Differential Absorption Lidar (DIAL) from Airborne and Space-Based Platforms

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ESTO EARTH SCIENCE TECHNOLOGY OFFICE

SBIR/STTR

WMD WELCH MECHANICAL DESIGNS

FIBERTEK, INC.

FREEDOM PHOTONICS

Earth Science Division

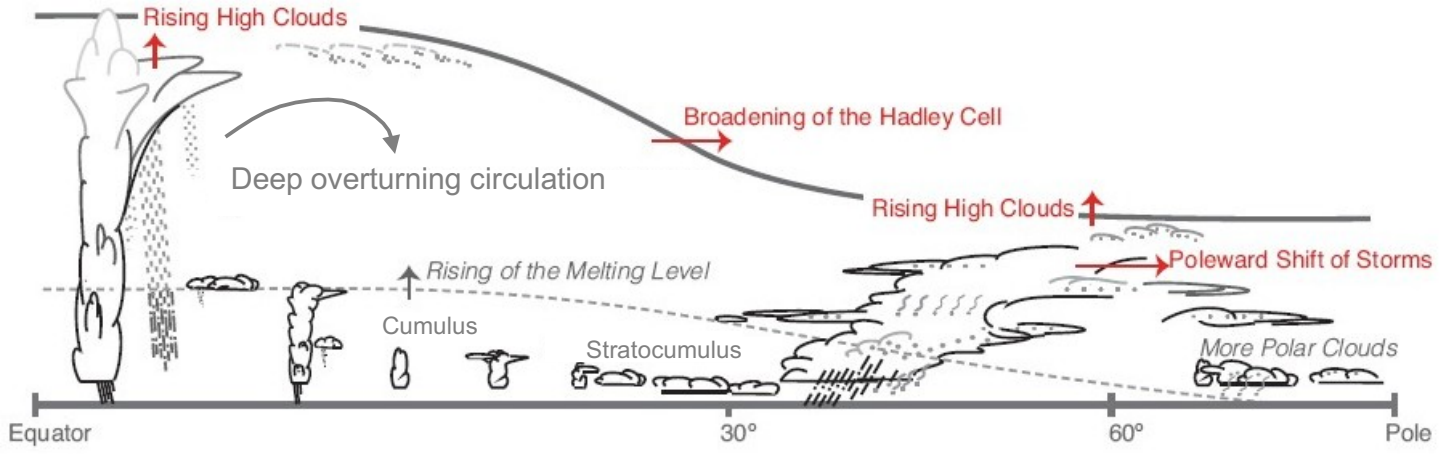
MIT LINCOLN LABORATORY

Observational Needs from Grand Challenges to the Decadal Survey

The 2017 Decadal Survey and the World Climate Research Program Grand Challenges highlight the need for:

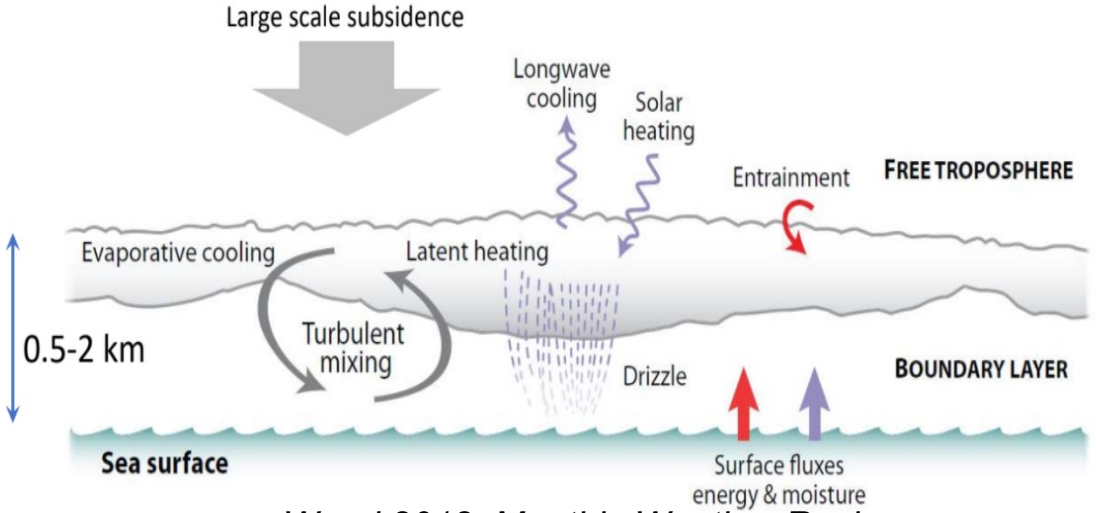
- accurate, high vertical resolution water vapor measurements in the PBL and aloft
- a deeper understanding of the role of clouds in weather and climate systems which requires accurate and high vertical resolution humidity observations around clouds

