Application of Lidar to Improved Understanding of Boundary Layer Processes

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NASA Langley Research Center

Boundary Layer Mini-Workshop

Greenbelt, MD

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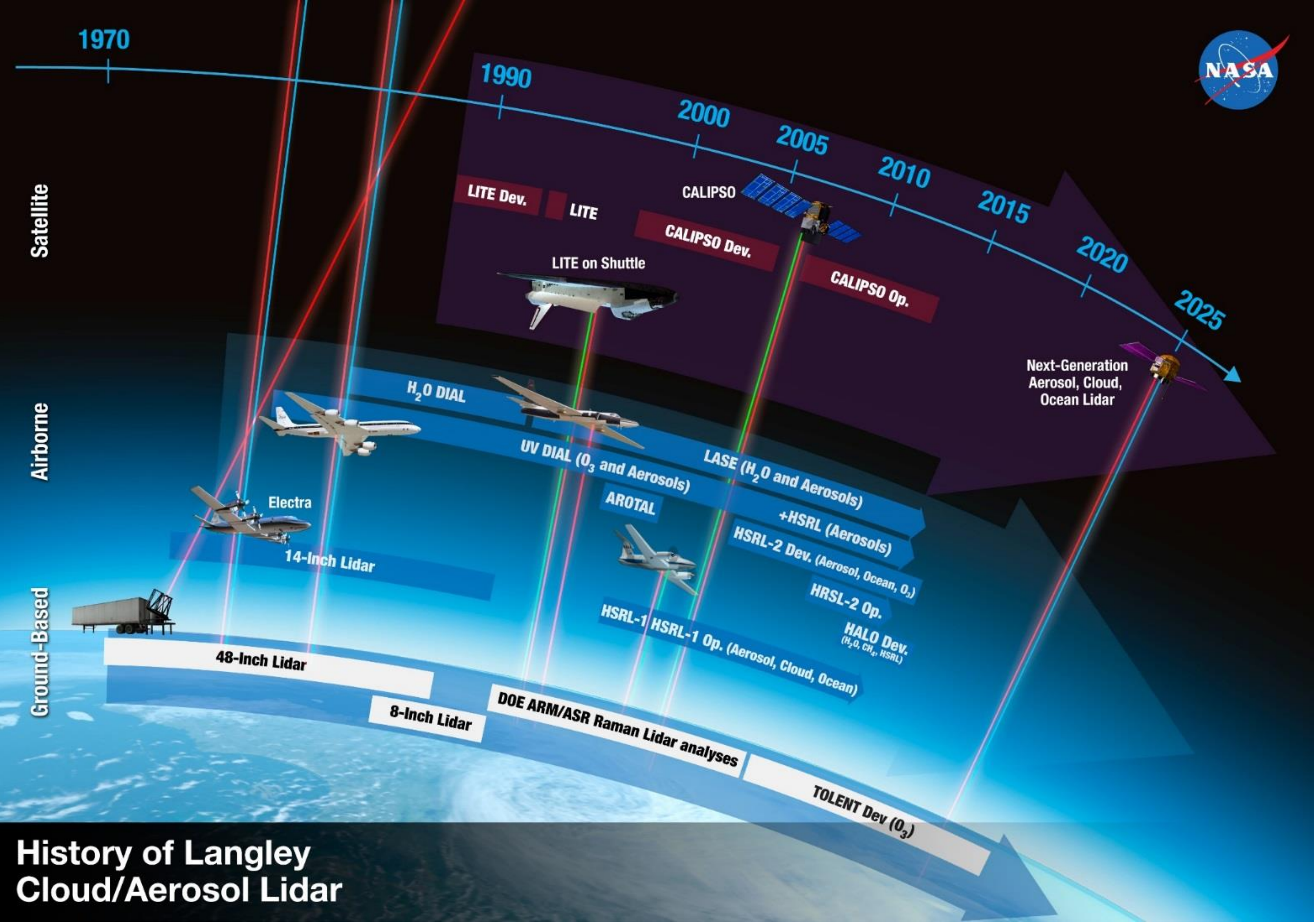
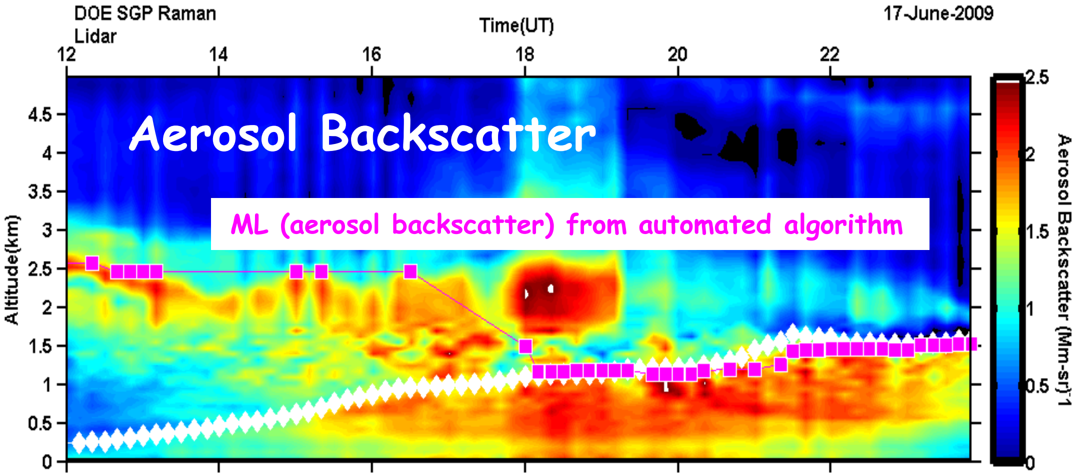
Outline

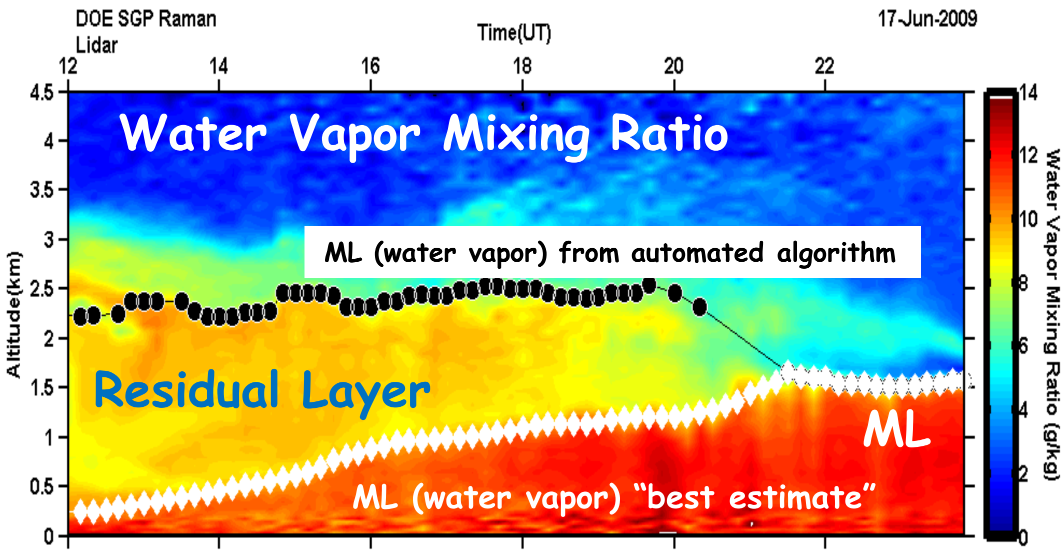
- Lidar…A brief history
- Mixed layer heights: ground, airborne, space-based lidar
- Water vapor DIAL-past, present, and future


1970
1990
2000
2005
2010
2015
2020
2025
NASA
Satellite
Airborne
Ground-Based
LITE Dev.
LITE
CALIPSO
CALIPSO Dev.
CALIPSO Op.
LITE on Shuttle
Next-Generation Aerosol, Cloud, Ocean Lidar
H2O DIAL
UV DIAL (O3 and Aerosols)
LASE (H2O and Aerosols)
AROTAL
+HSRL (Aerosols)
HSRL-2 Dev. (Aerosol, Ocean, O3)
HRSL-2 Op.
HALO Dev. (H2O, CH4, HSRL)
Electra
14-Inch Lidar
HSRL-1
HSRL-1 Op. (Aerosol, Cloud, Ocean)
48-Inch Lidar
8-Inch Lidar
DOE ARM/ASR Raman Lidar analyses
TOLENT Dev (O3)
History of Langley Cloud/Aerosol Lidar

Mixed Layer Heights from DOE Raman lidar water vapor profiles

DOE ARM SGP Raman Lidar



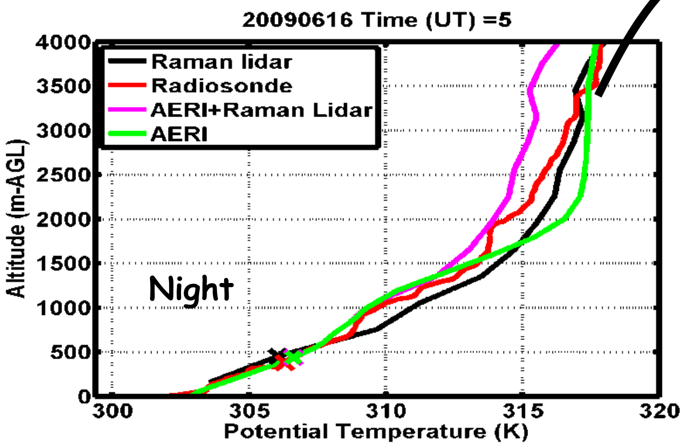


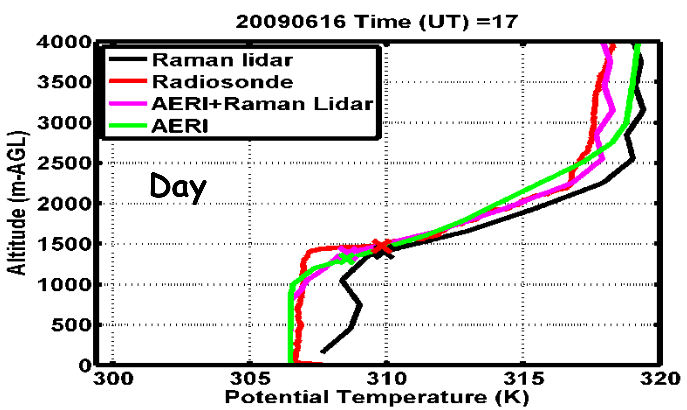
- **Complicated aerosol structures within the boundary layer or residual layer(s) above boundary layer can prevent the algorithm from producing satisfactory results.**
- **"Best-Estimate" mixed layer heights combine results from automated algorithm and manual inspection of Raman lidar water vapor profiles**

