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Some data are courtesy of the Pandora team. From Pandonia website

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TOLNet/NDACC joint meeting, May 2018
The LMOL Lidar

G. GRONOFF

O_3 Titration from a Nearby Point Source: The Wonders of the Very Near Field
The LMOL Lidar
O₃ Titration from a Nearby Point Source: The Wonders of the Very Near Field (OWLETS Campaign)
The LMOL Lidar
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Photonics Industries Int. Inc.
DS-527-15 Nd:YLF 527 nm laser
The LMOL Lidar

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The LMOL Lidar

New receiver

- Return Pulse from Atmosphere
- Laser Pulse to Atmosphere (286 + 291 nm)
- Beam Expander
- Laser Transmitter
- Far Field PMT module
- Licel Data System
- Near Field PMT module
- Fiber Optic Cable
- 40 cm Telescope
- Near Field Receiver (76 mm OAP)
The LMOL Lidar

Properties – before 2017-2018 improvements

- Nd:YLF Laser: 527 nm (12mJ/pulse) 1 kHz
- Pumping Ce: LICAF: UV lines (2.8mJ/pulse) 285-310 nm range.
- Far Field: Photon counting (> 2000 m)
- Near Field: Analog (600-3000 m)
- Very Near field: 100-1200 m
TOLNet validation

- Intercalibration of Lidars –including LaRC/LMOL and GSFC/TROPOZ–
- Validation of lidars against ozonesondes.
- Definition of common algorithmic techniques (vertical resolution, temporal resolution, uncertainty computations).
- Definition of common parameters (O$_3$ absorption cross sections, O$_2$ mixing ratio . . . ) across TOLNet and NDACC.

*Tropospheric Ozone LIDAR Network*
Data validation, control, and standardization

For those who were not there: TOLNet validation: Intercomparison with sondes during SCOOP. Courtesy Thierry Leblanc (JPL)
Validations and Campaigns

2014: DISCOVER-AQ Campaign

Boulder, Co
First version of the Lidar.
Still some technical problems.
Intercomparison with the other TOLNet lidars, and P3B plane.
(I was not present for that campaign.)

Warning on DAQ results

This was the first deployment of LMOL. The instrument has been dramatically improved since.
Validations and Campaigns

2016: SCOOP campaign

- Table Mountain Facility in California
- Improved version of the lidar.
- Real time analysis of data available.
- Laser very stable.
- More than 50 h of data.
- The Blue Cut Fire stopped the campaign
Validations and Campaigns

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Validations and Campaigns

2016-08-16 LMOL O3

Altitude (from Ground Level) [m]
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000 8500 9000 9500 10000

Time (UTC, hours)
0 20 21 22 23

O3 mixing ratio [ppbv]
0 10 20 30 40 50 60 70 80 90 100 110 120

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Validations and Campaigns

Conclusion of the SCOOP campaign

- The LMOL laser is stable and able to run for hours at a time.
- The configuration of the system is stable and gives consistent results.
- LMOL has been successfully inter-compared with other TOLNET lidars: all lidars retrievals differs by values inferior to their uncertainties.
- LMOL has been successfully compared with ozone sondes.
- The LMOL retrieval system computes uncertainties following the recommended techniques by Leblanc et al. 2016 (AMT).

LMOL is validated for ozone observation campaigns.
Validations and Campaigns

LMOL publications

- “Langley mobile ozone lidar: ozone and aerosol atmospheric profiling for air quality research” R De Young, W Carrion, R Ganoe, D Pliutau, G Gronoff... - Applied Optics, 2017
- Leblanc et al. SCOOP intercomparison (in prep)

The next slides are the first results of the OWLETS campaign. They are preliminary. Publication based on this work are in preparation/under review.
The OWLETS campaign
## The OWLETS campaign

### Motivations
- Primary: understanding the land/sea $O_3$ gradient
- Low altitude observations (<200 m – 500 m)
- Performing lidar/UAV intercomparisons

### LMOL role for owlets
- Observation at the 3rd island of the cbbt: “on-water” lidar
- Record of ground $O_3$, $NO_x$
- Secondary: performing lidar/uav intercomparisons

### Achievements
- Observations on every campaign days: 14 days
- LMOL record of over 30 hours observations
- Minimum altitude of $\approx 110$ m
- All data have been archived with resolution/time optimized for comparison with TROPOZ
The OWLETS campaign

a) Washington, D.C., Baltimore, NASA Goddard
b) NASA Langley, Hampton, Norfolk, Chesapeake Bay

