Capabilities & example data from the Langley Mobile Ozone Lidar (LMOL)

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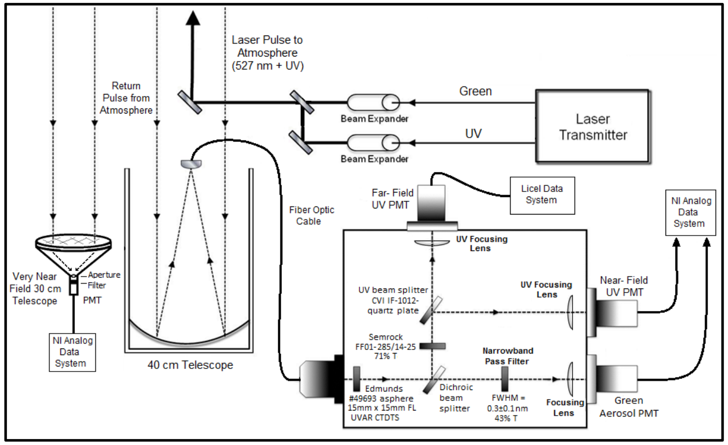
Outline

- Brief description of Langley Mobile Ozone Lidar (LMOL) & capabilities
- Hardware/software upgrades & calibration/validation
- Recent Air Quality Case studies:
  - April 19, 2016 Exceedance
  - May 24 & 26, 2016 Transport
- Possible future studies
- Summary & conclusions

NASA Langley Mobile Ozone Lidar (LMOL)

Deployed for the first time in the NASA DISCOVER-AQ campaign (2014).

System diagram



Mobile trailer

Trailer interior

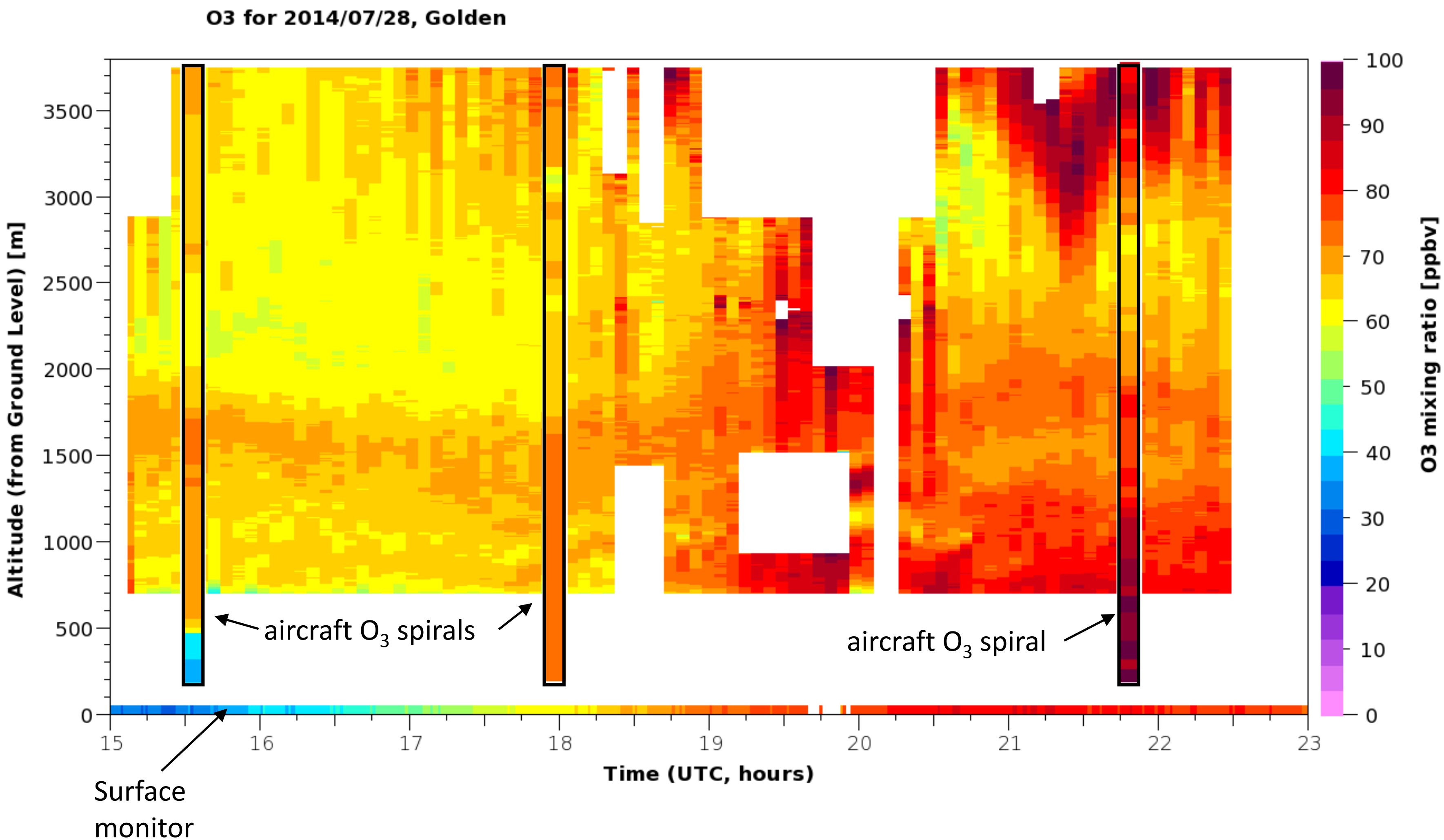
Capabilities:

- Small, highly mobile trailer, can be towed with a pick-up truck to relocate
- Ozone profiles up to 6-7 km AGL for a 5 minute time average
- New software upgrade provides real-time curtain display for ozone and aerosol profiles
- Possible to run 24 hours, but currently limited by staff support, looking into unattended options in 2017

Science investigations addressed:

- Provide high spatio-temporal profiles of Planetary Boundary Layer (PBL) and Free Troposphere (FT) ozone and aerosols.
- Help improve air-quality forecast models.
- Improve understanding of ozone and aerosols aloft and its influence on surface ozone and PM values.