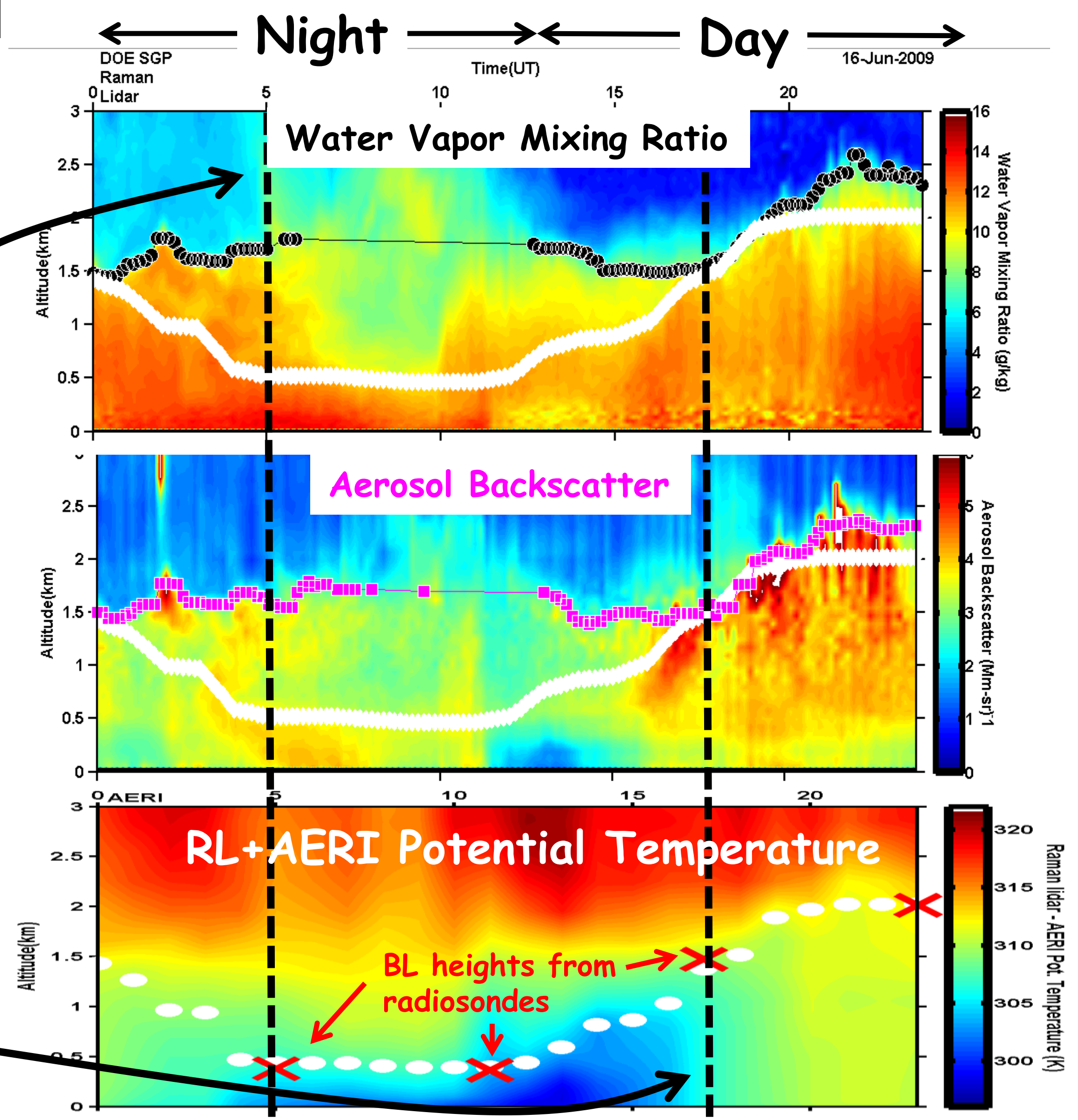
BL heights from DOE Raman Lidar using water vapor, aerosol backscatter, and pot. temp.

ASR Atmospheric System Research

BL heights from potential temperature may help provide more complete picture of diurnal BL behavior