Global Space-Based Observations



Adapted from 2013 IPCC 5AR

Detailed Process Studies

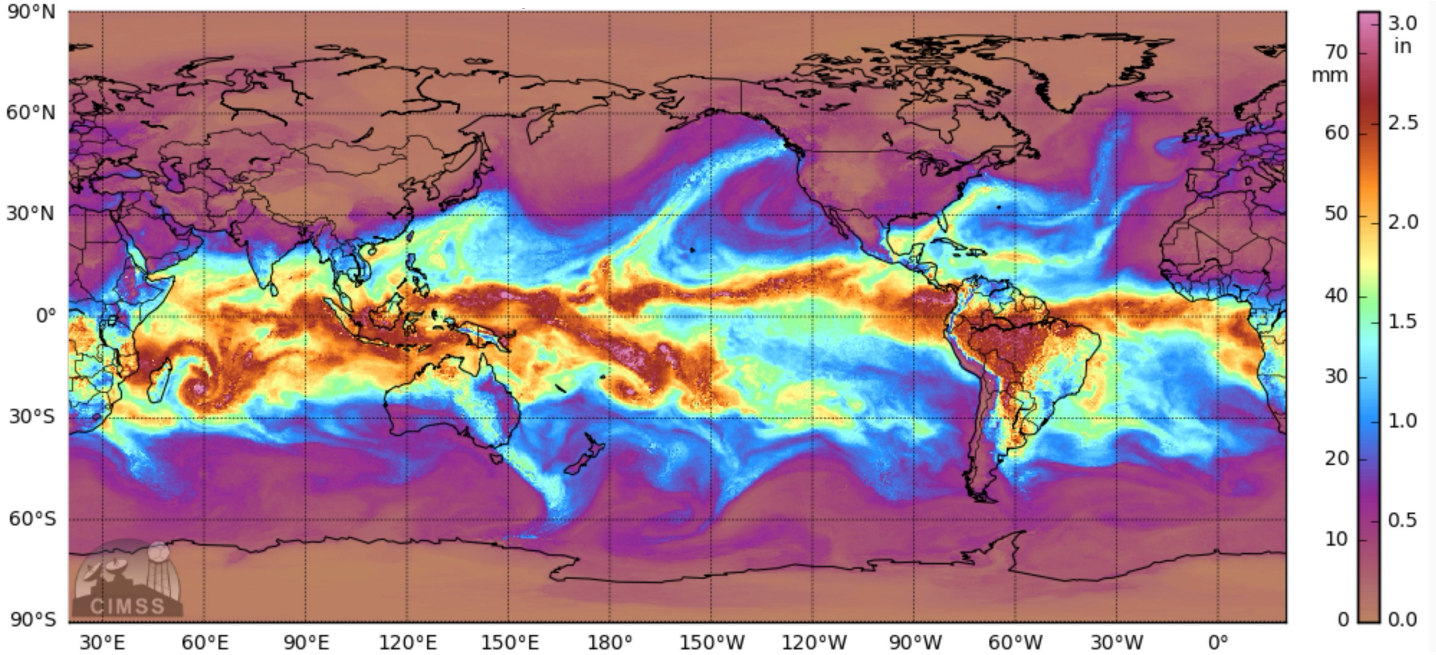


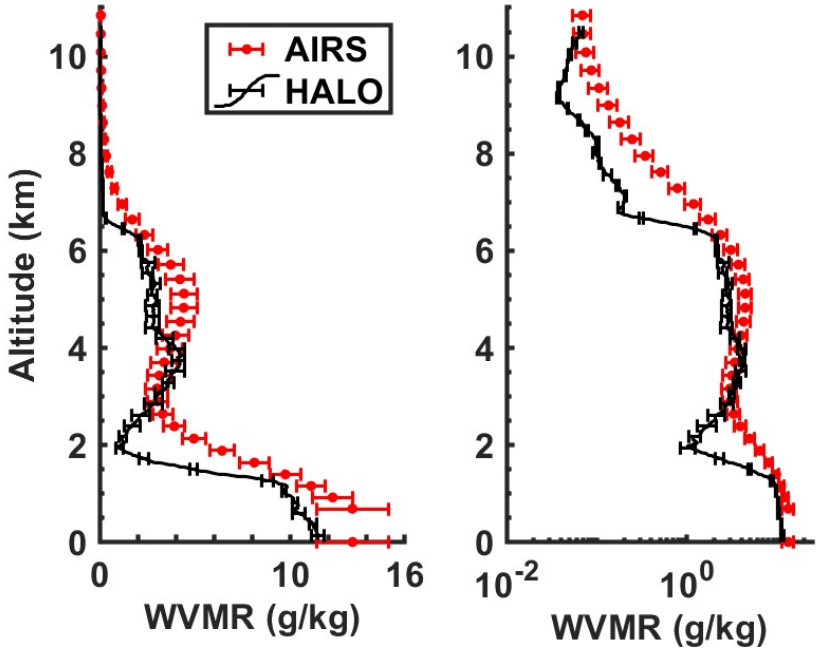
Wood 2012, Monthly Weather Review

Observational Needs – Program of Record

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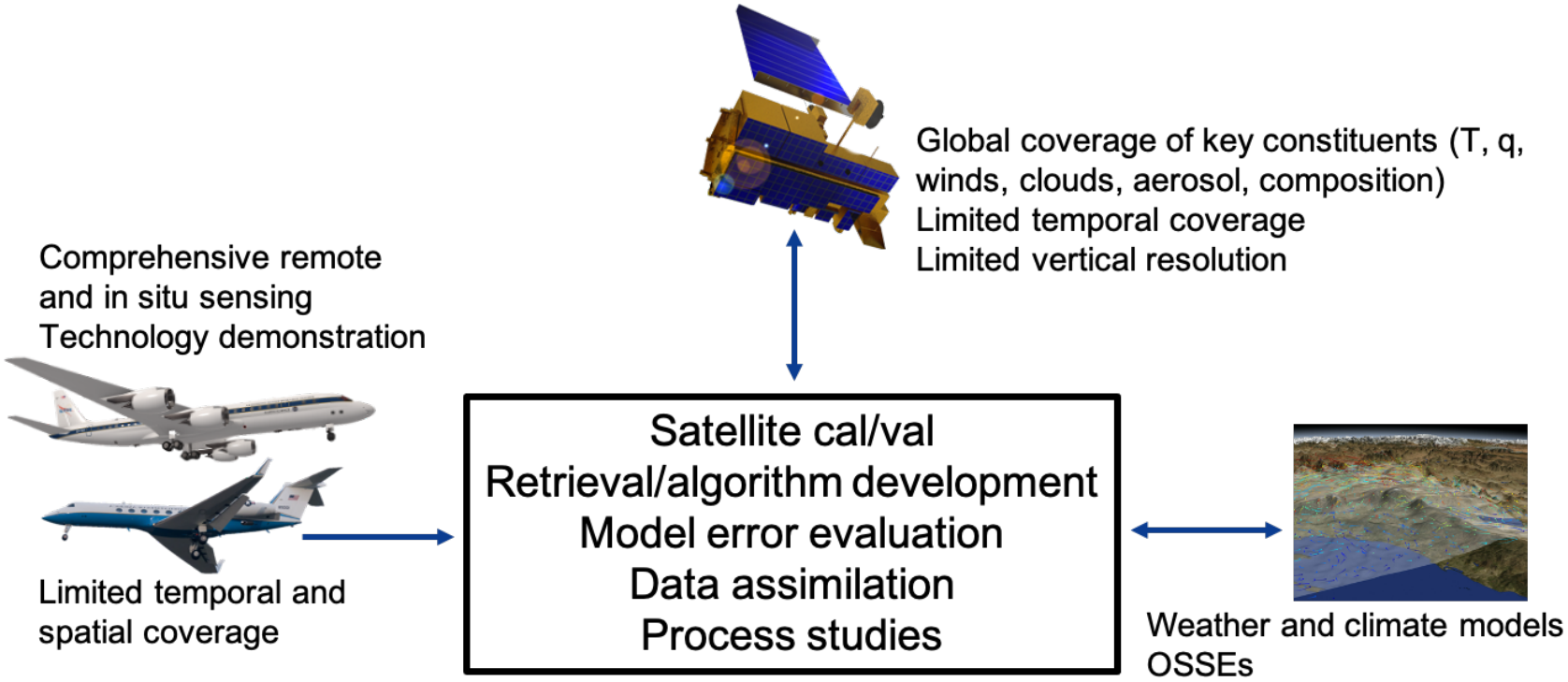