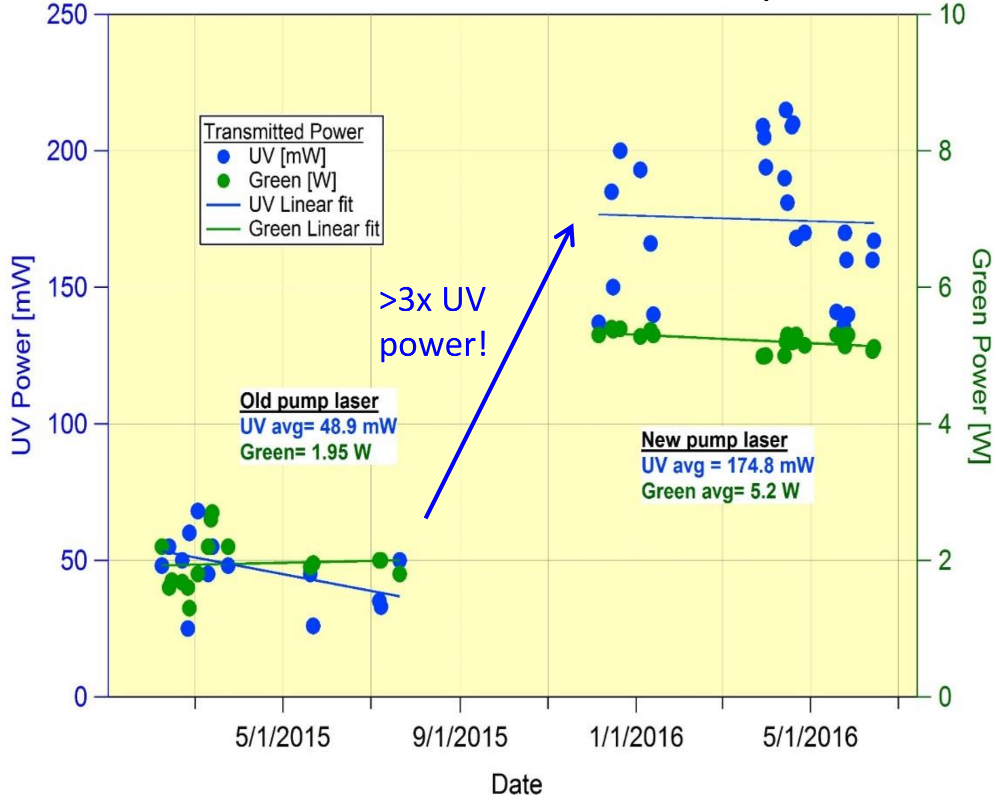
LMOL example data comparison with P3B spirals during DISCOVER-AQ



Recent LMOL hardware upgrades

- Recent LMOL laser pump replacement funded by NASA HQ/TOLNet: 3x increased transmitted laser power starting in 2016, dramatic increase in stability
- Receiver box re-alignment in May 2016, stray light & BP filter improvements
- Data system & detector upgrades expected in 2017
- Near-range (0-600m AGL) absolute stability to be improved in 2017
- Unattended operation in 2017?

LMOL increase in transmitted power



Operational for 6 months at higher power, no sign of difficulties

LaRC related laser development efforts for TOLNet

- John Hair NASA LaRC technical point of contact
- SBIR Phase II recently awarded to Bridger Photonics, Bozeman MT
- Addresses the need for a commercial source for TOLNet ozone DIAL lidar systems
- Estimated transmitter commercial cost: ~$200K
- 2-year maintenance-free interval

NASA SBIR/STTR Technologies

S1.01-8695 - Compact, Rugged and Low-Cost Atmospheric Ozone DIAL Transmitter

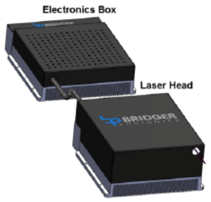
SBIR STTR

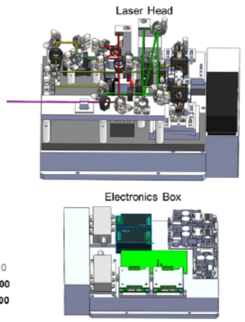
PI: Jason Brasseur
Bridger Photonics, Inc. - Bozeman, MT

Identification and Significance of Innovation

Real-time and high-frequency measurements of atmospheric ozone are becoming increasingly important to understand the impact of ozone towards climate change, to monitor and understand depletion of the ozone layer, to further understand its role in atmospheric chemistry, and to assess its impact on human health and the productivity of agricultural crops. Expansions of tropospheric ozone measurement efforts, such as NASA's TOLNet program, are critical to improve our understanding these effects. In response to this need, Bridger Photonics Inc proposes developing the most efficient, compact, rugged, low-power consumption and cost-effective UV ozone differential absorption lidar (DIAL) transmitter available. The proposed transmitter will enable widespread deployment of ozone DIAL systems capable of continuous range-resolved atmospheric ozone measurements from ground-based and airborne platforms to advance NASA's Earth science mission. To achieve this design goal, Bridger will apply innovations proven out during its Phase I effort and developed previously for its MIR series laser product.

Estimated TRL at beginning and end of contract: (Begin: 4 End: 6)





Estimated Transmitter Cost (4x Parts)

	QTY 1	QTY 10
One Laser/Two OPO option	**$190,000**	**$140,000**
Two Laser/Two OPO option	**$260,000**	**$200,000**

Technical Objectives and Work Plan

The overall Phase II goal for this effort is to design, construct, and test an autonomous, production-grade prototype, two-wavelength ozone LIDAR transmitter. The proposed transmitter will enable state-of-the-art continuous ozone LIDAR measurements without the need for a skilled operator. It will also provide a long maintenance-free interval (> 2 years), and will cost under $200k per transmitter. In this Phase II effort Bridger will pursue four main objectives: 1) refine its Phase I breadboard prototype to increase output pulse energy, mode quality, and system stability, 2) design and construct a brassboard prototype transmitter for system testing and demonstration, 3) perform lifetime and damage testing on critical system components to ensure long term operability, and 4) perform environmental sensitivity and long-term performance testing on the brassboard prototype. Successful completion of this Phase II program will allow Bridger to demonstrate a simultaneous DIAL, production prototype transmitter with pulse energies >200 µJ in both DIAL wavelengths capable of autonomous operation, without degradation, for 3 months.

NASA Applications

NASA's primary application for the proposed transmitter would be for widespread deployment of ground-based and airborne sensors to map ozone concentrations with high spatial and temporal resolution. This will allow NASA to carry out its Earth Science missions with smaller, lower cost DIAL transmitters enabling NASA programs to meet multiple mission needs and make the best use of limited resources. Our system will be highly useful for both integrated column and range-resolved measurements due to its short pulse durations and high energies.

Non-NASA Applications

Both NOAA and the EPA would be potential customers for the complete UV transmitter. Our base pump laser can be frequency down-converted into the SWIR spectral band for profiling other important greenhouse gases and pollutants. Bridger envisions a variety of applications for the pump laser including hard-target ranging, laser ablation, nonlinear spectroscopy, and as a general purpose OPO pump.

Firm Contacts

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FAX: (406) 587-0808

NON-PROPRIETARY DATA

LMOL Algorithm improvements & calibration/validation

- Working closely with TOLNet team members for routine cross-comparison with measurements & algorithm improvements
  - August 2016 field deployment planned in California, multiple TOLNet lidar systems
- Routine ozonesonde launches from LaRC (Travis Knepp)
- Cross-comparisons with LaRC HSRL-2 lidar (John Hair) measurements (June 2016) and other opportunities when they occur
- Overpasses from other aircraft (ie. C130 ACT-America mission overflight in May 2016)
- Working with Danette Allen/Intelligent Flight Systems at NASA LaRC for possible use of LaRC UAV platform in 2017 for more effective near range (low altitude) calibration/validation tests