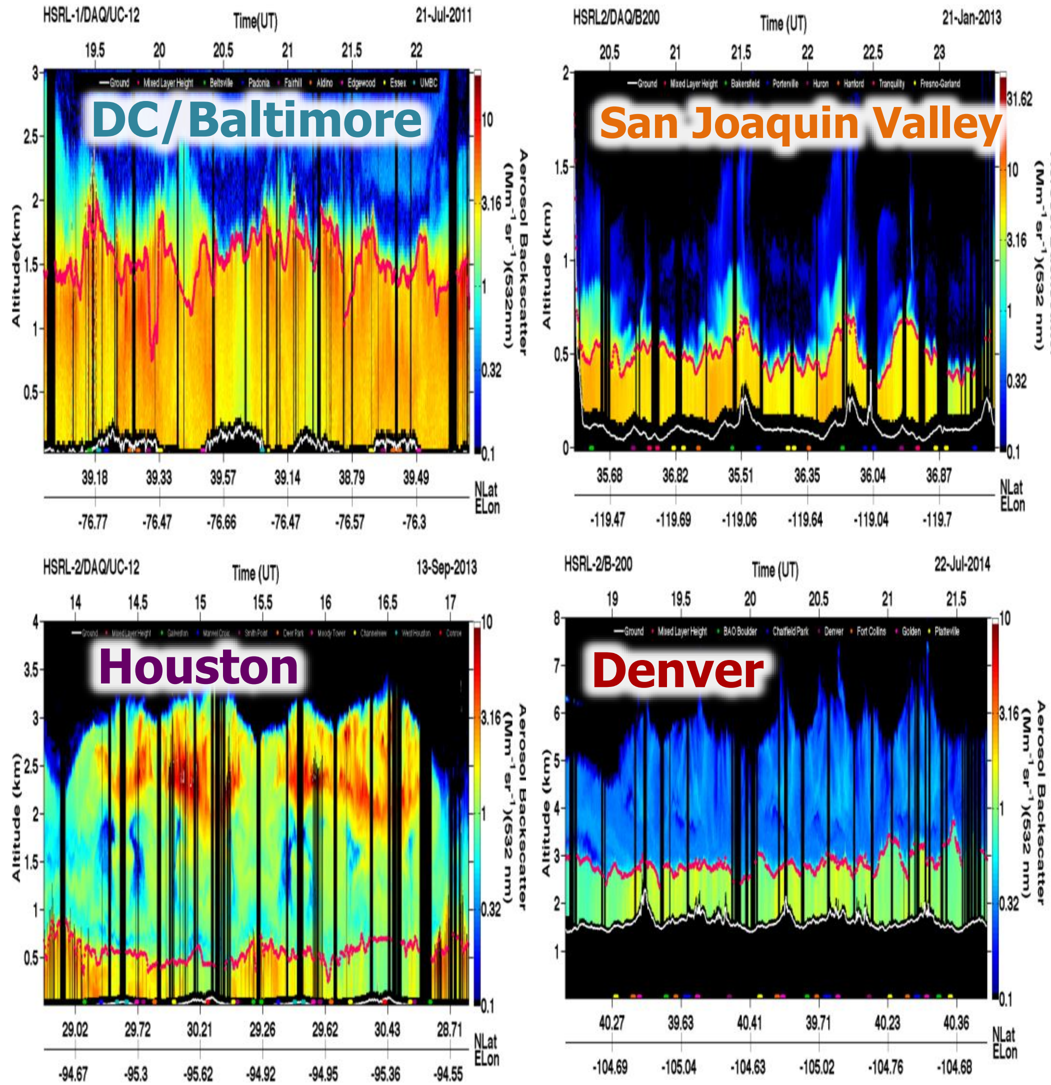






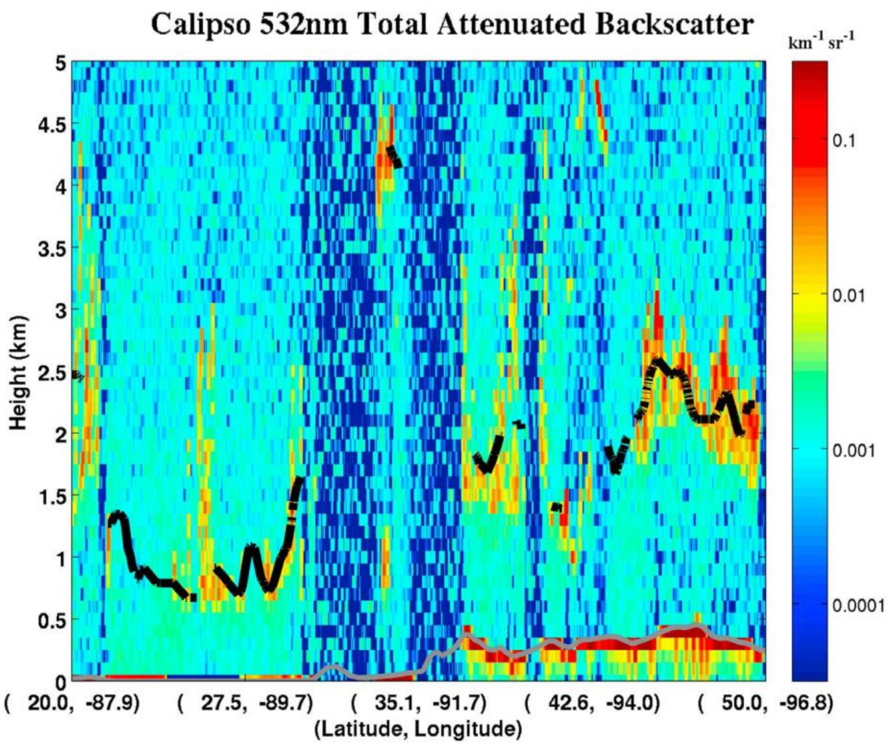
Airborne HSRL Mixed Layer Heights

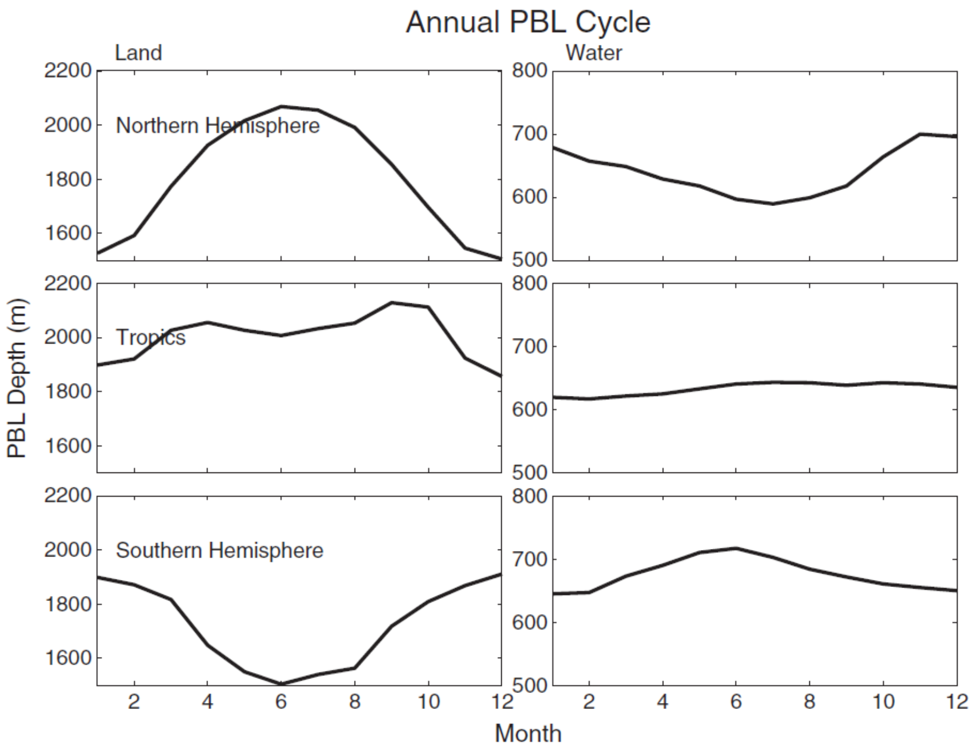
- Mixed Layer (ML) heights derived from daytime-only cloud-screened aerosol backscatter profiles measured by HSRL
- Technique uses a Haar wavelet covariance transform with multiple wavelet dilations to identify sharp gradients in aerosol backscatter at the top of aerosol layers (adapted from Brooks, JAOT, 2003)
- Automated HSRL algorithm chooses ML from among aerosol gradients in HSRL backscatter profiles with input from manual inspection where necessary



Scarino et al., 2014, Atmos. Chem. Phys.

CALIPSO Mixed Layer Heights



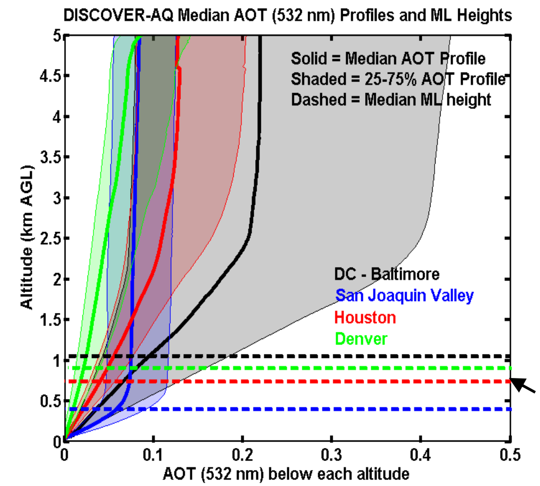


McGrath-Spangler and Denning, 2012, JGR

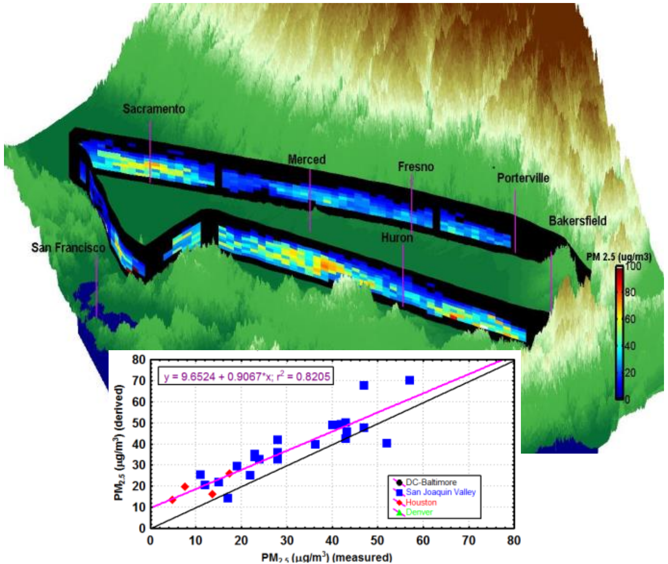
McGrath-Spangler and Denning, 2013, JGR

NASA Designated A+CCP Mission will also address BL measurements

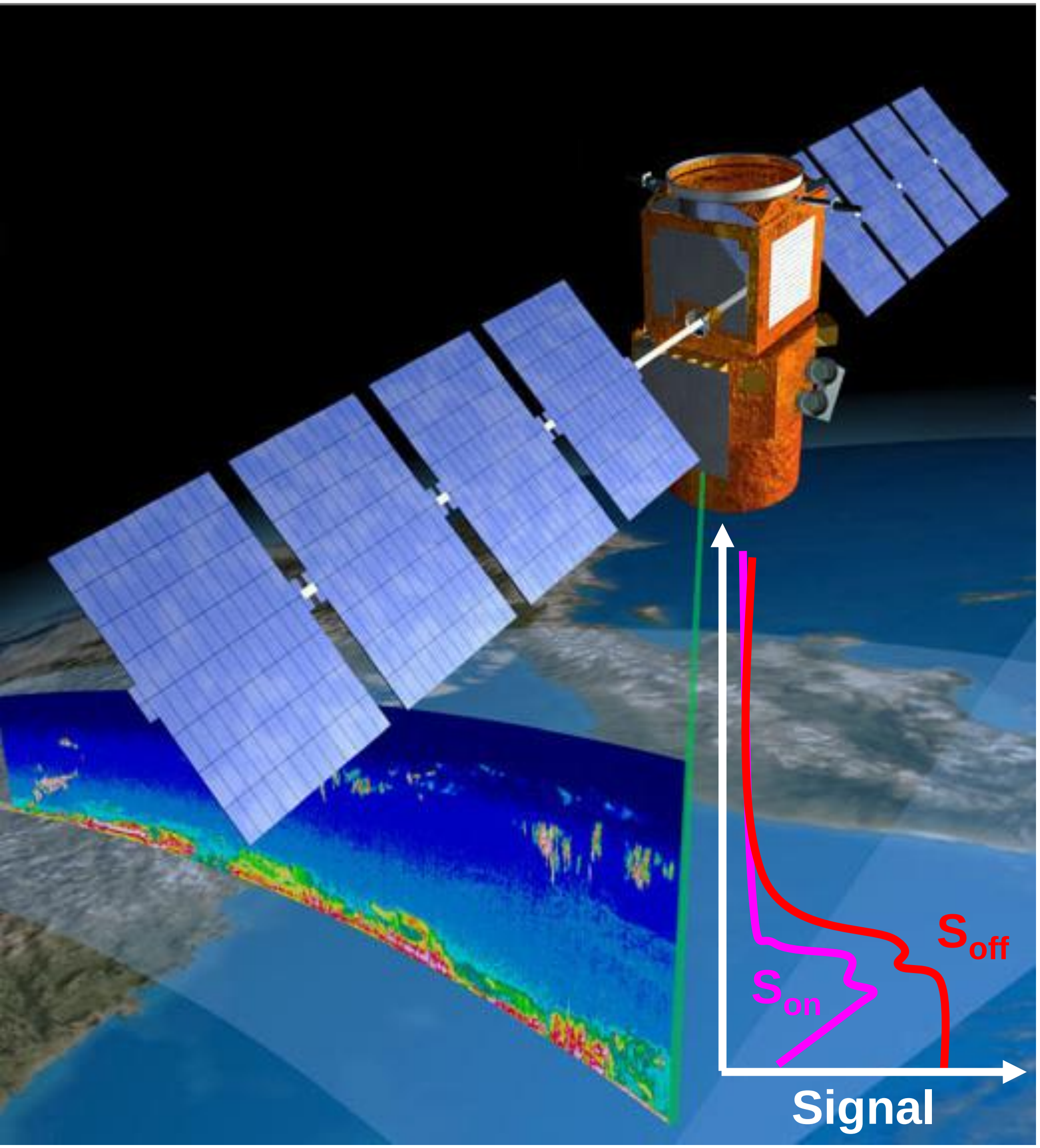
- 2017 Decadal Survey (DS) for Earth Science and Applications identified five "Designated" missions to be NASA's priority in the next decade
- DS recommendations include objectives addressing BL measurements
  - Suggested Geophysical Observables – AOD within BL, PM concentration and speciation within BL
  - Weather and Air Quality Focus Area – determine effects of key BL processes on weather, hydrological, and air quality forecasts; improve understanding of processes that determine air pollution distribution
- In addition to providing measurements of BL height, HSRL measurements can provide:
  - Accurate AOT within and above BL
  - Accurate near-surface extinction for inferring $PM_{2.5}$ concentration
  - Aerosol type for inferring speciation
  - Aerosol concentration (from multiwavelength HSRL) – direct means to derive $PM_{2.5}$ concentration