Observational Needs - Enabling and Integrated System

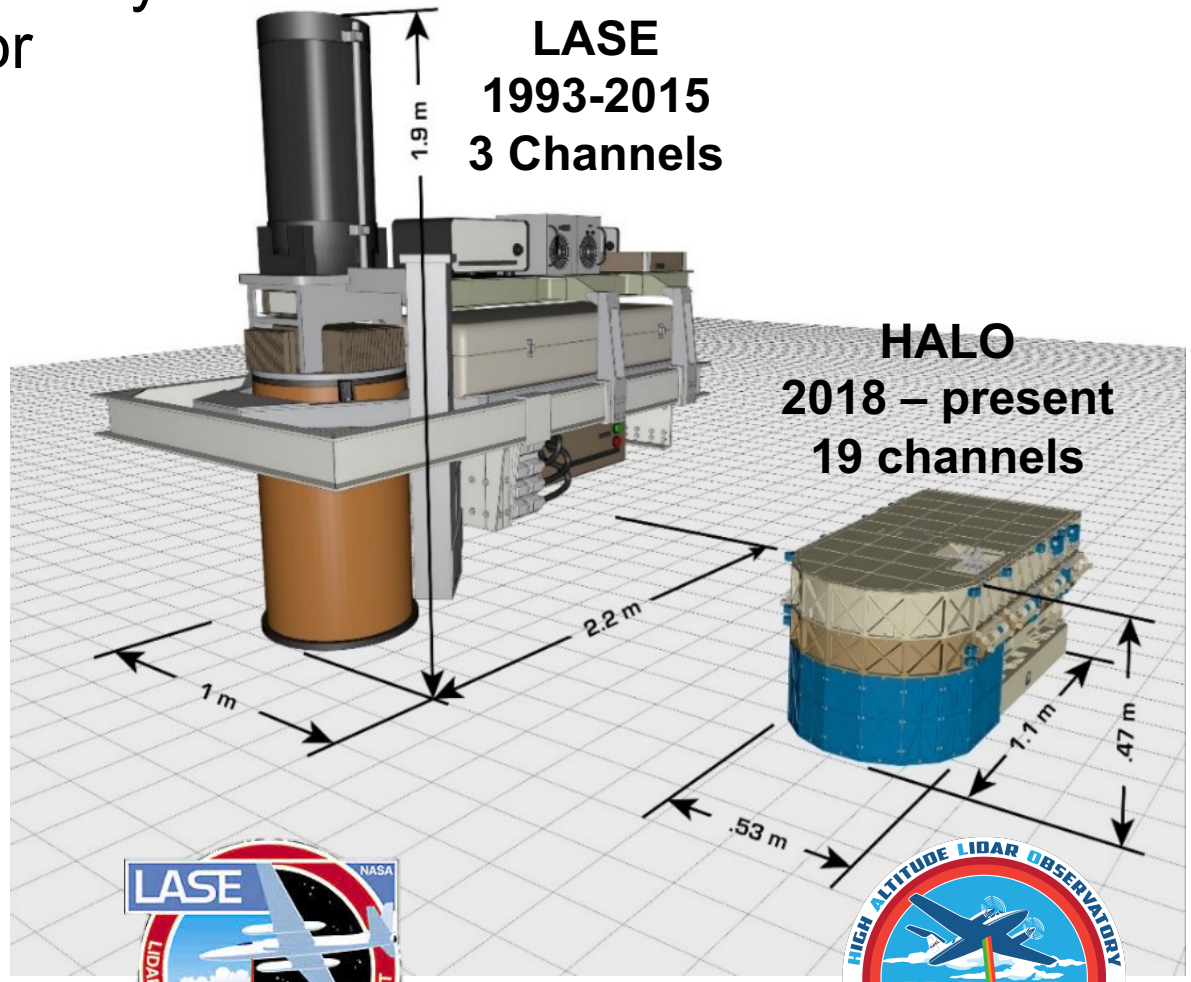
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High Altitude Lidar Observatory (HALO) - Motivation

- Develop a more capable, robust, and operationally flexible replacement for the LASE water vapor DIAL
  - H_2O DIAL, CH_4 DIAL/IPDA, and HSRL
- Cross-cutting airborne lidar in support of weather and dynamics, atmospheric composition, radiation, and carbon cycle
  - Water vapor profiles
  - Aerosol/cloud/ocean profiles
  - Methane columns/profiles
  - Satellite calibration/validation
- Technology testbed for future missions



HALO Observables and Platform Compatibility

Three Measurement Techniques Enable Cross-Cutting Science

Differential Absorption Lidar
Water vapor DIAL

Integrated Path DIAL
Methane IPDA

Coherent Doppler Lidar
3-D winds (future)

High Spectral Resolution Lidar
Aerosol/cloud/ocean HSRL

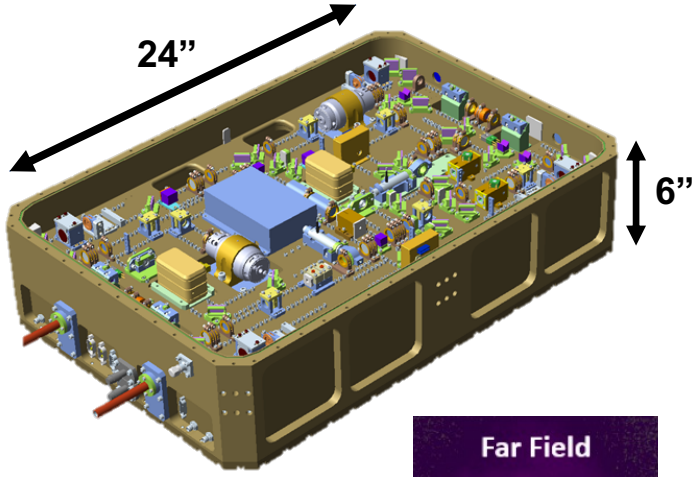
Parameter	Wavelength (nm)	Approximate Precision	Horizontal Resolution	Vertical Resolution
Water Vapor Mixing Ratio	935/820	5% or .001 g/kg	1-12 km variable	100-600 m variable
Methane Column	1645	<8 ppb	1 km	column
PBL height	532/935 /1645	<50	200 m	N/A
Aerosol Backscatter	532/1064	0.2 $Mm^{-1}sr^{-1}$	1 km	15 m
Aerosol Extinction	532	0.01 km sr^{-1}	12 km	300 m
Depolarization	532/1064	0.01	1 km	15 m
Aerosol Type	N/A	Qualitative	12km	300 m

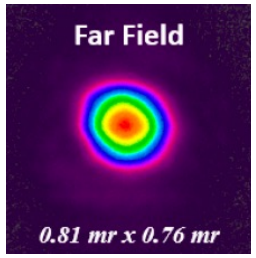
Compatible Platforms

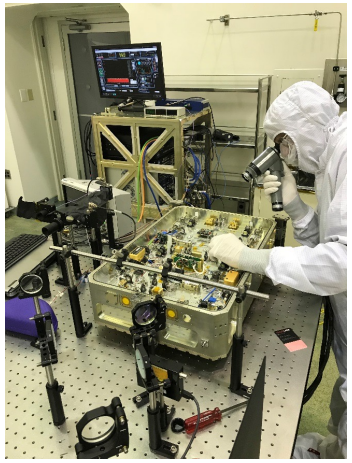


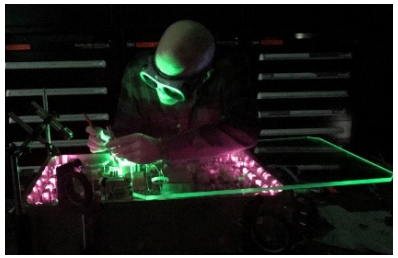
Enabling Technologies for Operational Suborbital DIAL