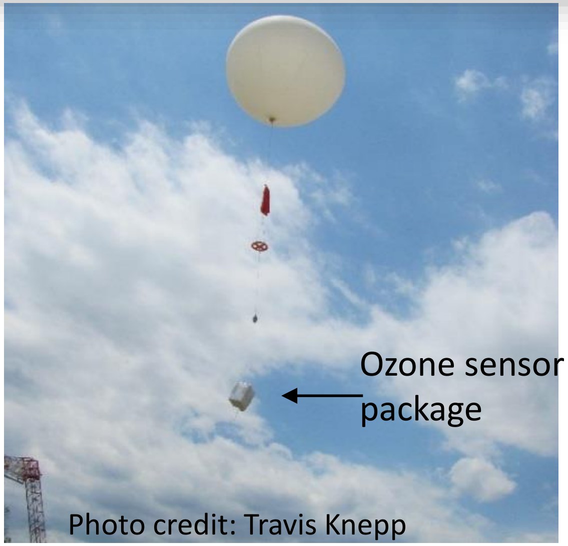
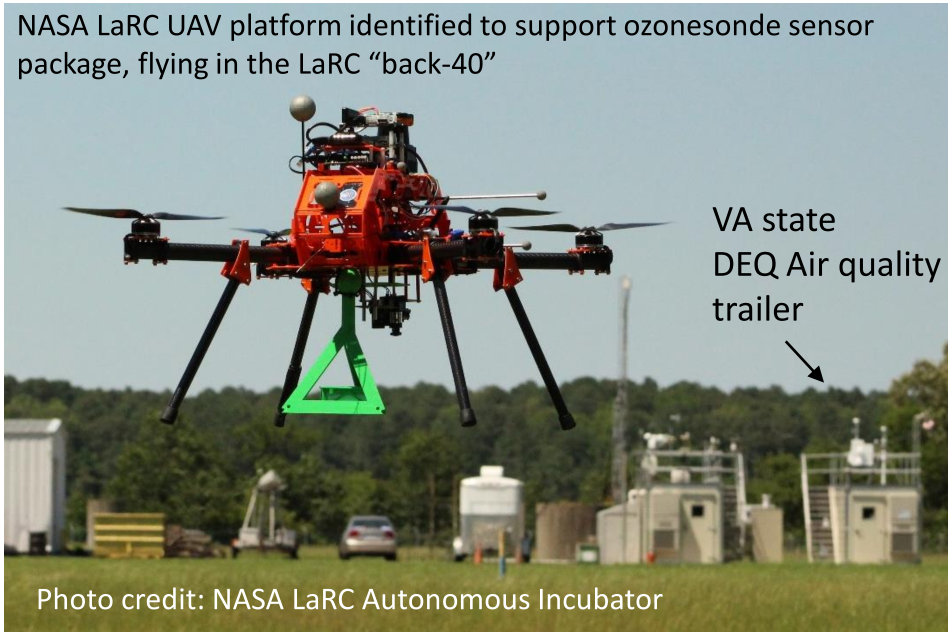


Photo credit: Travis Knepp



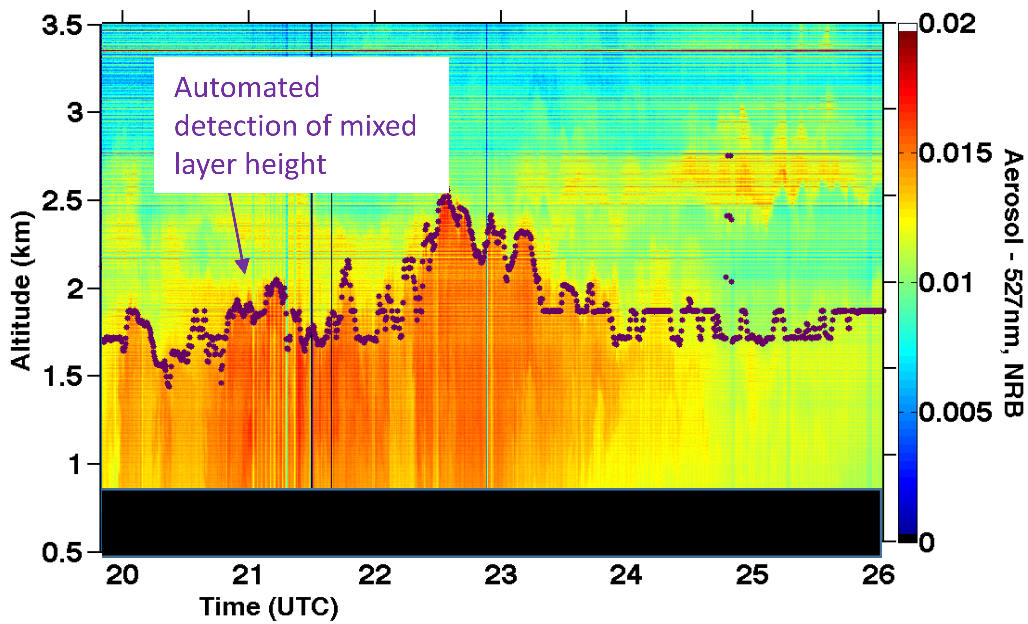
NASA LaRC UAV platform identified to support ozonesonde sensor package, flying in the LaRC "back-40"

Photo credit: NASA LaRC Autonomous Incubator

First test-case applied to LMOL data for "PBL" height retrieval

- Feasibility test of processing LMOL backscatter signal through Scarino's MLH algorithm (Scarino et al, 2014 ACP)
- Uses a Haar wavelet covariance transform with multiple dilations to identify sharp gradients in aerosol backscatter (Brooks, 2003, Davis et al., 1997 & 2000)
- Daytime lidar MLH can be used as a proxy for PBL under certain conditions (ie. well-mixed, daytime boundary layer)
- Tested on one day from DAQ Colorado and did a good job on aerosol, possible further development and validation in 2017

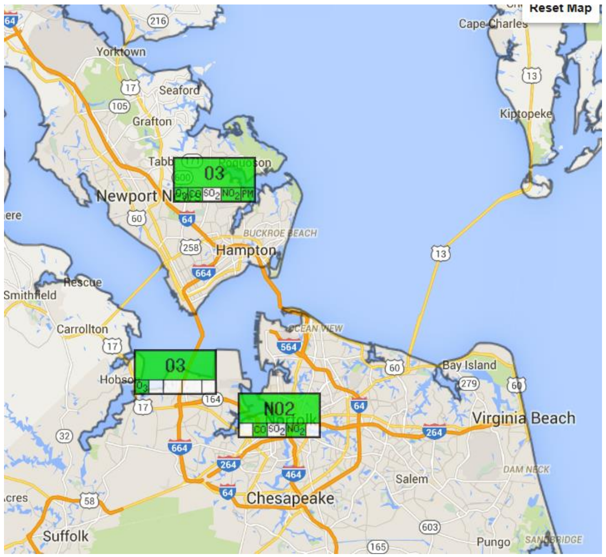
LMOL PBL retrieval provided by Amy Jo Scarino (SSAI/NASA LaRC) 20140811