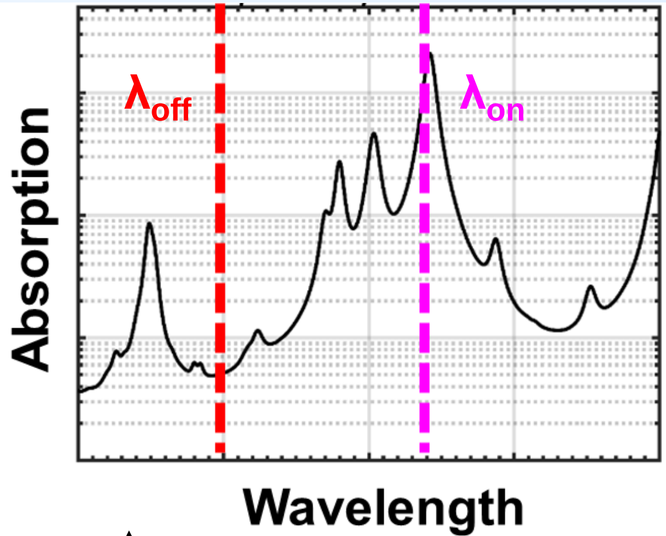


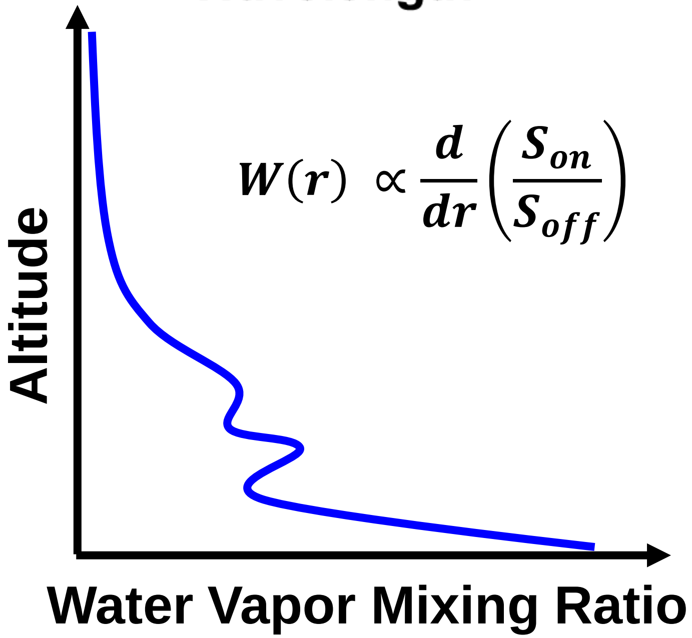
$PM_{2.5}$ Concentration derived from HSRL-2 measurements - Jan. 31 , 2013 California Central Valley



Differential Absorption Lidar for Trace Gas Profiling



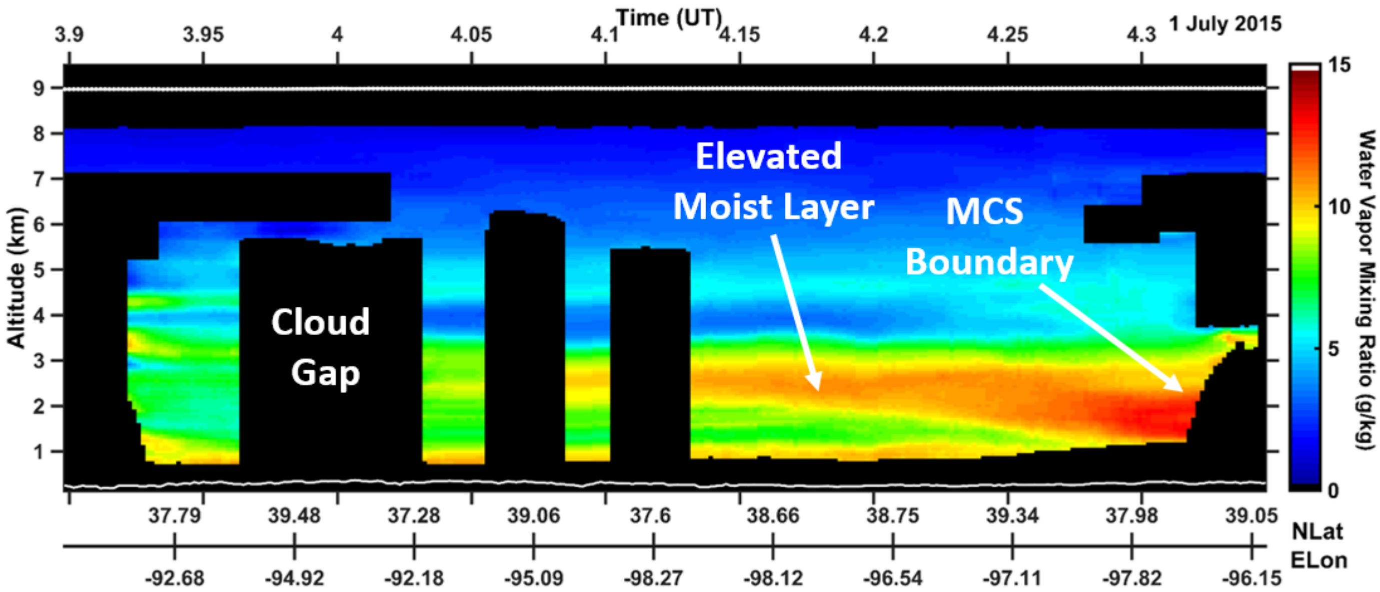


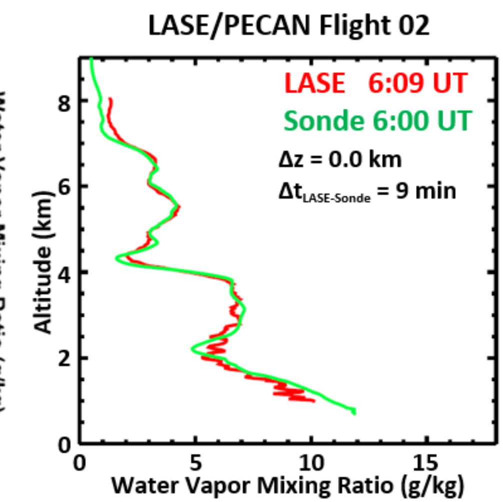


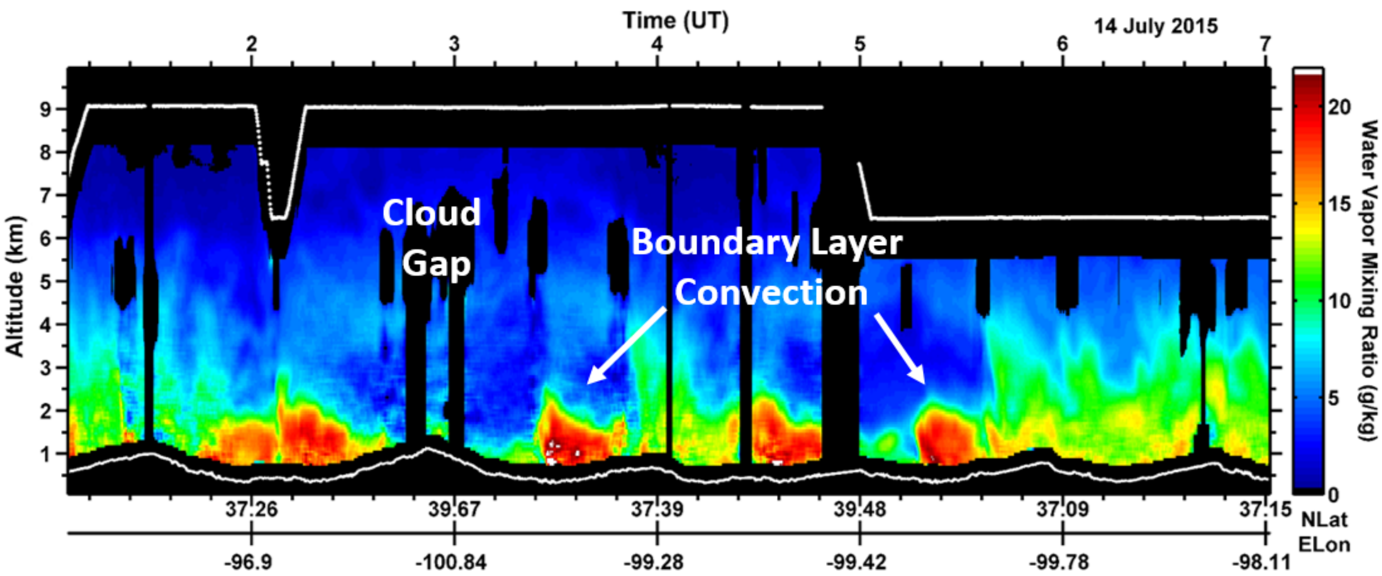
Why DIAL-Enables Direct Profile Measurements