Tunable High Power Pulsed Lasers







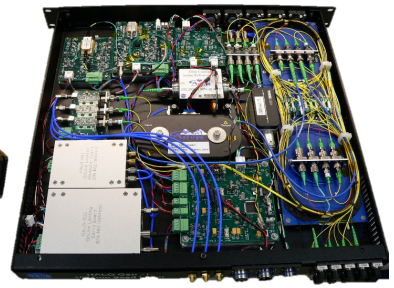


Frequency Agile Seed Lasers



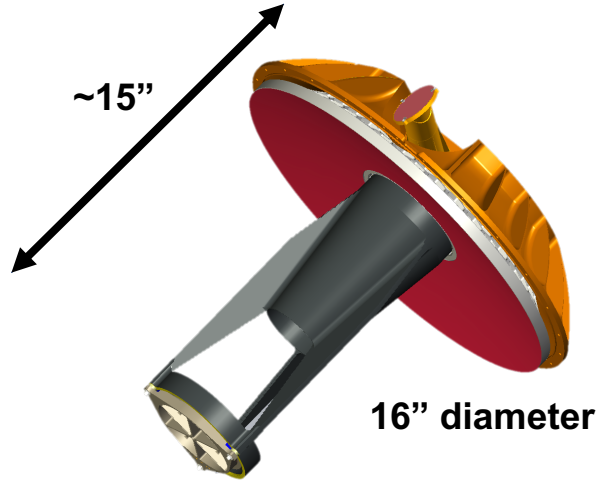


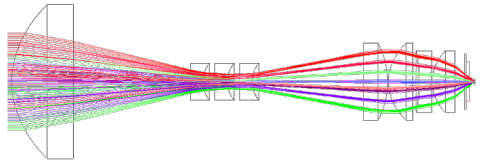


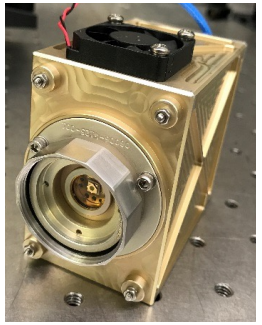




Compact Optics & Electronics

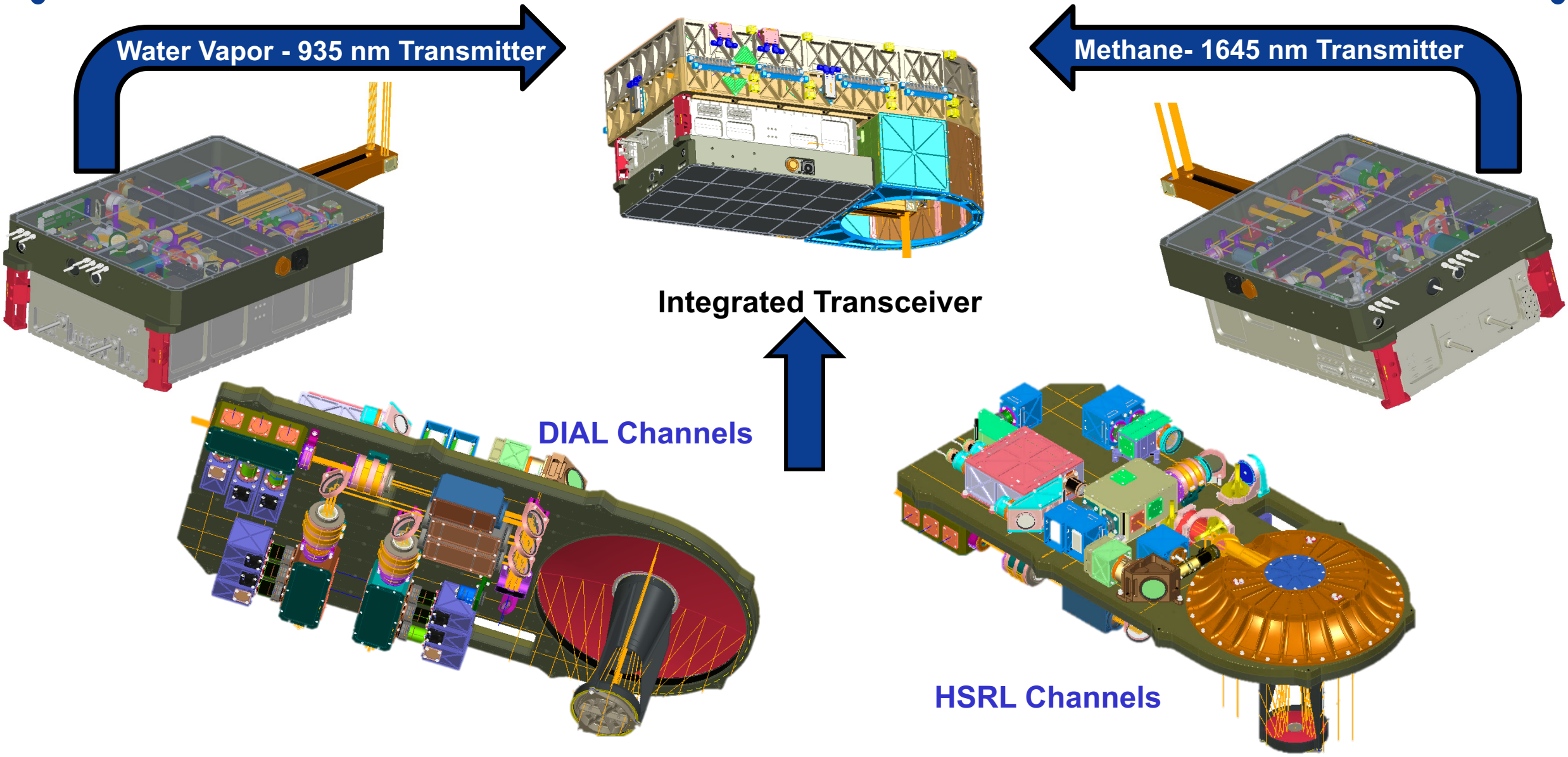






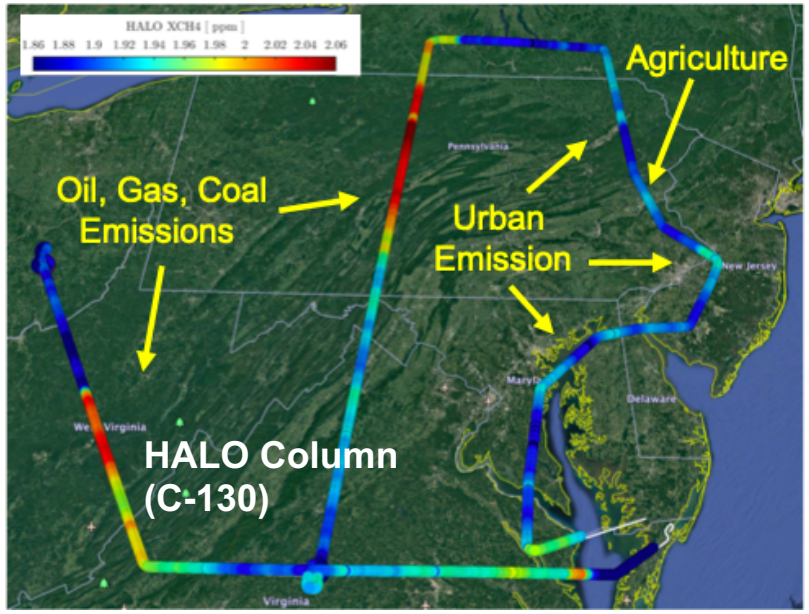


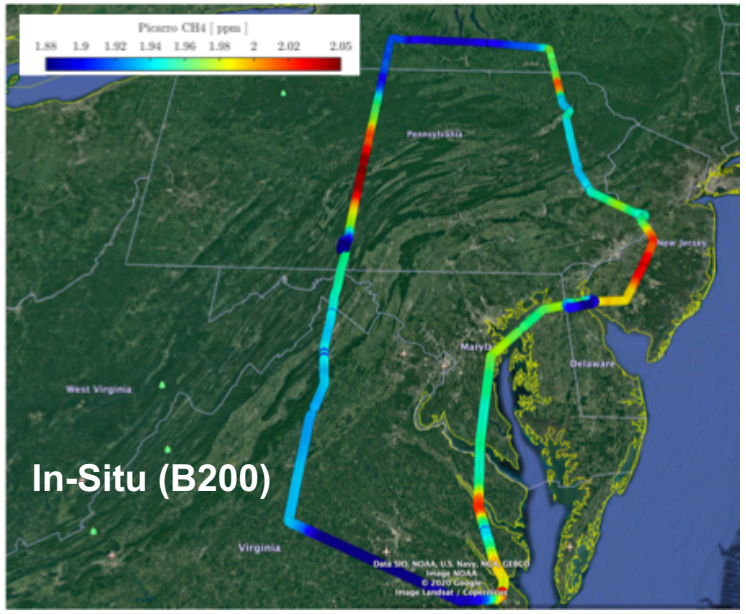
Integrated System – Plug and Play Architecture