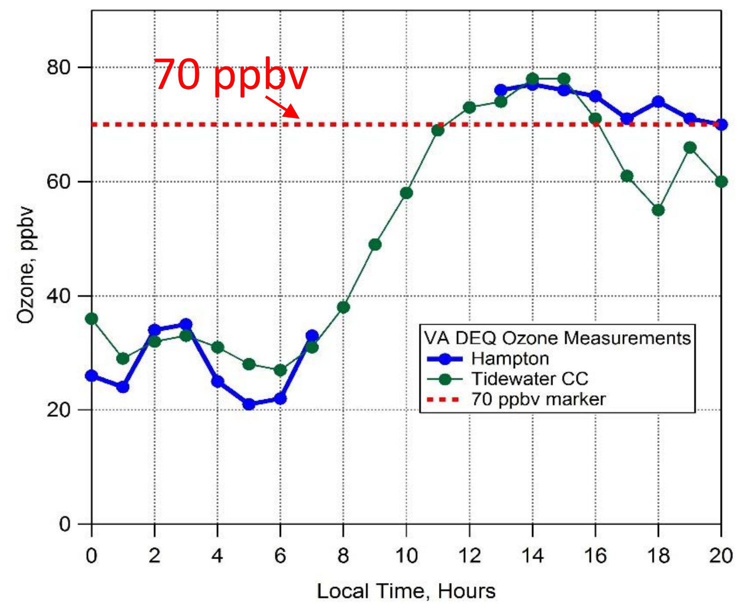
PBL height critical to constrain atmospheric models to better represent boundary layer concentrations of ozone

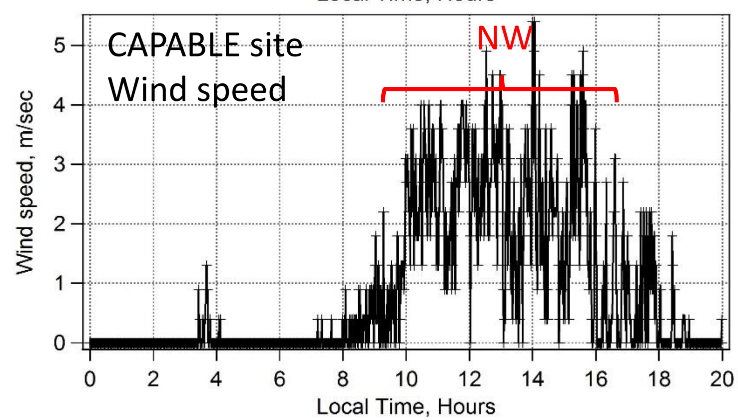
April 19: First Hampton Roads Exceedance for 2016

Map of VA DEQ monitors near LaRC



VA DEQ Surface Ozone

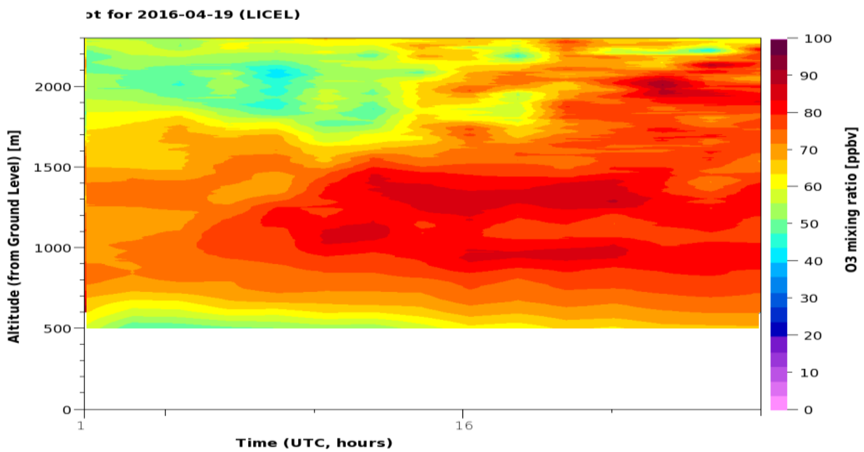


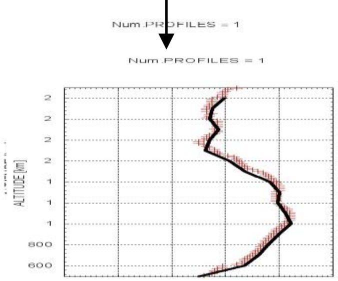


Ozone exceeds 70 ppbv in the afternoon

Increase in winds in the afternoon from the NW

LMOL measurement on April 19, 2016





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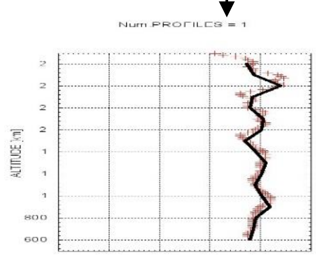
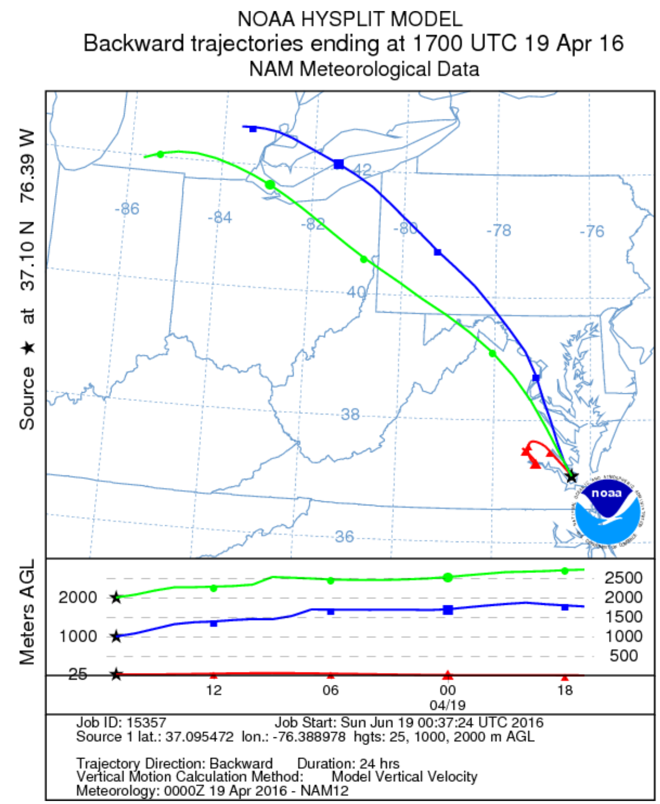


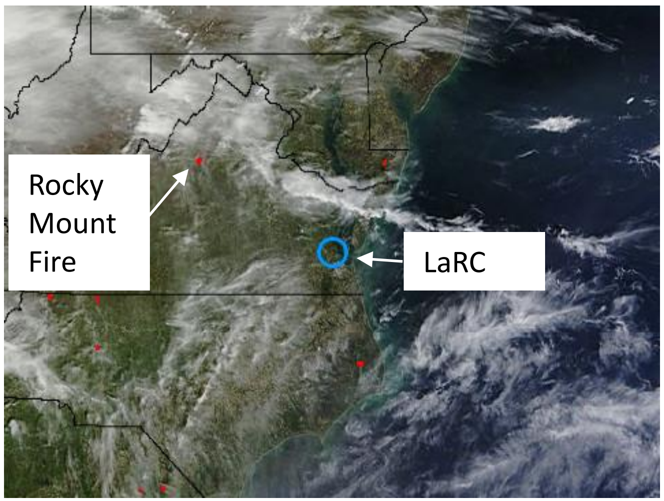


LMOL reveals a strong aloft ozone from 0.6 to 2 km in altitude, that extends down towards the surface around mid-day

