB) of the system. When the lidar is deployed to remote locations, the LED lidar simulator can also be used to rapidly verify the instrument's performance at the operational site.

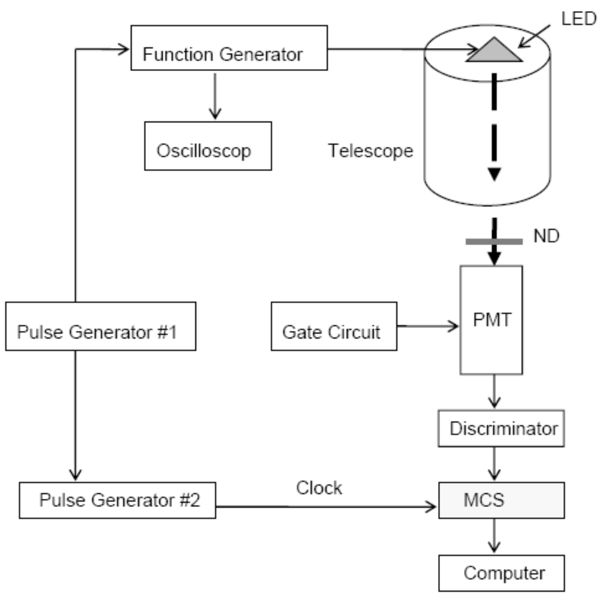

Figure 1. Block diagram of the LED experimental setup.

4. MEASUREMENT EXAMPLES

The RAPCD-DIAL currently retrieves ozone under both daytime and nighttime conditions from approximately 4 km to 10 km altitudes depending upon operational conditions. An example of continuous lidar measurements is shown by Fig. 2. Ten 30-min DIAL measurements shown in Fig. 2 (a) were made between 11:13 and 16:42 local time 23 Dec. 2006. Fig. 2 (b) shows the average DIAL profile of the ten retrievals and its 1-sigma standard deviation which represents the measured uncertainty. The average ozone DIAL profile shows good agreement with ozonesonde measurement between 4 and 10km. The standard deviation increases from ~5% at 4 km to ~60% at 10 km.

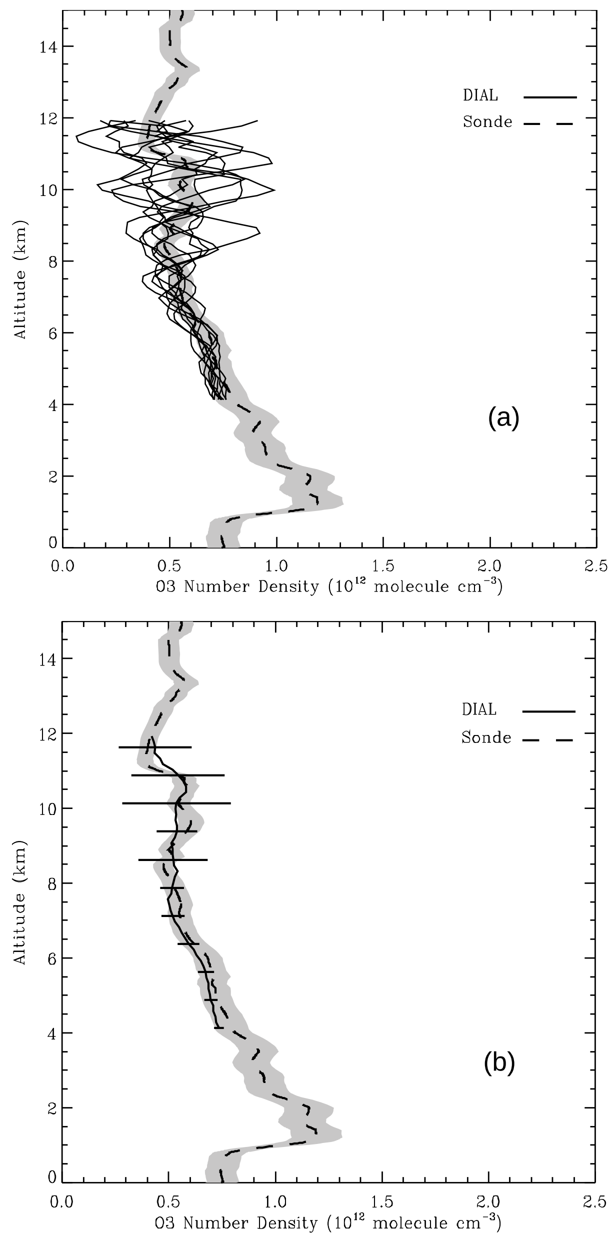

Figure 2. (a) Ten Ozone DIAL retrieval profiles (solid lines) with 750-m vertical resolution and 30-min integration time are compared with co-located ozonesonde measurements (dash line) with $\pm 10\%$ uncertainty (gray envelope). The lidar data were taken between 11:13 and 16:42 local time 23 Dec. 06. The ozonesonde measurement was made at 13:00 local time 23 Dec. 06. (b) Average DIAL retrieval of the ten profiles shown in (a) and its 1-sigma standard deviation.

5. ANTICIPATED HARDWARE IMPROVEMENT

There will be some future hardware enhancements. The first improvement involves replacing the current photon counting system with a more sophisticated commercial unit (manufactured by Licel) designed specifically for lidar applications. The second improvement is to add an independent low-altitude telescope, aft optics and the Hamamatsu 7400 PMTs to obtain profiles within the boundary layer. These improvements will increase the ozone measurement range so that we can monitor the ozone down to the altitude of ~100 m which is the most challenging layer for ozone DIAL measurements due to aerosol interference.

6. CONCLUSION

The RAPCD-DIAL system can measure ozone profiles between 4 and 10 km with errors ranging from ~5% at 4km to ~60% at 10 km. The error sources include the statistical uncertainty, differential scattering and absorption from non-ozone species, uncertainty in ozone absorption cross section, and imperfection of the dead-time and SIB corrections. The statistical uncertainty dominates the error sources in the free-troposphere and could be reduced by increasing the sampling time or reducing the range resolution. The aerosol interference in the free-troposphere is relatively small. A smaller telescope and detection modules will be used for our low-altitude channel in the future to decrease the full overlap altitude and avoid PMT saturation in the near range.

REFERENCES

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