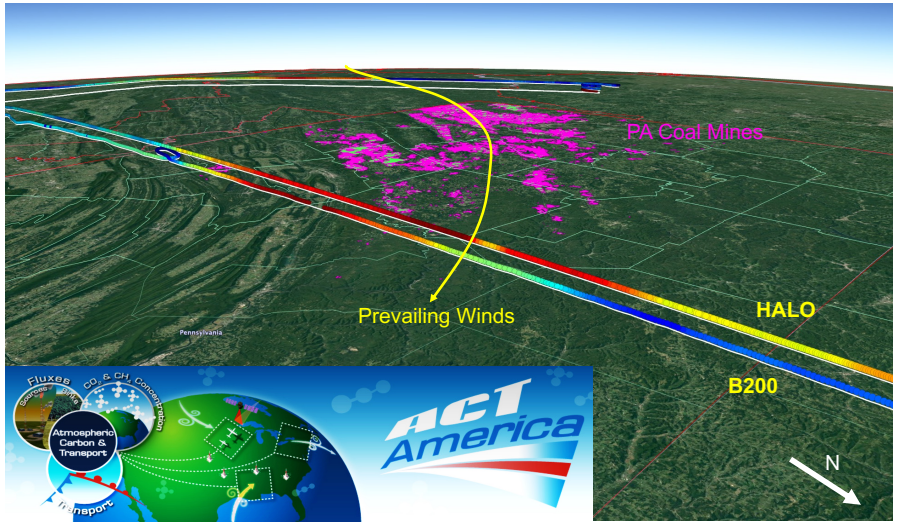


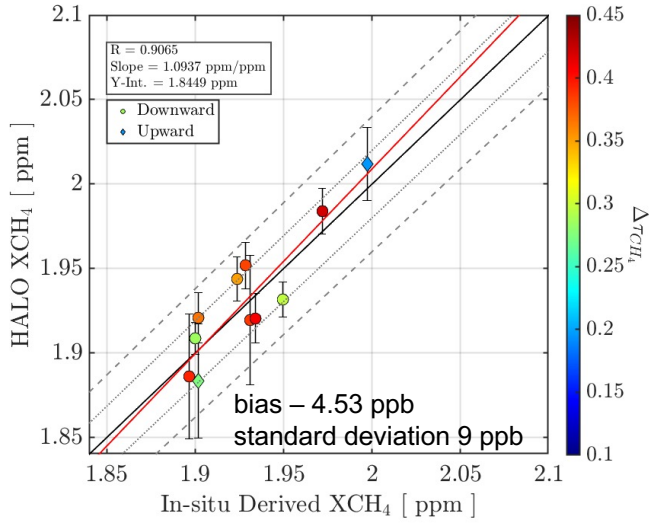
HALO XCH_4 Observations

Atmospheric Carbon and Transport – America

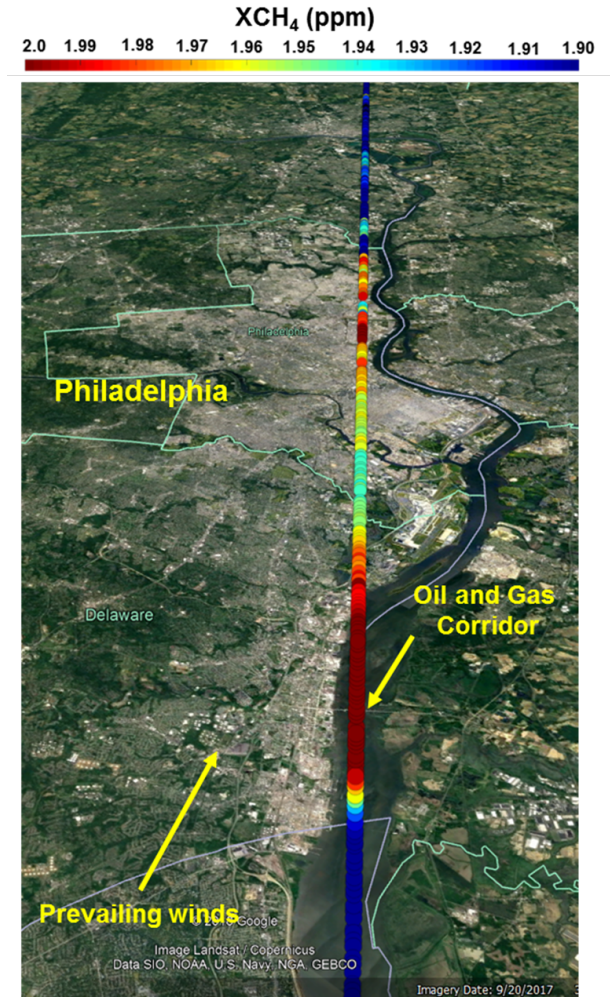




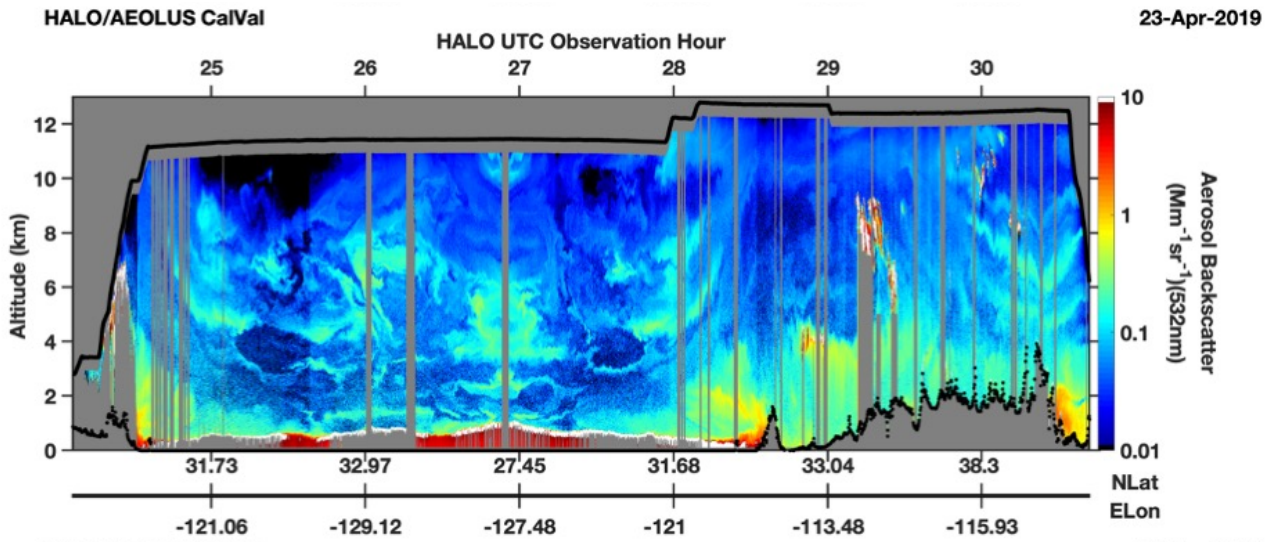


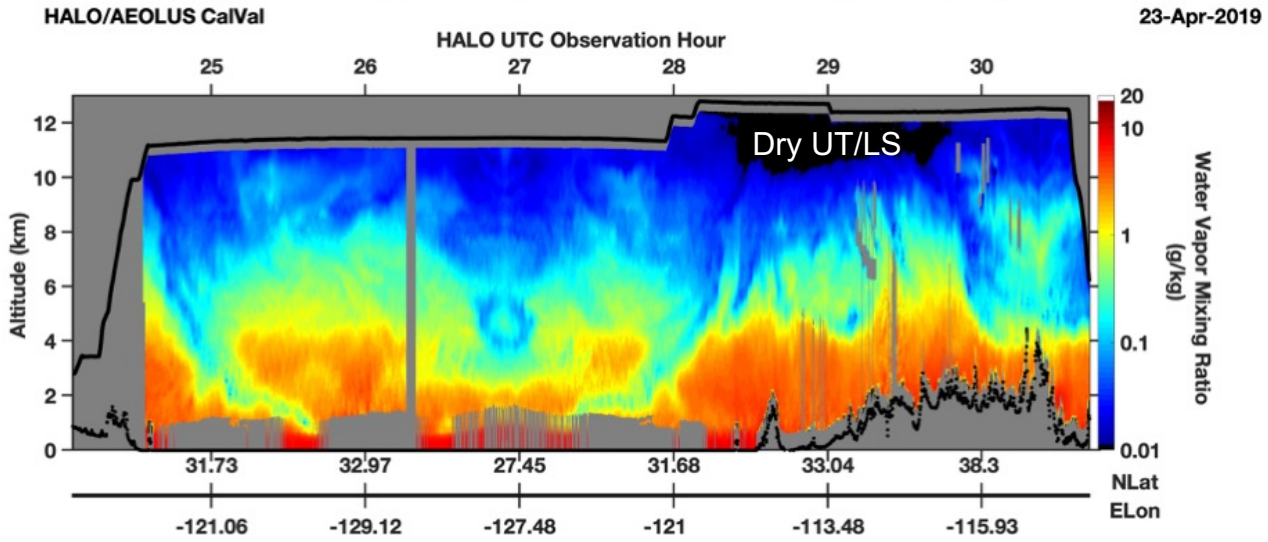


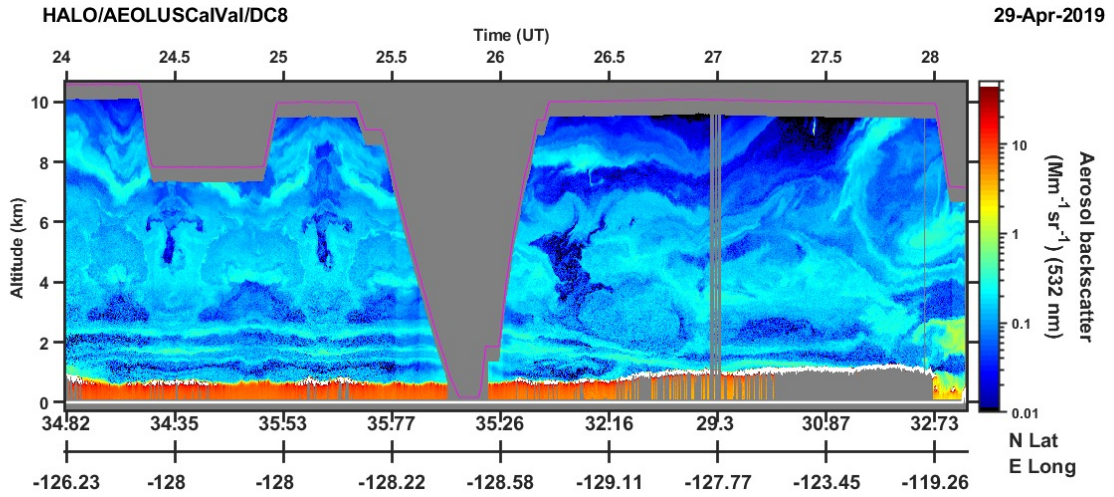
Long Island Sound Tropospheric Ozone Study