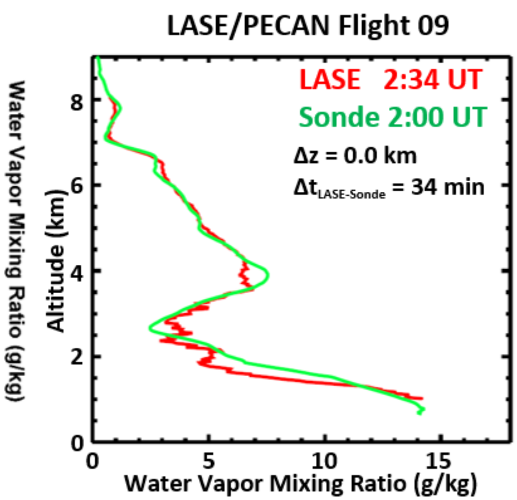
- **Enables direct measurements of water vapor profiles throughout the troposphere**
  - Increased spatial resolution and sensitivity to near surface atmosphere
  - Capability to resolve above cloud tops as well as through and below thin clouds
  - Can profile between broken clouds
  - Multi-line approach provides sensitivity from upper troposphere down to surface
- **Overall accuracy of the measurements**
  - Inherently self calibrating
  - Low sensitivity to uncertainties in atmospheric state parameters (e.g., temperature)
  - Immune to contamination from aerosol and cloud layers
- **Active+passive observing system will provide most coverage**
  - Passive infrared and microwave sensors are most uncertain near the surface
  - Lidar water vapor profiles can help constraint IR derived temperature profiles
- **Cross-cutting applications**
  - Simultaneous information on aerosol and cloud distributions (CALIPSO continuity)
  - Retrieval of mixed layer heights
  - Absolute reference for calibration of passive sensors

LASE Measurements During PECAN

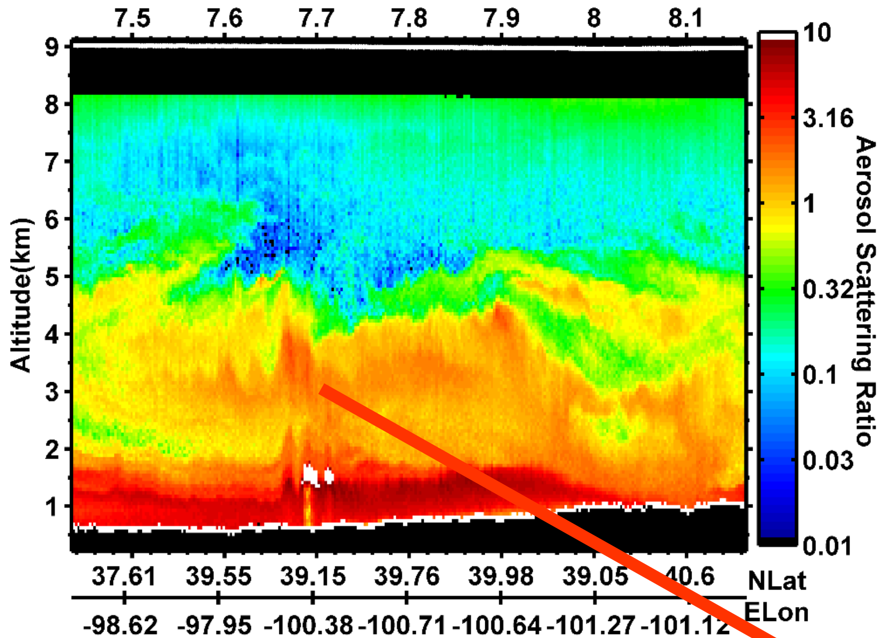


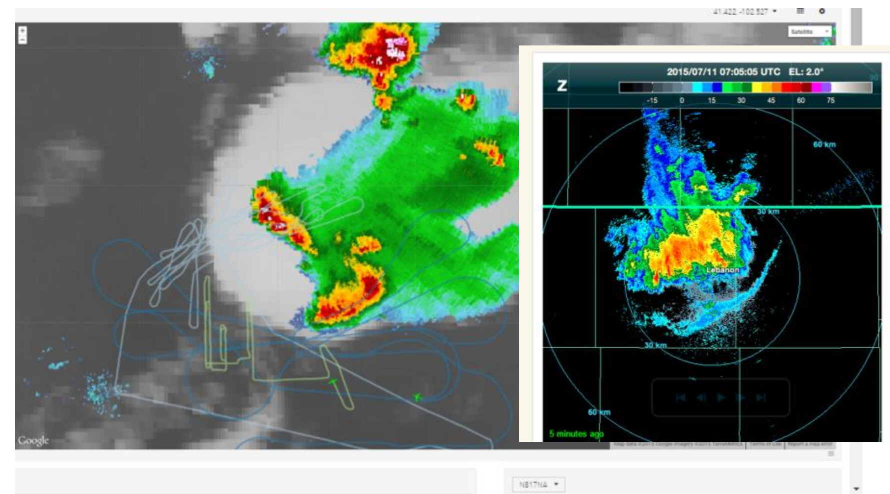


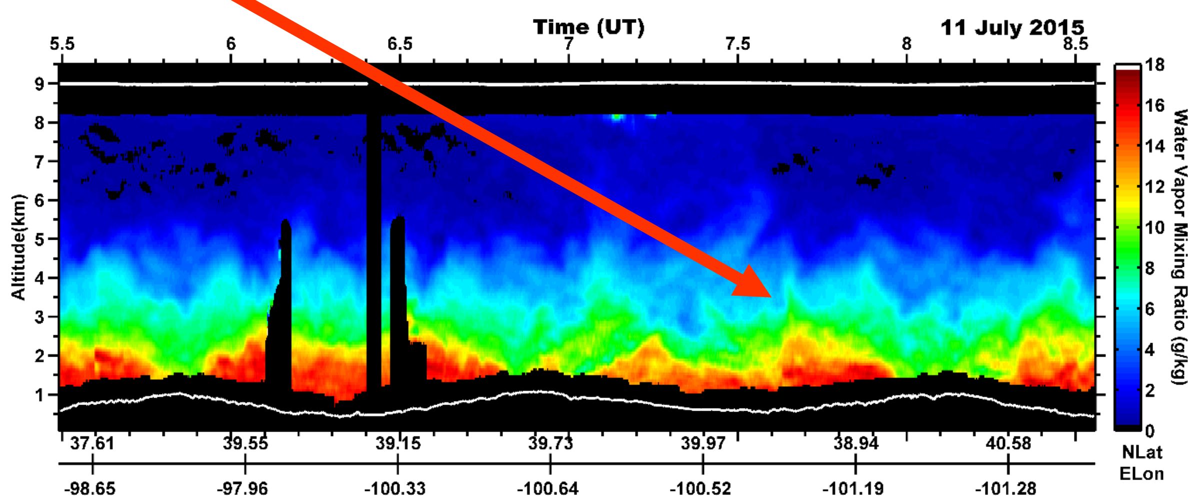




LASE Measurements During PECAN





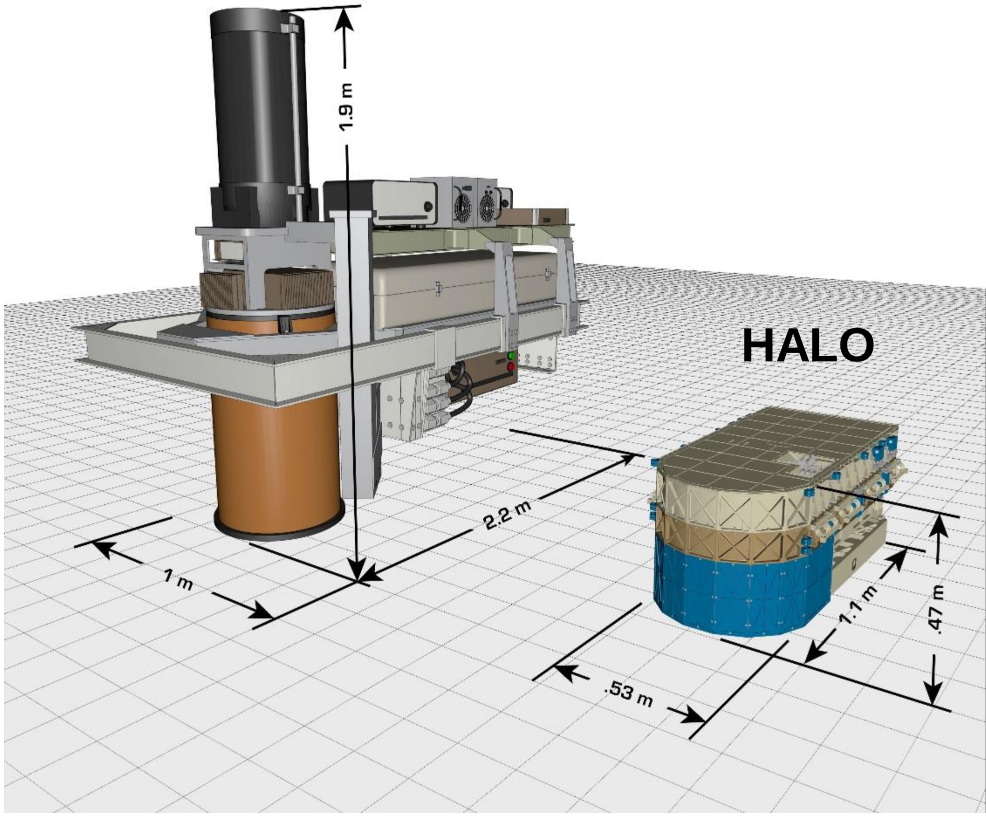


Motivation- Advanced Airborne Demonstrator

- New capability to measure H_2O profiles from smaller and high altitude airborne platforms
  - Currently: LASE is only capable of going on large aircraft (DC-8)
  - Development of more compact H_2O DIAL system with additional (CH_4) DIAL and HSRL measurement capabilities
- DIAL measurements along with measurements of aerosol/cloud properties combines many of the measurement requirements for airborne campaigns and satellite calibration and validation
- **Technology test-bed for maturing technologies and <u>algorithms</u> required for future DIAL missions**

