Langley Mobile Ozone Lidar (LMOL) results from the Denver, CO DISCOVER-AQ campaign

Russell De Young
Science Directorate
NASA Langley Research Center
Hampton, VA 23681
Russell.j.deyoung@nasa.gov

William Carrion
Coherent Applications Inc.
Hampton, VA 23681

Denis Pliutau
Science Systems and Applications Inc.
Hampton, VA 23681
Counts With Monitors Projected to Violate Primary 8-hour Ground-Level Ozone Standards in 2020

0.060 - 0.070 parts per million

Notes:
1. The modeled emissions in 2020 reflect the expected emissions reductions from federal programs by 2020 including: the Clean Air Interstate Rule, the Clean Air Mercury Rule, the Clean Air Visibility Rule, the Clean Air Nonroad Diesel Rule, the Light-Duty Vehicle Tier 2 Rule, the Heavy Duty Diesel Rule, the proposed rules for Locomotive and Marine Vessels and for Small Spark-Ignition Engines, and an estimate of State-level mobile and stationary source controls that were projected to be needed to attain pre-existing PM 2.5 and ozone standards.
2. Controls applied are illustrative. States may choose to apply different control strategies for implementation.
3. EPA did not model future violations outside the continental U.S.
4. EPA is proposing to determine compliance with a revised primary ozone standard by rounding the 3-year average to three decimal places.
Langley Mobile Ozone Lidar is part of the Tropospheric Ozone Lidar Network (TOLNet)
Langley Mobile Ozone Lidar (LMOL) Schematic
DISCVOVER-AQ Campaign Denver, CO
July-August 2014

Image credit: Tim Marvel / NASA
DISCOVER-AQ Goals

• Relate column observations to surface conditions for aerosols and key trace gases O3, NO2, and CH2O. How well do column and surface observations correlate? What additional variables (e.g., boundary layer depth, humidity, surface type) appear to influence these correlations?

• Characterize differences in diurnal variation of surface and column observations for key trace gases and aerosols. How do emissions, boundary layer mixing, synoptic transport, and chemistry interact to affect these differences?

• Examine horizontal scales of variability affecting future satellites measurements and model calculations. How do different meteorological and chemical conditions cause variation in the spatial scales for urban plumes?
The system has been configured to enable mobile operation from an environmentally controlled trailer.

This mobility allows lidar to be set up at remote sites to support major air quality field campaigns.
Weekly Ozonesonde Launches Used to Validate Ozone Lidar
Ground, Ozonesonde and Lidar Ozone Profile January 31, 2014 at LaRC

Merge of 3 channels (very near field at 36m resolution up to 900 meters, near field analog at 90m resolution from 900 to 3200 meters, and the far-field photon counting at 90m resolution above 3200 meters)
All data post ozone profile extraction smoothed using 5-point least squares

The Science Directorate at NASA’s Langley Research Center
At 2500-m the air mass was clean coming from the northwest mountains.
August 29, 2014 Table Mountain, Golden, Colorado Ozone and Aerosol Scattering Ratio Profiles
July 29, 2014 – L-MOL Analog profile: 90 meters (5-point smoothing) x 10 minutes resolution
Photon counting profile: 112.5 meters (9-point smoothing) x 10 minutes resolution
Very near field: 36 meters (5-point smoothing) x 10 minutes resolution
Location: Golden, CO (Lat: 39.755742, Lon: -105.184479), Altitude: 1842 m
The spirals show the airplane sampling projections (~spiral diameter 4–9 km)
August 11, 2014 – L-MOL Analog profile: 90 meters (5-point smoothing) x 10 minutes resolution
Near field: 60 meters (5-point smoothing) x 10 minutes resolution
Location: Golden, CO (Lat: 39.755742, Lon: -105.184479), Altitude: 1842 m
Peak Ozone Lidar Trends from South Table Mountain, Golden, CO
(July 16, 17 at Boulder Atmospheric Observatory, Erie, CO)

- Altitude of peak ozone AGL, m
- Peak ozone, ppbv
- Time of peak ozone, UTC

Background ozone 45 ppbv
Local time = UTC - 6

July 2014
August 2014
Conclusions

- LMOL validated by many ozonesonde comparisons within ~5% of sonde.
- Participated in DISCOVER-AQ Denver campaign summer 2014.
- Ozone and aerosol (527 nm) profiles from ground (2B in-situ) to ~4-km.
- Current research with Virginia Dept. of Environmental Quality and Colorado Air Pollution Control Division.
Langley Mobile Ground-based Lidar Ozone Profiling

Russell De Young
Langley Research Center

Operational ozone lidar taking weekly atmospheric profiles with ozonesonde launch

Operational lidar in Langley lab

Four Channel Lidar
- In-situ ozone 4 m
- Far Field ozone 4-7 km
- Near field ozone 1.5-4 km
- Very near field ozone .1-1.5 km
- Green aerosol 1-10 km

Lidar to be deployed in trailer

Receiver Detector Module

- The receiver box contains optics which direct the transmitted light from the fiber optic cable into the APD and two UV PMT detectors.
- The APD is used for collection of the visible return signal.
- One PMT is used for near-field UV detection.
- The other PMT is used as a far-field UV detector for a Licel Transient Recorder that can acquire both analog and photon counting signals.
Science Investigations Addressed by the Mobile Ozone Lidar System

• Provide high spatio-temporal profiles of Planetary Boundary Layer (PBL) and Free Troposphere (FT) ozone and aerosols to study the atmospheric structure that GEO-CAPE will observe and assess the fidelity with which a geo instrument can measure that structure.