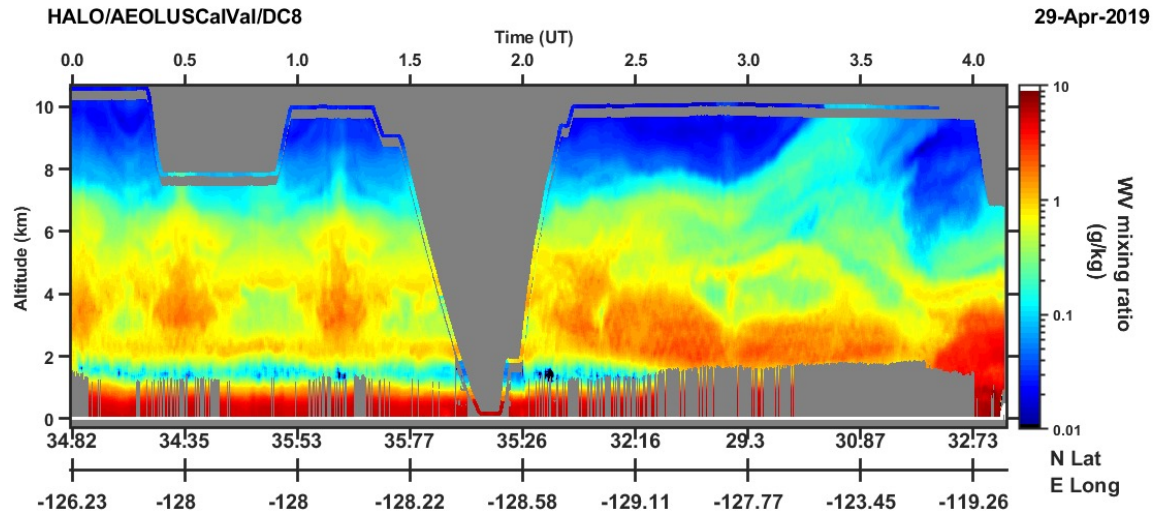


HALO Water Vapor DIAL Observations – Tropospheric coverage



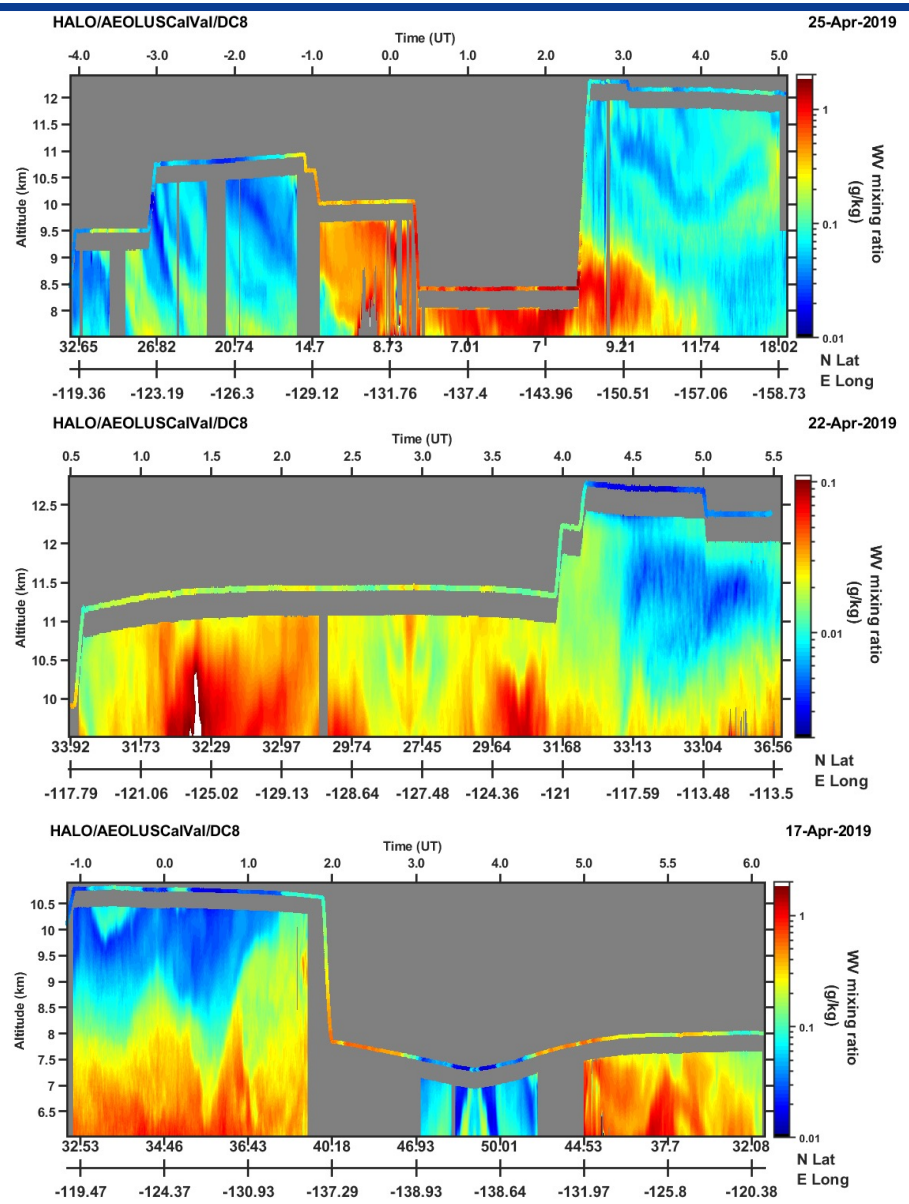




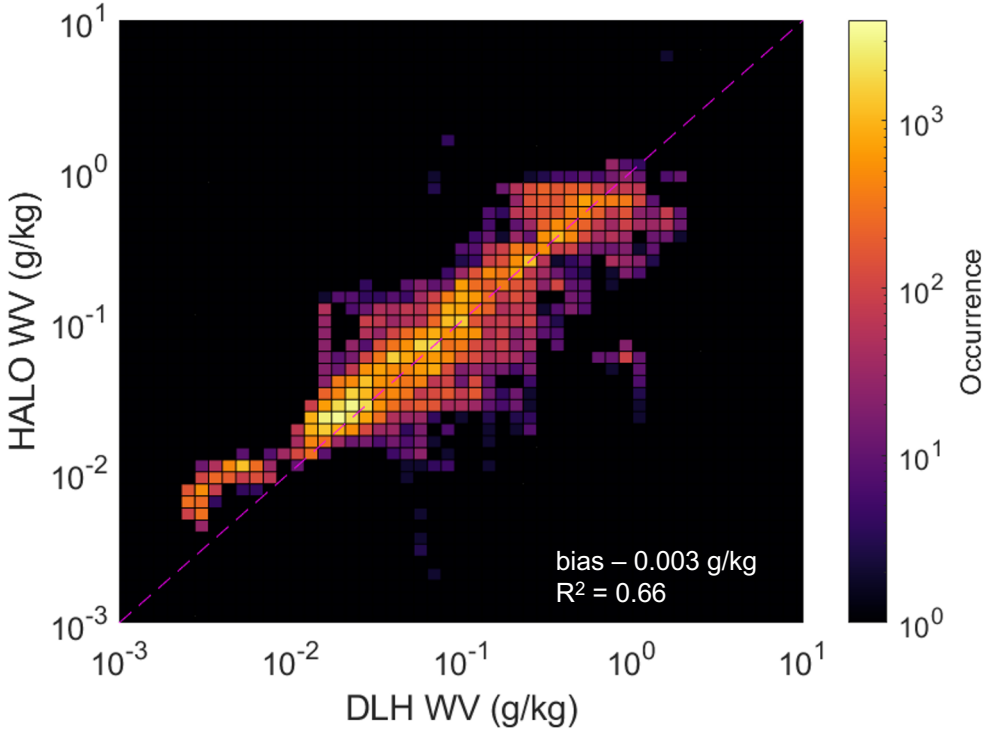


Bedka et al. 2021, AMT