C) Locations 1, 2, 3

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The OWLETS campaign

CBBT O3 Curtain Plot - 2017 July 20

Altitude (from Ground Level) [m]

Time (UTC, hours)

O3 mixing ratio [ppbv]

0 20 40 60 80 100 120 140 160 180 200

0 500 1000 1500 2000 2500

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The OWLETS campaign

CBBT O3 Curtain 2017 Aug 1-2

Altitude (from Ground Level) [m]

0 500 1000 1500 2000 2500 3000 3500 4000

O3 mixing ratio (ppbv)

0 10 20 30 40 50 60 70 80 90 100

Local Time

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

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O3 Titration from a Nearby Point Source: The Wonders of the Very Near Field
The OWLETS campaign

8/2/2017 10:02:24

8/2/2017 04:02:22

Altitude [m]

O3 [ppb]

Sonde ± 5%

LMOL ± Uncert.
The OWLETS campaign: Observation of $O_3$ titration due to a ship
The OWLETS campaign: Observation of $O_3$ titration due to a ship
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Titration (very simplified)

$$O_3 + NO \rightarrow NO_2 + O_2$$
Fast reaction (minutes)
The OWLETS campaign: Observation of $O_3$ titration due to a ship
The OWLETS campaign: Observation of O$_3$ titration due to a ship
Pandora / LMOL intercomparison

O₃ Titration from a Nearby Point Source: The Wonders of the Very Near Field (OWLETS Campaign)
Pandora / LMOL intercomparison

- $O_3 + NO \rightarrow NO_2 + O_2$ verified
- The ship emitted mainly NO, the NO$_2$ coming from the titration
- NO$_2$ leads to reaction that can make more O$_3$ than initially present in the long term (hours)
- The plume was aloft
- The multi-instrumental observation was crucial to diagnose the event
- Ring et al. 2018: the vertical structure of the ship plume has impact on TROPOMI-like observations of the Chesapeake region.

Submitted to AMT
To be on AMTD soon.
LMOL recent improvements and validation

- Improved PMT (reaching ≈9 km with a 5min averaging during the night.
- Off axis system / window (to prevent rainwater)
- Autonomy / remote control
- Eye Safe System (for safety and aviation regulation)

TROPOMI Overpasses

- Observation around 12-15h
- A few ozonesondes launched during that window (T. Knepp)
- Real time preview
TROPOMI Overpasses / Preparation for OWLETS II

O$_3$ Titration from a Nearby Point Source: The Wonders of the Very Near Field
TROPOMI Overpasses / Preparation for OWLETS II

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O₃ Titration from a Nearby Point Source: The Wonders of the Very Near Field
TROPOMI Overpasses / Preparation for OWLETS II

PRELIMINARY - REAL TIME VIEW (not optimized)
TROPOMI Overpasses / Preparation for OWLETS II

PRELIMINARY - REAL TIME VIEW (not optimized)

LaRC O₃ Curtain 2018-04-18 Preliminary

O₃ mixing ratio [ppbv]

Altitude (from Ground Level) [m]

Time (UTC, hours)
TROPOMI Overpasses / Preparation for OWLETS II

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O₃ Titration from a Nearby Point Source: The Wonders of the Very Near Field
Conclusions
Conclusions

LMOL

- Mobile Lidar for Aerosols and O$_3$ measurements, part of the TOLNet network.
- Inputs parameters, outputs parameters, uncertainty validation, etc, validated by the network.
- Adapted to study evolution of O$_3$.
- Available to support calibration/validation of satellites (TROPOMI, TEMPO).
- In Constant evolution.
- Strong collaboration with Pandora / measurements complementary.
- Next Step: 2018 campaigns. OWLETS-2 / LISTOS
Conclusions

Unique LMOL capabilities

- Mostly Autonomous
- Typical resolution: 5 min, 20 m – 1000 m (vertical).
- Capabilities: 100m – 6/7 km altitude (day), 10 km (night)... and improving!
- Smallest TOLNet Lidar / most mobile.
- EYE SAFE!