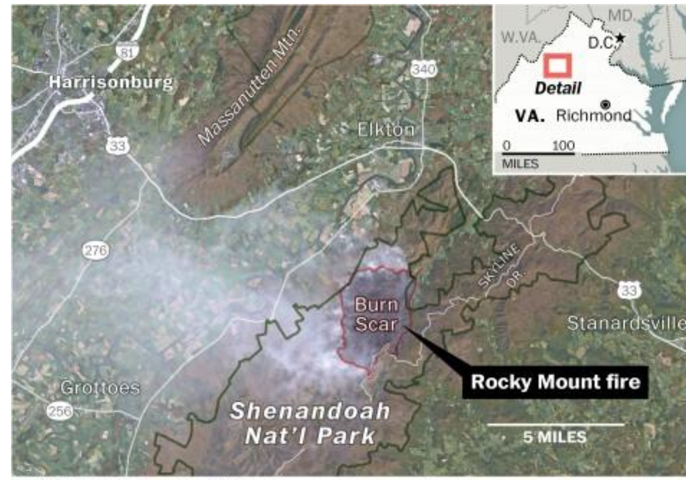
Back-trajectories indicate surface air recirculating in region, upper levels in the O3 layer formed from a NW airmass subsiding in the boundary layer

April 2016 Rocky Mount Fire

April 19 MODIS image



Washington Post April 19



April 20 satellite image via NASA

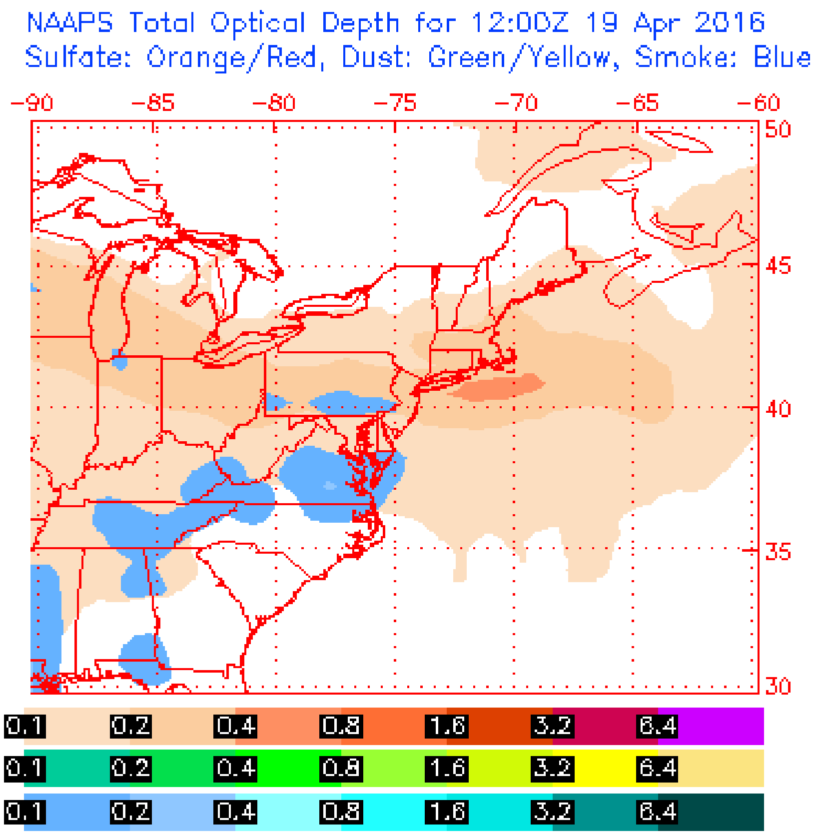
LARIS KARKLIS/THE WASHINGTON POST

The Rocky Mount fire burns in Shenandoah National Park, seen from McGaheysville, Va., on the night of April 19. (Larry W. Brown)

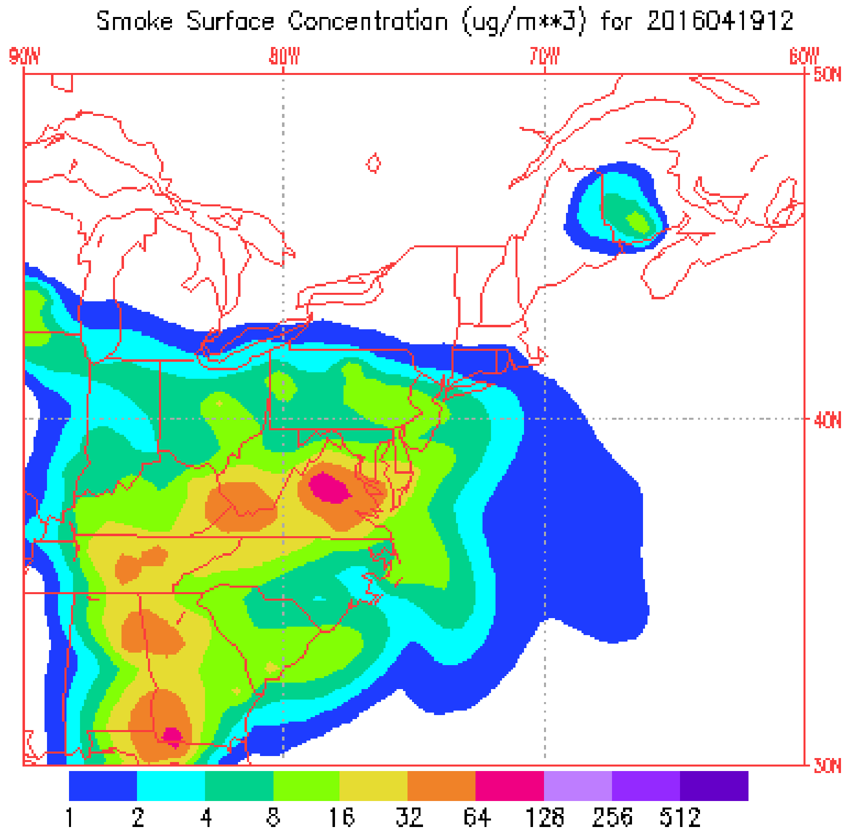
250 km NW of NASA LaRC
Second largest fire in history of Shenandoah National Park

NRL-NAAPS Aerosol Model for April 19, 2016

Columnar AOD (Blue= smoke)