HALO Water Vapor DIAL Observations – Upper Atmosphere Dynamics

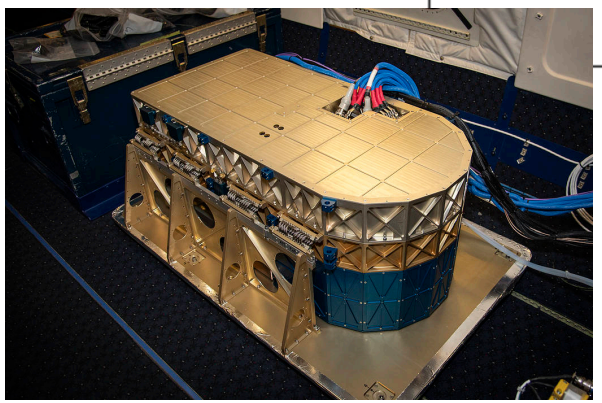


Validation against Diode Laser Hygrometer



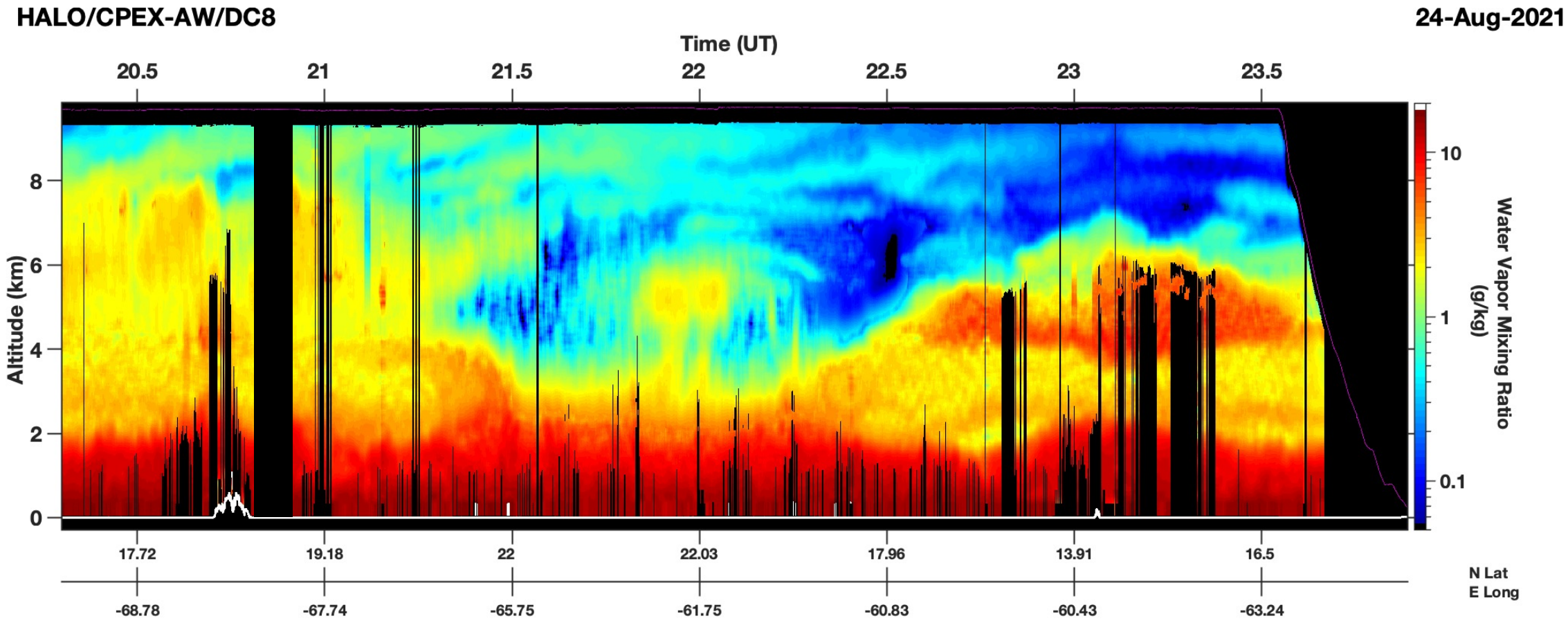