LASE

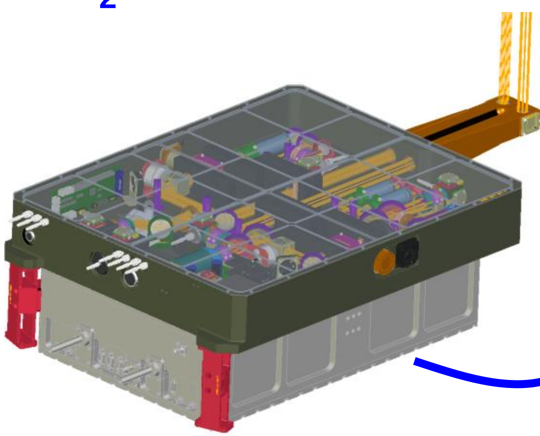
HALO

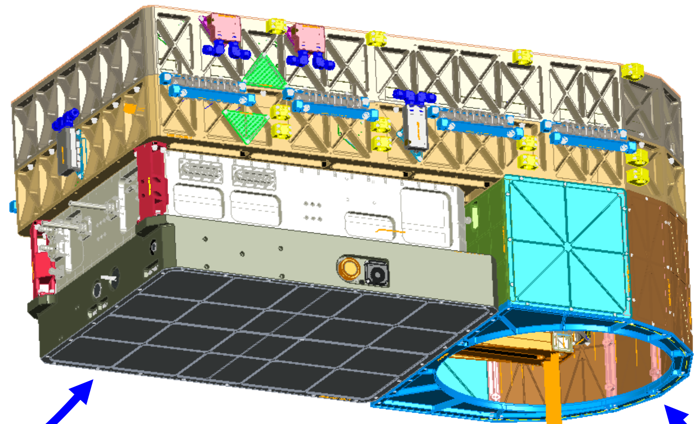


HALO Architecture

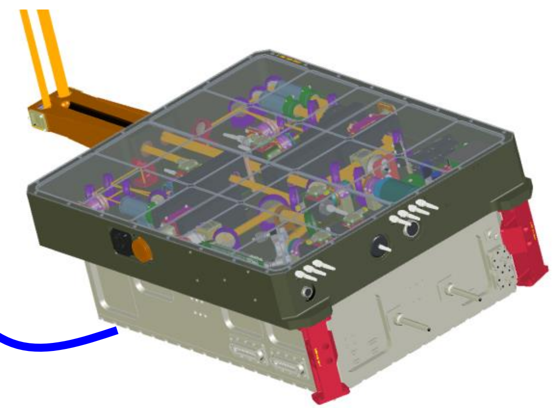
Interchange two common architecture lasers and single receiver to enable **H_2O DIAL+HSRL or CH_4 DIAL+HSRL** measurements

H_2O Transmitter

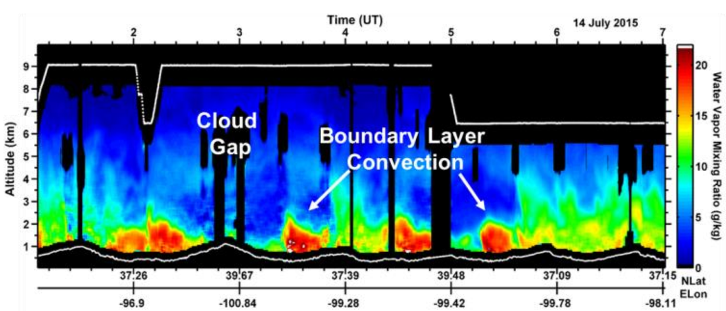


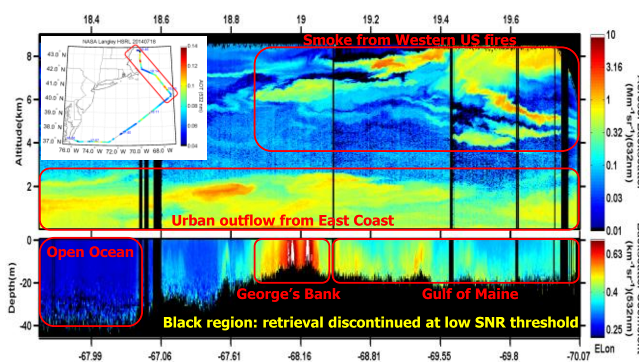


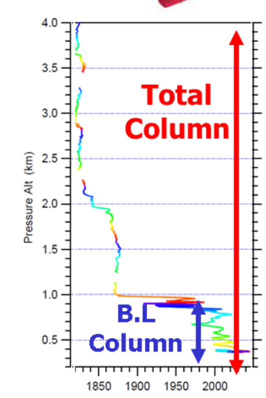
CH_4 Transmitter



HSRL Measurements (common to both)







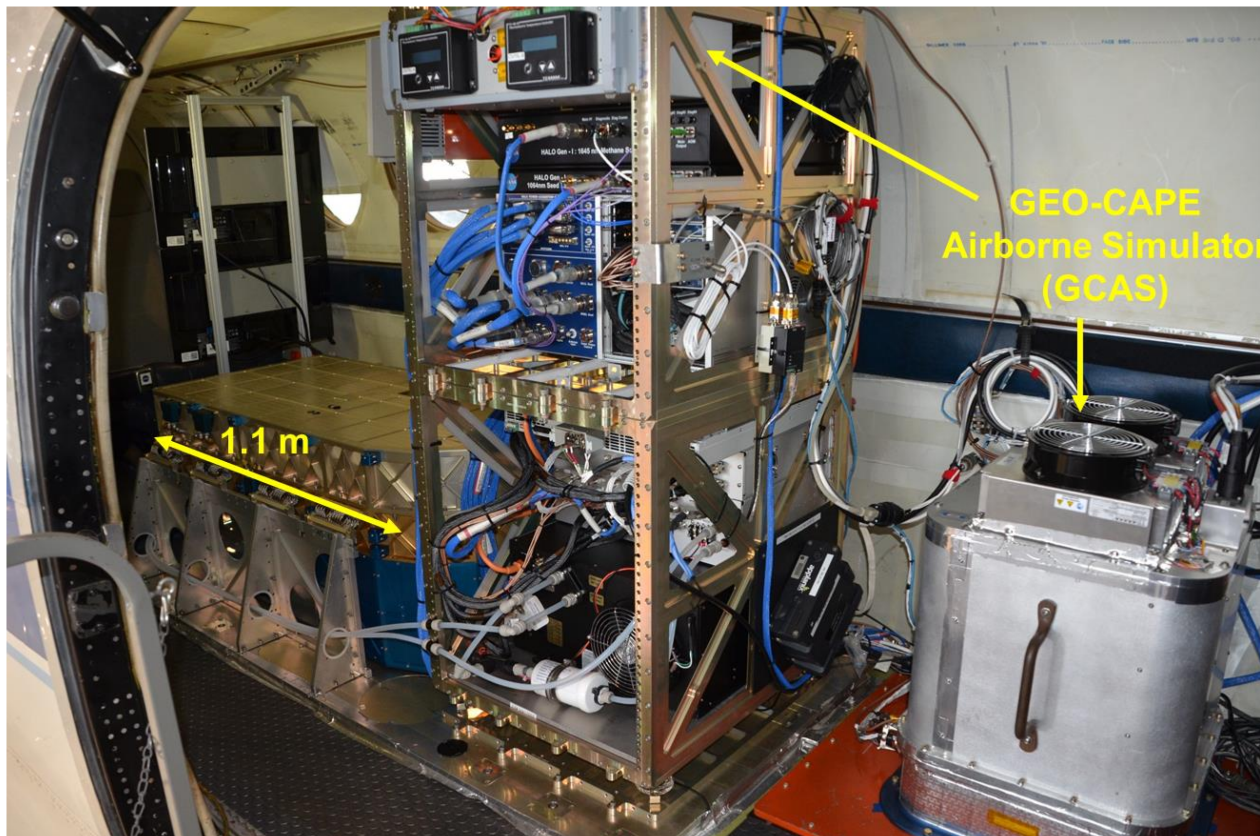
- Water vapor profiles
- Total perceptible water

- Aerosol, cloud, and ocean profiling

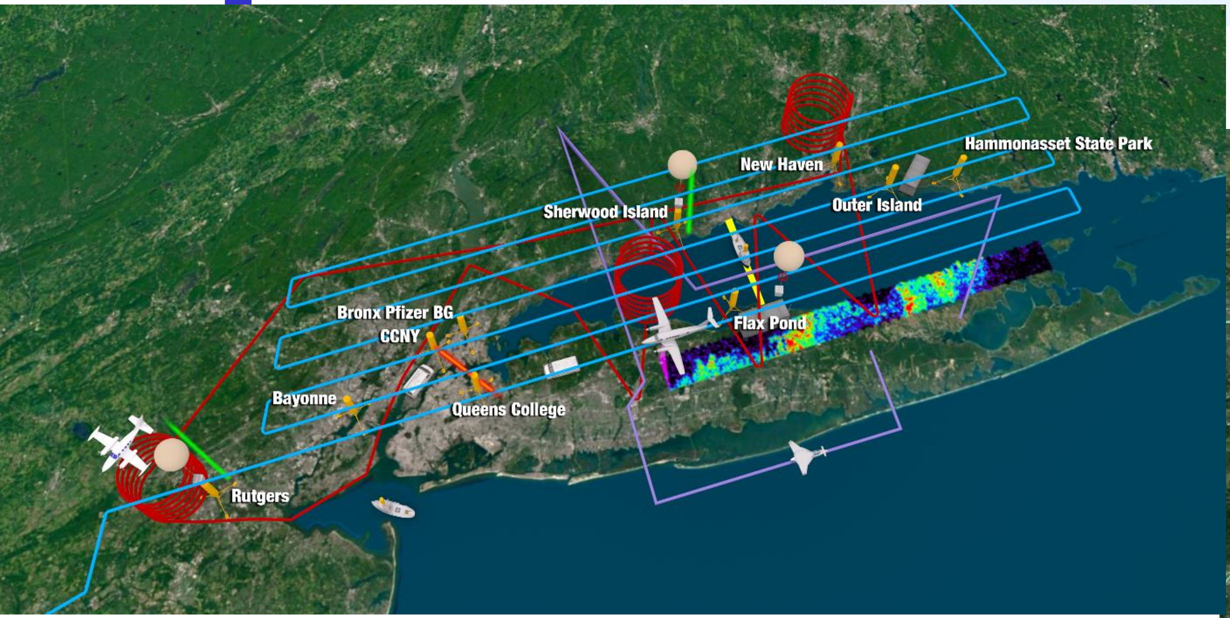
- Column weighted XCH_4
- Multi-layer XCH_4 retrieval