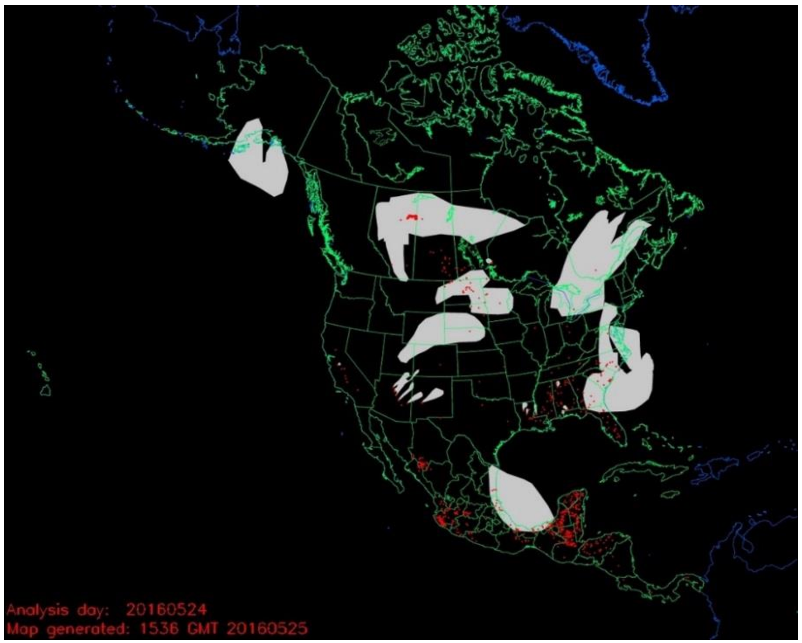


Surface Smoke Concentration

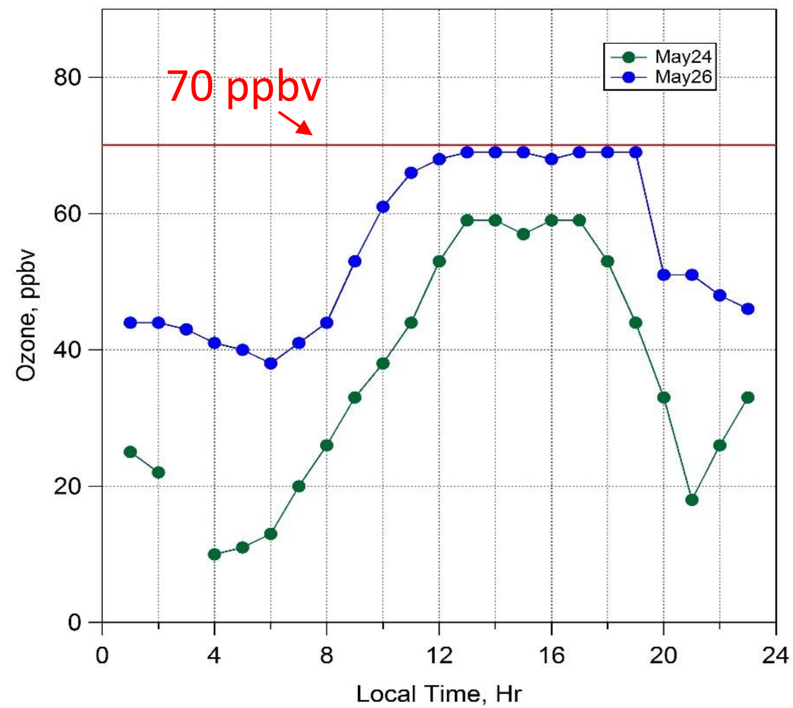


May 24 & 26, 2016 Hampton Roads

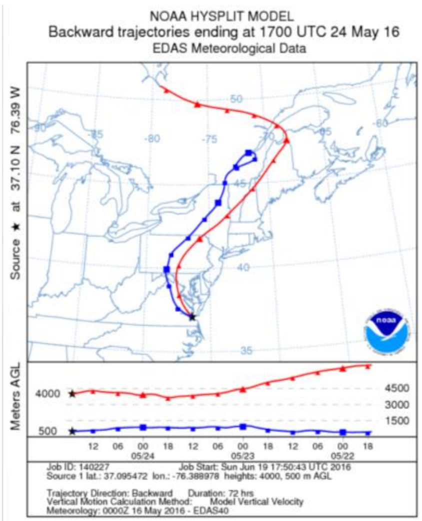
NOAA HMS smoke product

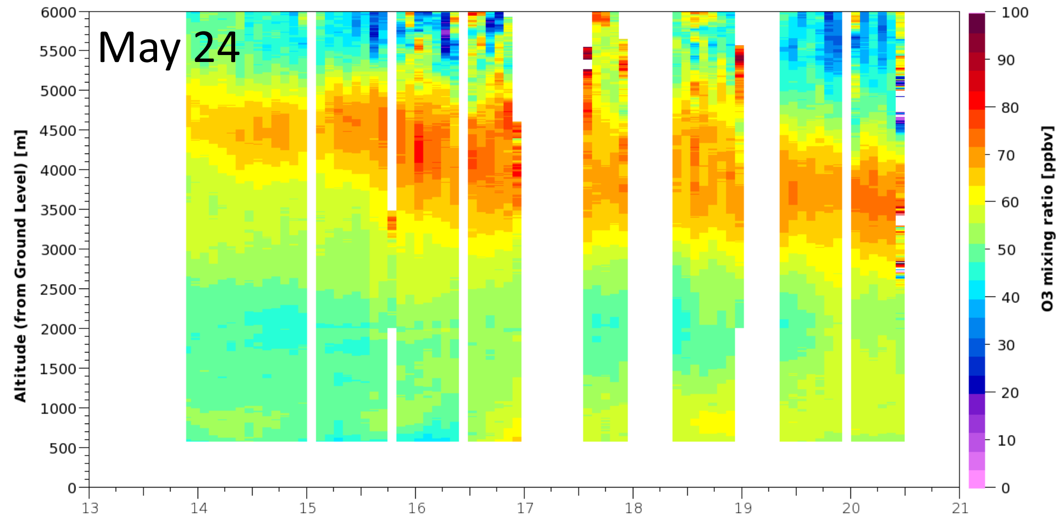


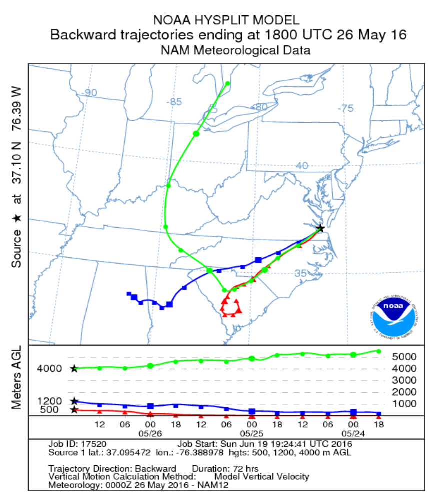
VA DEQ surface Ozone
Hampton, VA

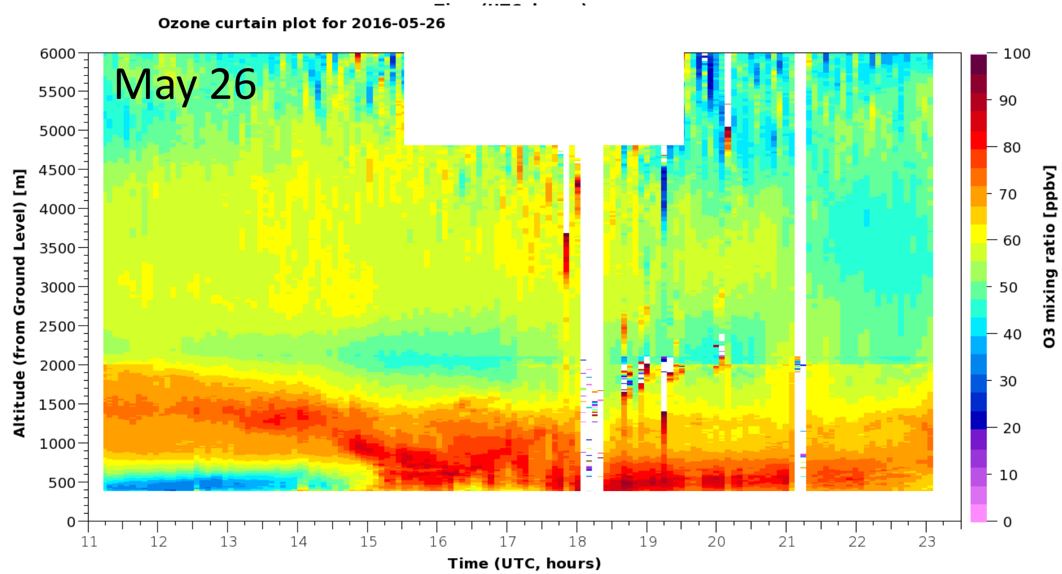


May 24 & 26: Aloft ozone layers appear to be from different sources
May 26 mixed into the boundary layer, but May 24 did not









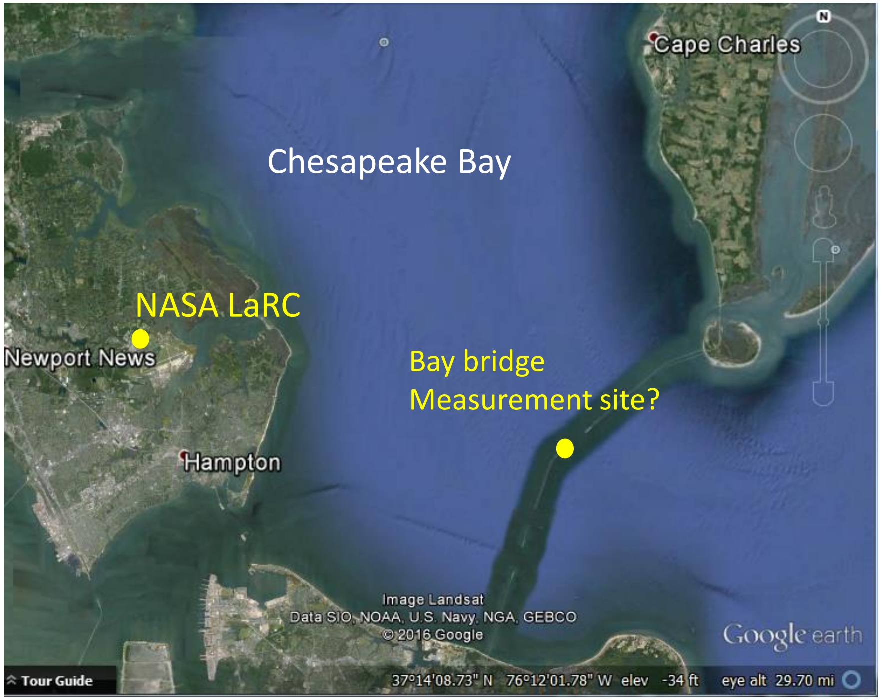
Future studies?

- LMOL can be paired with other TOLNet systems to help characterize ozone transition zones in a variety of situations
- Rural v. Urban, Water v. Land
- Ryan Stauffer et al., J. Atmos. Chem (2015):

> **"The observation of land/water horizontal and vertical gradients of O3 over the Chesapeake Bay on four separate days during DISCOVER-AQ 2011 point to a need for more consistent monitoring of air quality over the Chesapeake Bay waters, allowing more statistically stringent analyses to determine if the existence of higher O3 mixing ratios over the Chesapeake is commonplace during the summer months."**

- LMOL is small enough to go onto a small ship/barge
- Chesapeake Bay Bridge/Tunnel is close to LaRC, and could be a possible site for over-water measurements

Over-water ozone profiling



Summary

- Case studies presented illustrate the complex nature of ozone vertical structure & temporal dynamics