LMOL can be shipped internationally for campaigns

It is based on published laser/techniques, and therefore not a problem for export.
Stay tuned for Owlets II
Appendix 1: The DIAL method

Lidar equation

\[ P_\lambda R^2 = \gamma_\lambda B_\lambda e^{-2 \int_0^R \beta_{\text{aero}}, \lambda(r) + \beta_{\text{Rayleigh}}, \lambda(r) + N_{\text{O}_3}(r) \sigma_{\text{O}_3}, \lambda + \sum_{\text{sp}} \sigma_{\text{sp}(z), \lambda} N_{\text{sp}}(r) dr}. \]

*\( N_{\text{sp}} \): the density for species *sp*
*\( P \): the lidar power. *z* the altitude. \( R \): the range.
\( \lambda \): the lidar wavelength (on: the wavelength the most absorbed by \( \text{O}_3 \), off: the least absorbed by \( \text{O}_3 \)).
\( \gamma_\lambda \): the lidar constant for the specified wavelength.
\( \sigma_{\text{sp}(z), \lambda} \): the cross section
\( \Delta \beta_{\text{aero}} = \beta_{\text{aero}, \text{off}} - \beta_{\text{aero}, \text{on}} \)
\( \Delta \sigma_{\text{sp}(z)} = \sigma_{\text{sp}(z), \text{on}} - \sigma_{\text{sp}(z), \text{off}} \)
\( \Delta \lambda = \lambda_{\text{off}} - \lambda_{\text{on}} \)
\( B \): the total backscatter. Rayleigh scattering + aerosol scattering
\( \beta_{\text{sp}} \): the absorption by the species *sp*. 
Appendix 1: The DIAL method

Lidar equation

By deriving the logarithm of ratio $P_{\text{off}}/P_{\text{on}}$, we get:

$$N_{O_3(z)} = \frac{1}{\Delta \sigma_{O_3(z)}} \left( \frac{1}{2} \frac{\partial}{\partial z} \left( \ln \left( \frac{P_{\text{off}}}{P_{\text{on}}} \right) - \ln \left( \frac{B_{\text{off}}}{B_{\text{on}}} \right) - \ln \left( \frac{\gamma_{\text{off}}}{\gamma_{\text{on}}} \right) \right) \right)$$

$$+ \Delta \beta_{\text{aero}}$$

Aerosol extinction

$$- \Delta \sigma_{M(z)} N_a(z) - \sum_{sp} \Delta \sigma_{sp(z)} N_{sp(z)}$$

Rayleigh extinction

(1)

The aerosol corrections appears on two parts: the backscatter correction $(\ln \left( \frac{B_{\text{off}}}{B_{\text{on}}} \right))$ and the extinction correction $(\beta_{\text{aero,off}} - \beta_{\text{aero,on}})$.
Appendix 2: The Aerosol retrieval

Retrieving the Aerosol content

\[ P_\lambda R^2 = \gamma_\lambda B_\lambda e^{-2 \int_0^R \beta_{aero,\lambda}(r) + \beta_{Rayleigh,\lambda} r dr}. \]

- \( B_{Rayleigh} = \frac{3}{8\pi} \beta_{Rayleigh} \)
- \( B_{Aerosols} = \frac{\beta_{Aerosols}}{S_\lambda} \) : this is the biggest unknown \( S=20 \) to 50.
- We know \( B_{Rayleigh} \) from the atmosphere, and the cross sections.
- The Green channel allows us to retrieve the ratio \( \frac{B_{Rayleigh}}{B_{Aerosols}} \) at 527 nm, with the uncertainty from the aerosol absorption factor \( S \).
- The 2 UV channels allows us to retrieve this ratio in the UV, which is different, but varies accordingly. (Browell et al. 1985 for the technique).
Appendix 2: The Aerosol retrieval

Aerosols for 2016-01-13, NASA LaRC

- Altitude (from Ground Level) [m]
  - 0
  - 500
  - 1000
  - 1500
  - 2000
  - 2500
  - 3000
  - 3500
  - 4000
  - 4500
  - 5000
  - 5500
  - 6000

- Time (UTC, hours)
  - 9
  - 10
  - 11
  - 12
  - 13
  - 14
  - 15
  - 16
  - 17
  - 18
  - 19
  - 20

- Aerosol scattering ratio
  - 0
  - 0.5
  - 1
  - 1.5
  - 2
  - 2.5
  - 3

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Appendix 2: The Aerosol retrieval

Aerosols from O3 analysis for 2016-01-13, NASA LaRC

- Altitude (from Ground Level) [m]
- Time (UTC, hours)
- Aerosol scattering ratio