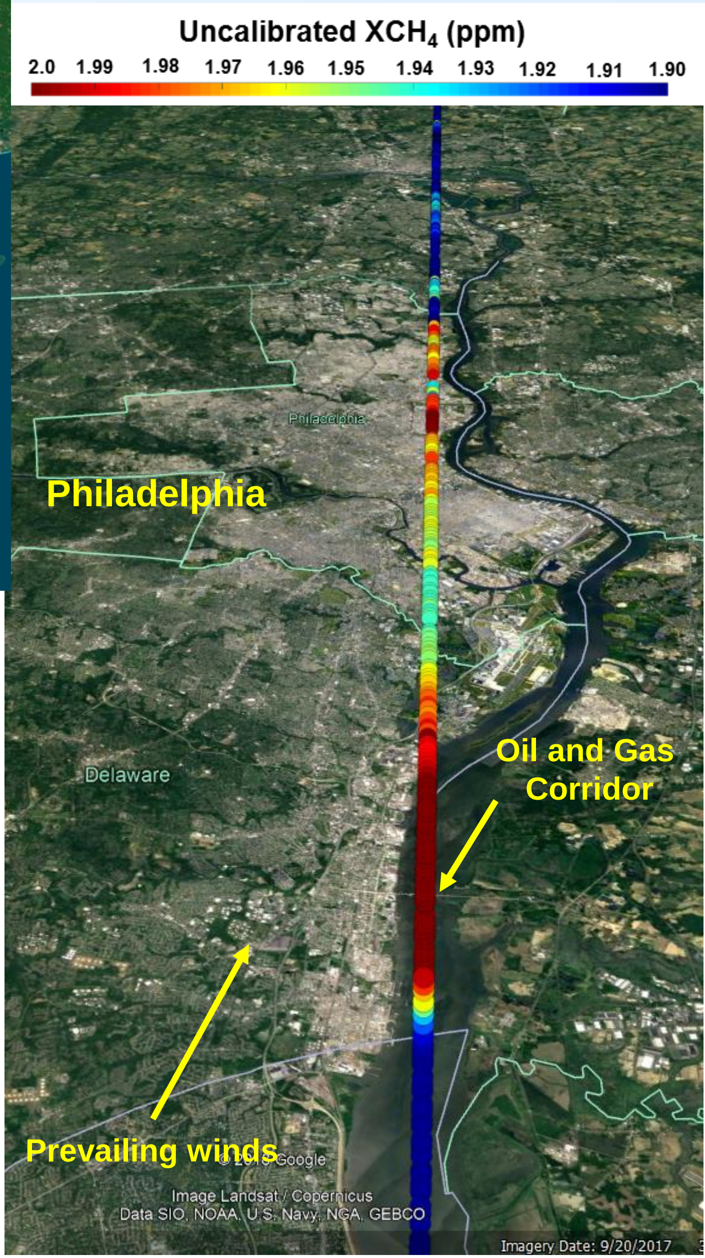
Timeline for HALO Development

- **~3.5 year development cycle for three measurements**
  - Enabled by adapting heritage designs and algorithms from LaRC HSRL/DIAL instruments
- **We are currently flying the methane config.**
  - Flying on the B200 as a part of the Long Island Sound Tropospheric Ozone Study mission



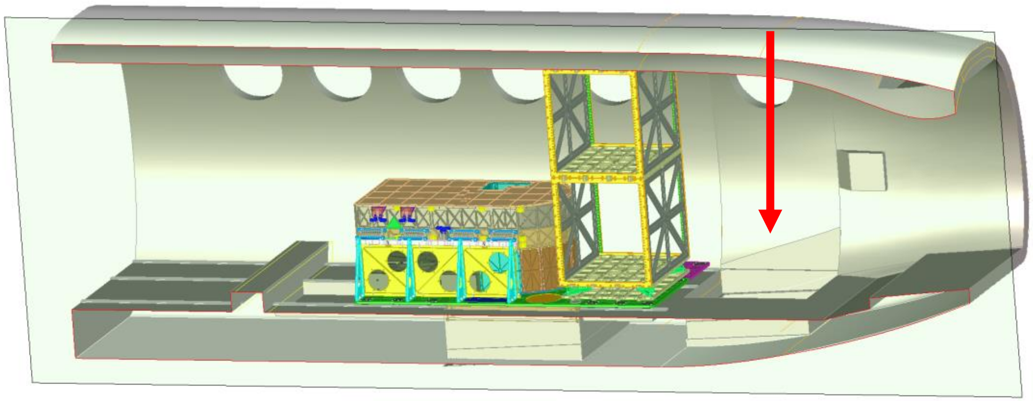
Initial CH_4 measurements and prospects for H_2O DIAL





- **Water vapor measurements coming up in spring 2019 as a part of Aeolus cal/val effort**

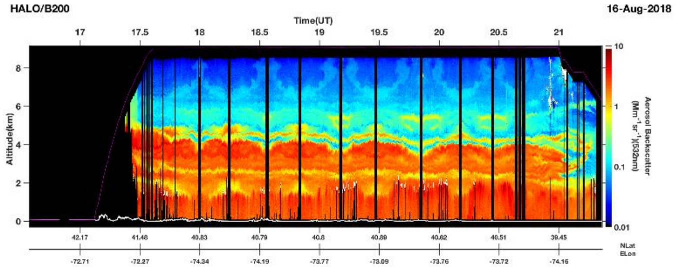
Radar, IR/microwave radiometer, spectrometer over aft port



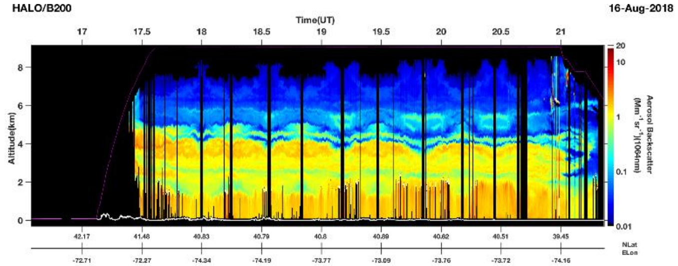
Aerosol Products (simultaneous with DIAL)

Aerosol Extensive Parameters

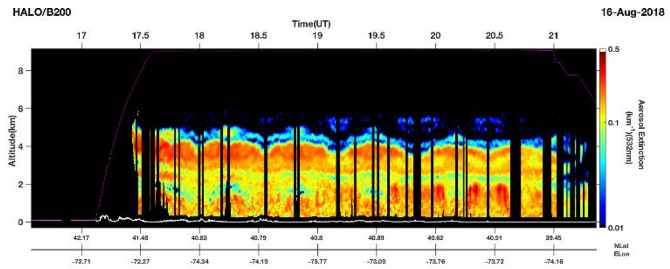
532 nm Backscatter



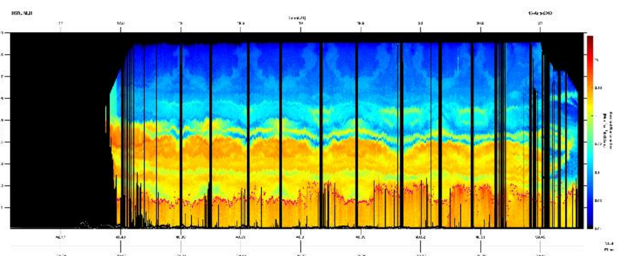
1064 nm Backscatter



532 nm Extinction

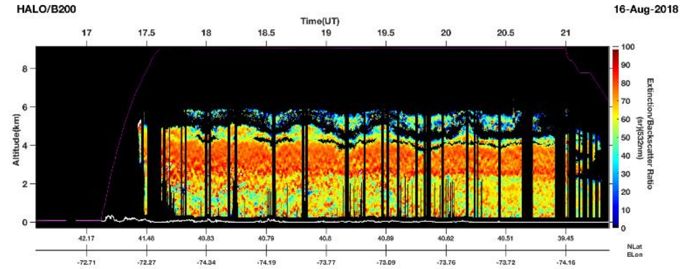


Mixed Layer Heights

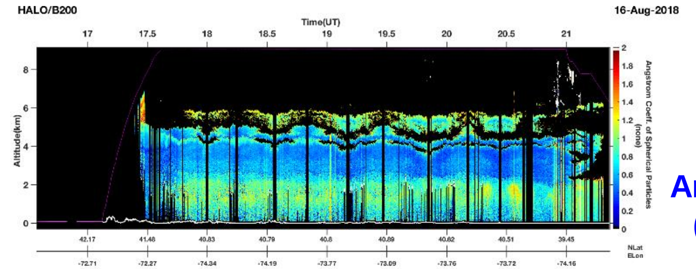


Aerosol Intensive Parameters

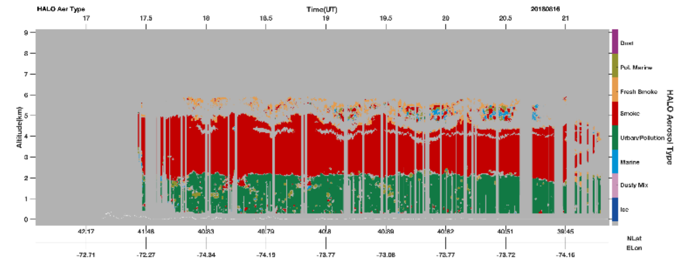
532 nm Lidar Ratio



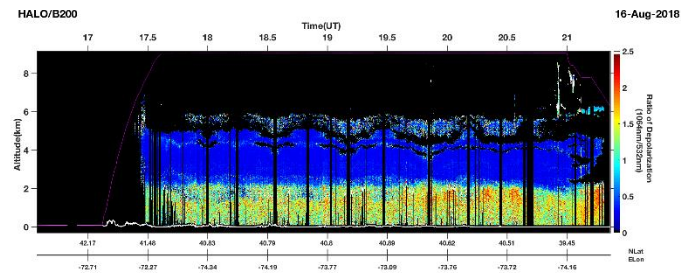
1064/532 nm Backscatter Angstrom Coeff. (particle size)