- LMOL/TOLNet lidars are able to more fully characterize these complex events, i.e. when aloft ozone may be mixing down into the boundary layer and compromising surface air quality
- Assessment of local v. transport generated ozone
- Combined with back-trajectory and model information to help identify contributing sources (ie. wildfires, urban, etc.) and improve
- With multiple TOLNet lidars, possible to study ozone transition profiles (ie. water v. land, urban v. rural, etc.)

Acknowledgements/credits

- Support from NASA HQ/TOLNet, NASA DISCOVER-AQ
- Data/images from VA DEQ, NOAA Hysplit, NRL-NAAPS aerosol model, NOAA HMS, MODIS, Washington Post
- Amy Jo Scarino (NASA LaRC) for mixed layer height analysis of LMOL data
- Travis Knepp (NASA LaRC) for ozonesonde support

Call for Papers

AMS 2017

American Meteorological Society

97th ANNUAL MEETING | SEATTLE

Eighth Symposium on Lidar Atmospheric Applications in Seattle, WA - 22–26 January 2017

This year's theme is

Observations Lead the Way

Please consider submitting your work! Go to the link annual.ametsoc.org, select call for papers and scroll to "Eighth Symposium on Lidar Atmospheric Applications" for more information. Abstracts are due by 1 August 2016.

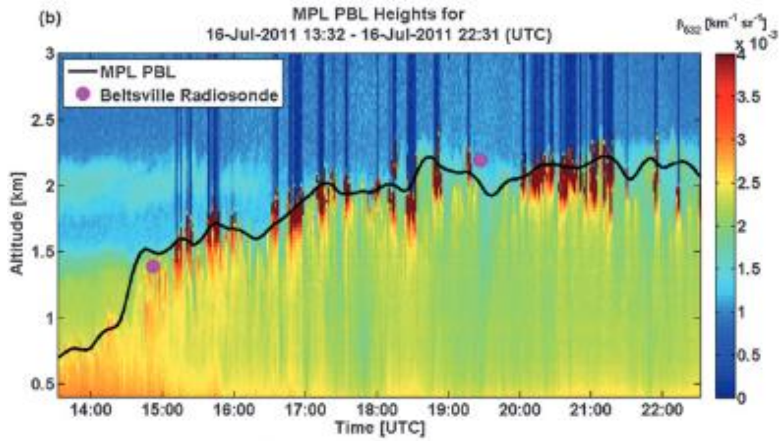
Questions? Please contact the program chairperson(s), Sara Tucker (email: sara.tucker4ea@gmail.com) and Tim Berkoff (email: timothy.a.berkoff@nasa.gov)