• Discover new structures and processes at the PBL/FT boundary, especially in the diurnal variation of that interface.

• Help improve air-quality forecast models. Field an ozone lidar that would be suitable to populate a network to address the needs of NASA/EPA/NOAA air-quality scientists and managers who increasingly express a desire for ozone profiles.

• Participate in Denver DISCOVER AQ campaign July-August 2014.

• Improve understanding of ozone and aerosols aloft and surface ozone and PM values. Advance our understanding of processes controlling regional background atmospheric composition and their effect on surface air quality to prepare for the GEO-CAPE era.
O3 8-hour Design Value Projections to 2020
Hampton Roads Ozone Profile: Example of Ozone Transport and Local Ozone Generation
Hampton Roads Ozone Profile: Example of Low Ozone Generation with Little Transport
May 4 (12:00 AM through 3:20 PM). Combined curtain plot (analog below 3000 m, photon counting above 3000 m). Analog: 10 min x 90m resolution with 5-point least squares smoothing, and Photon counting: 112.5m with 9-point least squares smoothing of the final ozone profile. Sonde launched at 2:46 AM used in ozone concentration profile extraction. The plot spans over 15 hours and combines 2664 Liel files, online = 287.09 nm, offline = 292.7 nm, diff. cross-section of 2.677e-23 m²*2.
**Optical Schematic of Pump Laser and Tunable UV Laser**

**Nd:YLF diode pumped laser** with intra-cavity frequency doubling (Coherent Evolution 30 TEM$_{00}$)

**Ce:LiCAF tunable UV laser.** Green 527nm is the second harmonic output beam from the Nd:YLF laser. Fourth harmonic 263nm output, generated in CLBO crystal, is split into two beams then focused on the Ce:LiCAF crystal. Oscillating mirror cavity generates tunable 280-300nm output.
Laser Transmitter Conversion Steps

Coherent Pump Laser

527-nm
1kHz,
130-ns
7.3 W

CLBO

262-nm
1.2 W

Ce:LiCAF

Crystal

Oscillating Mirror

Output Coupler

286/292-nm
0.180-mW

Tunable UV Laser Cavity
Solar Actinic Flux and Ozone Absorption Cross-section vs Wavelength

Analog (red) and Photon Counting (Green) Ozone Compared to Ozonesonde (black)

Sonde launch 9:48 AM EST
May 5, 2014
Combined files No. 1728 through 1758

112.5 m with 9-point least squares
90 m with 5-point least squares
# Ozone Lidar Specifications

<table>
<thead>
<tr>
<th><strong>PUMP LASER</strong></th>
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<tbody>
<tr>
<td>Green output of Nd:YLF laser</td>
<td>12 mJ/pulse, 527 nm (max)</td>
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<tr>
<td>UV output for pumping Ce:LiCAF laser</td>
<td>2.8 mJ/pulse, 263 nm (max)</td>
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<tr>
<td>Repetition rate</td>
<td>1 kHz</td>
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<tr>
<th><strong>LIDAR TRANSMITTER</strong></th>
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<tr>
<td>Ce:LiCAF laser energy</td>
<td>0.1 mJ/pulse</td>
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<tr>
<td>Wavelength tuning range</td>
<td>285-300 nm</td>
</tr>
<tr>
<td>Typical ozone wavelengths</td>
<td>285.7 and 291.4 nm, 500 Hz each</td>
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<tr>
<td>Laser line width</td>
<td>~0.2 nm</td>
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<tr>
<td>Laser beam diameter, divergence</td>
<td>~0.8 cm and 0.13 mrad</td>
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<tr>
<td>Transmitted green, divergence</td>
<td>2 mJ/pulse, 527 nm; 0.85 mrad</td>
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<tr>
<th><strong>LIDAR RECEIVER</strong></th>
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<tr>
<td>Near Field Telescope</td>
<td>40 cm dia. Newtonian (62% efficiency)</td>
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<tr>
<td>Fused silica optical fiber</td>
<td>1 mm dia., NA=0.28</td>
</tr>
<tr>
<td>Field of view</td>
<td>1.4 mrad</td>
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<tr>
<td>UV channel, $\lambda_c$ 285-300 nm, $T = 60%$</td>
<td>PMT – analog + photon counting</td>
</tr>
<tr>
<td>Green channel , $\lambda_c$ 527 nm, $\Delta \lambda = 0.3$ nm, $T = 43%$</td>
<td>PMT – analog</td>
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<tr>
<td>Very near field telescope</td>
<td>30 cm dia. Fresnel telescope</td>
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<th><strong>POWER REQUIREMENTS</strong></th>
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<tr>
<td>Laser + control system</td>
<td>1 KW</td>
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<tr>
<td>Chiller</td>
<td>1 KW</td>
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