Aerosol Typing

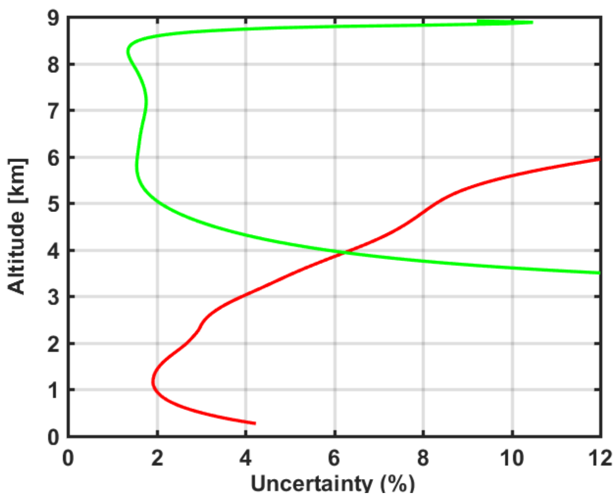


1064/532 nm Depolarization Ratio

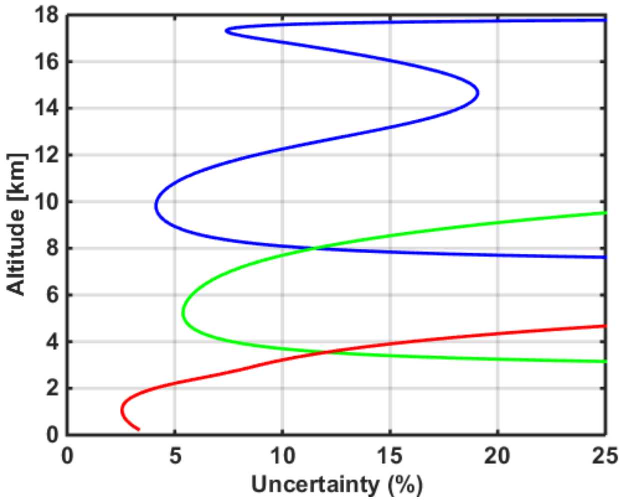


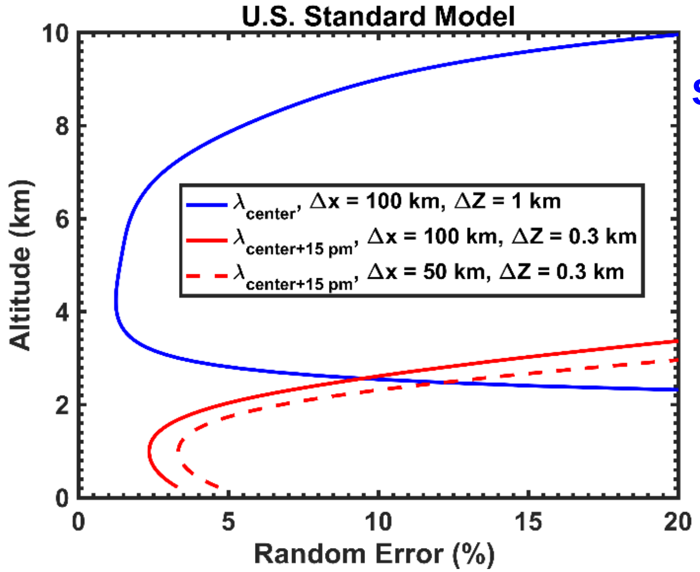
Water Vapor DIAL: Current (almost) and Future Prospects

Simulated Performance (B200)

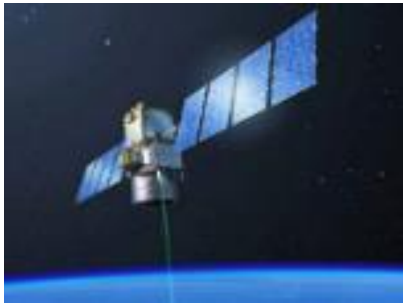


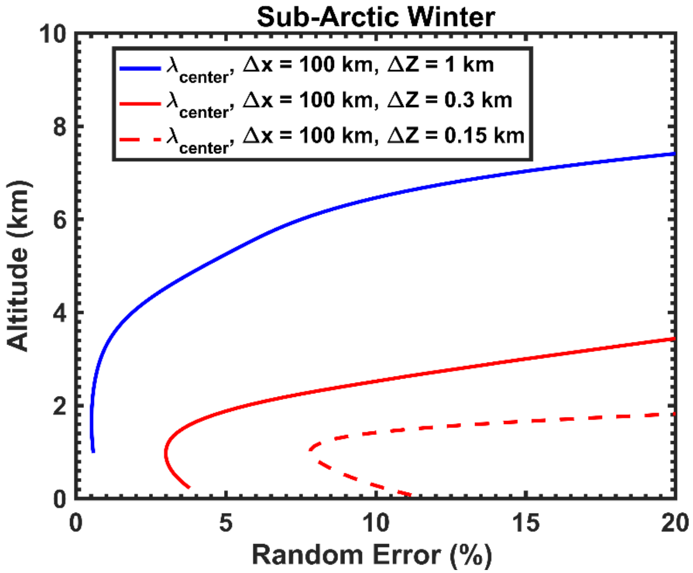
Simulated Performance (ER-2)





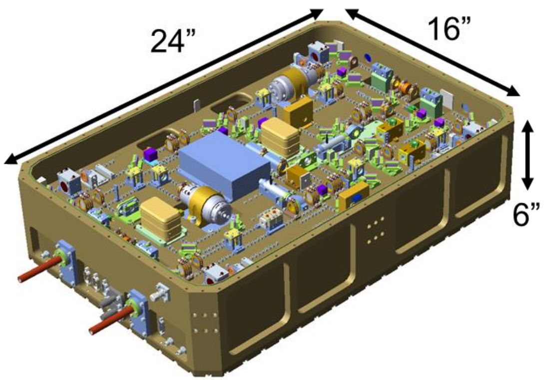
Space-Based Simulations



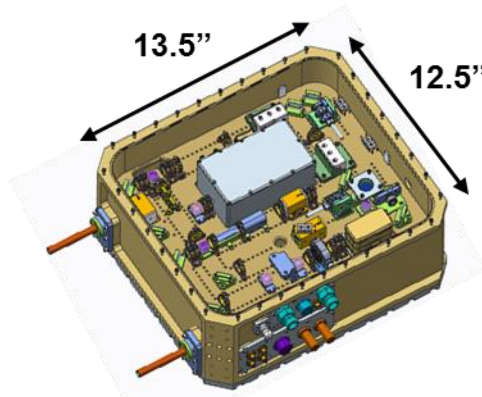


Path to Space-Based Observations

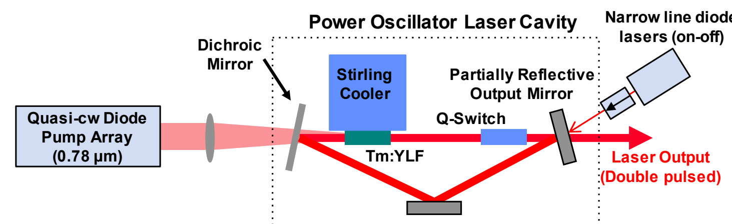
HALO
Water vapor DIAL + HSRL



HALO/Tech Development
H_2O+CH_4 DIAL



Space-Based
Water Vapor DIAL
NASA ESTO ACT Award



Airborne — Airborne/Space — Space

Process Studies:

- DIAL
- Precip. Radar
- Microwave/IR Sounder
- Diff. Abs. Radar

EVI/DS Explorer mission

Next Decadal Survey

Summary

- **Lidar plays an important role in observing boundary layer processes**
- **Airborne and ground based lidar can accurately measure planetary boundary layer height in different conditions. The more information, the better**
- **NASA's Designated A+CCP mission will also address global BL measurements using similar technique as ground based and airborne lidars. HSRL implementation will also provide accurate near-surface extinction for inferring $PM_{2.5}$ concentrations for air quality index. Multi-wavelength HSRL for aerosol microphysics and aerosol cloud interactions**
- **Airborne water vapor DIAL is mature and has can provide high spatial resolution water vapor profiles for process studies**
- **NASA's new HALO water vapor DIAL is coming online in 2019. Future airborne mission concepts should consider joint payload with IR/microwave sounder, DAR, Radar, and polarimeters**
- **Technology investments are required now to enable the observing system for the next decade**