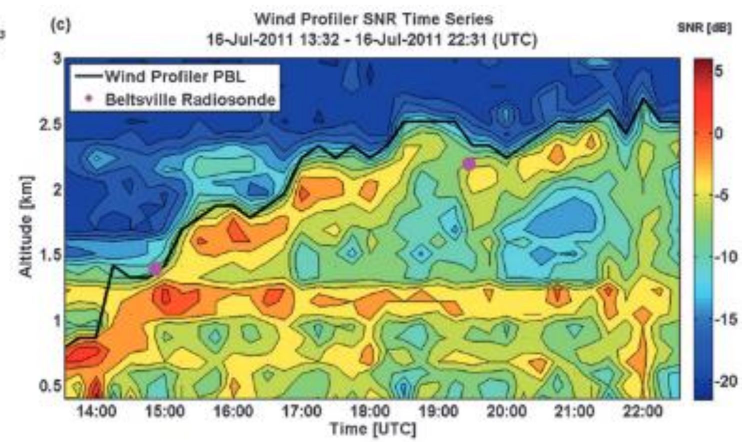
Papers for this conference are solicited on:

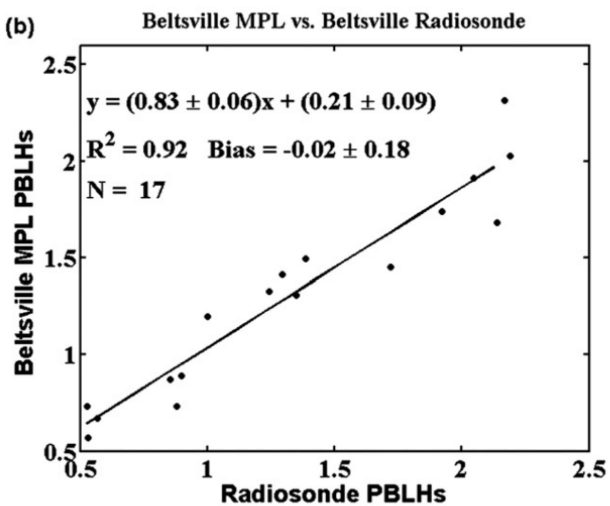
- Lidar observations as model assimilation inputs and verification data-sets
- Lidar applications to air quality and climate studies
- Lidar networks
- Making lidar data accessible to decision makers and the public
- New lidar technologies for atmospheric applications: from instrumentation to data distribution
- Lidar applications to the energy sector
- Space-based lidar observations
- The CALIPSO Mission and its impact on AMS community interests.
- Polar lidar observations

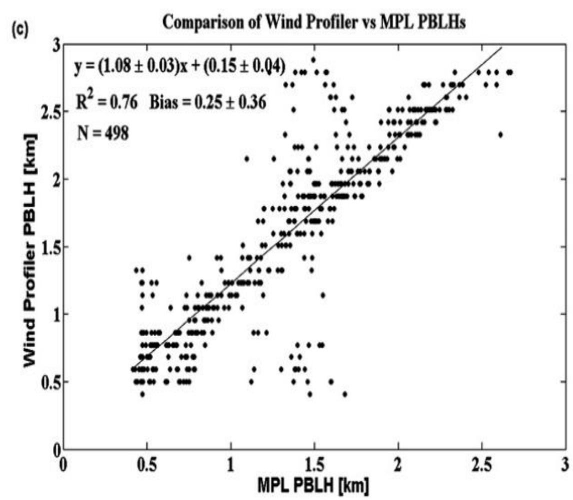
Example “PBL” height determination from lidar data

From Compton et al., *J. Atmos. Oceanic Technol.*, **30**, 1566–1575





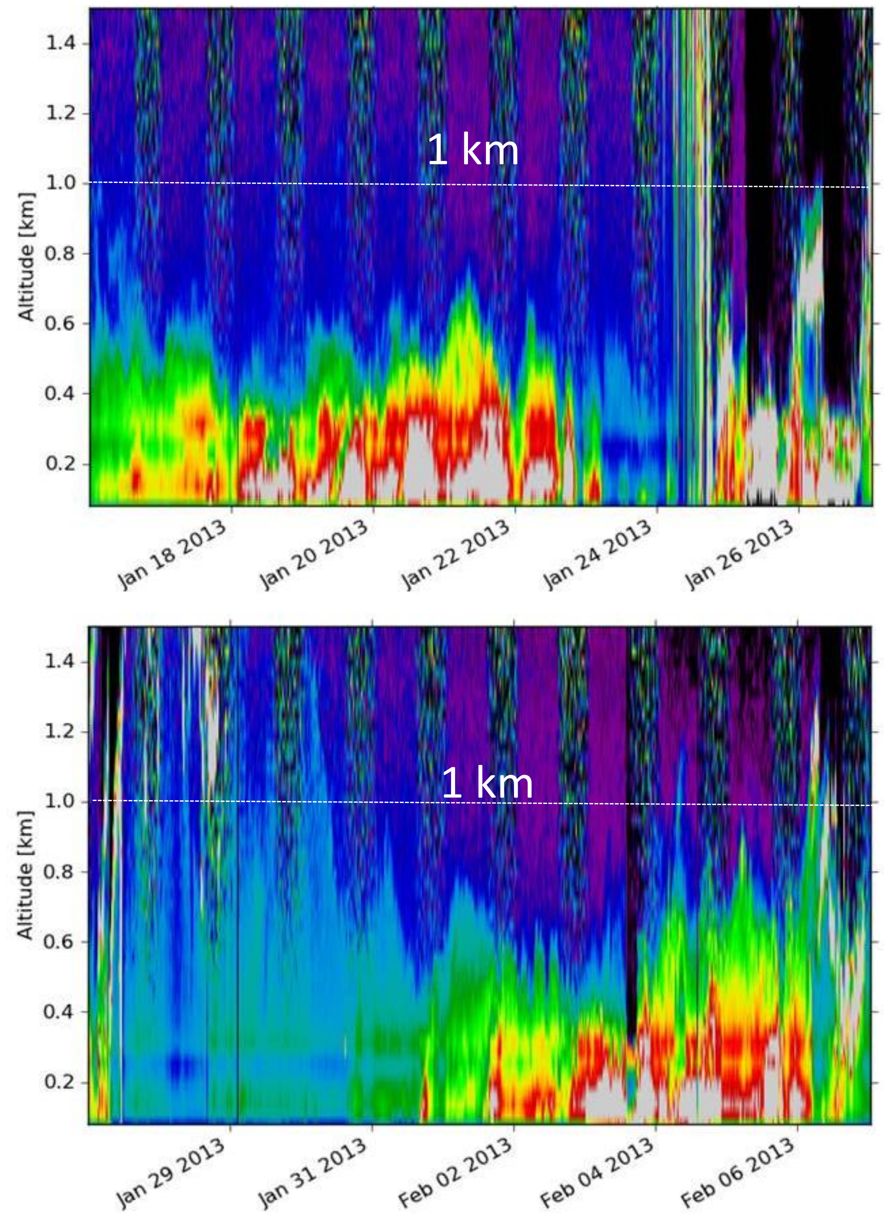




Recovery of near-surface signal with wide field-of-view (WFOV) receiver

Extra receiver on top of telescope

Porterville, CA MPL WFOV Data



- San Joaquin Valley has extremely low PBL, so low that standard MPL channel would not ordinarily capture aerosol dynamic
- WFOV implemented at some DAQ sites in California, Houston, & Denver to enable on-site cals and better retrievals of near-field (< 1 km) aerosols