Carroll et al. 2021, AMTD

HALO Water Vapor DIAL Observations – Tropical Dynamics

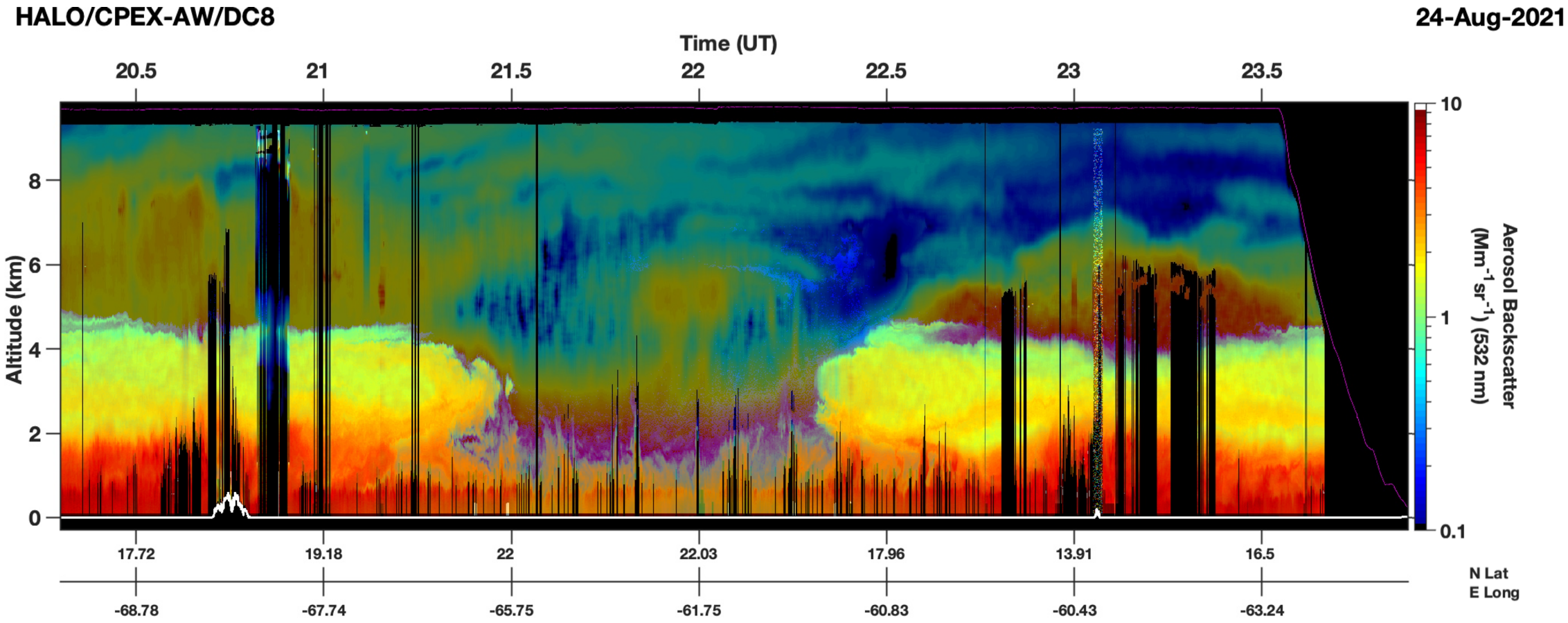




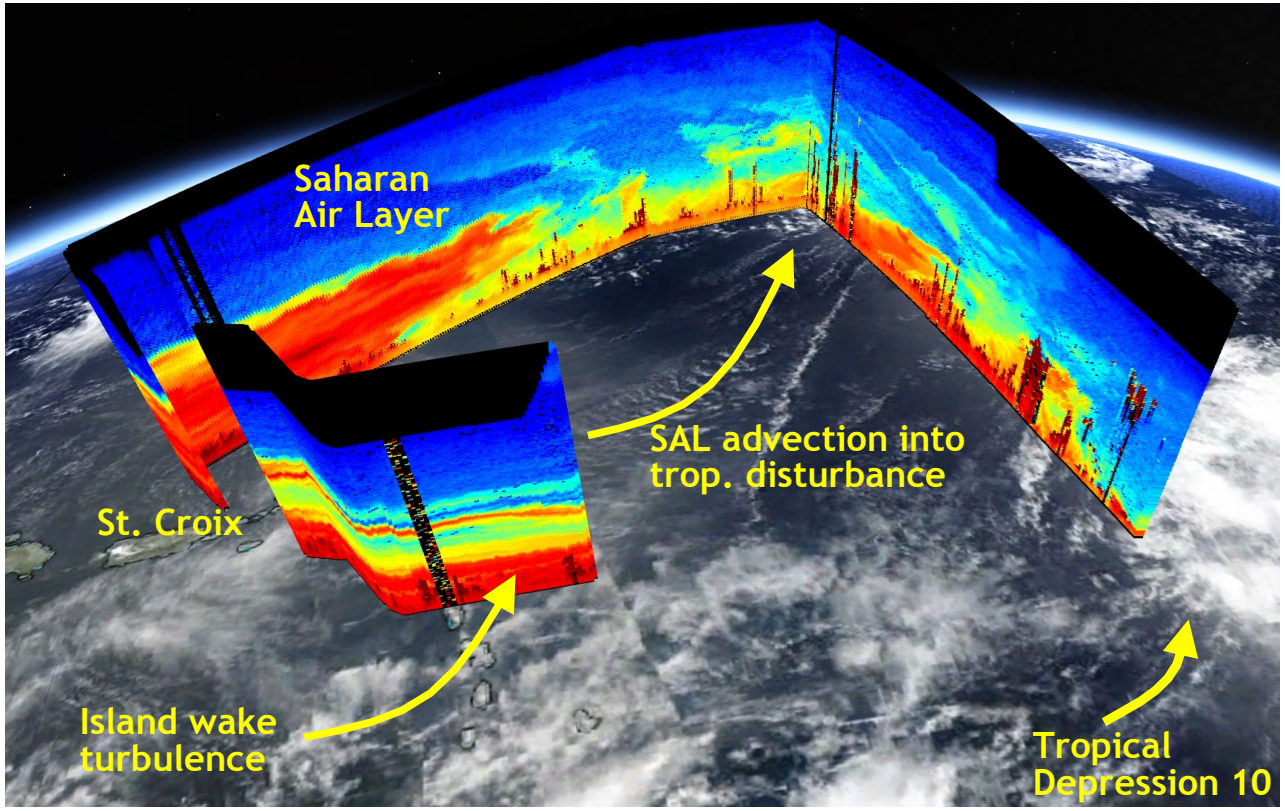
HALO Water Vapor DIAL Observations – Tropical Dynamics

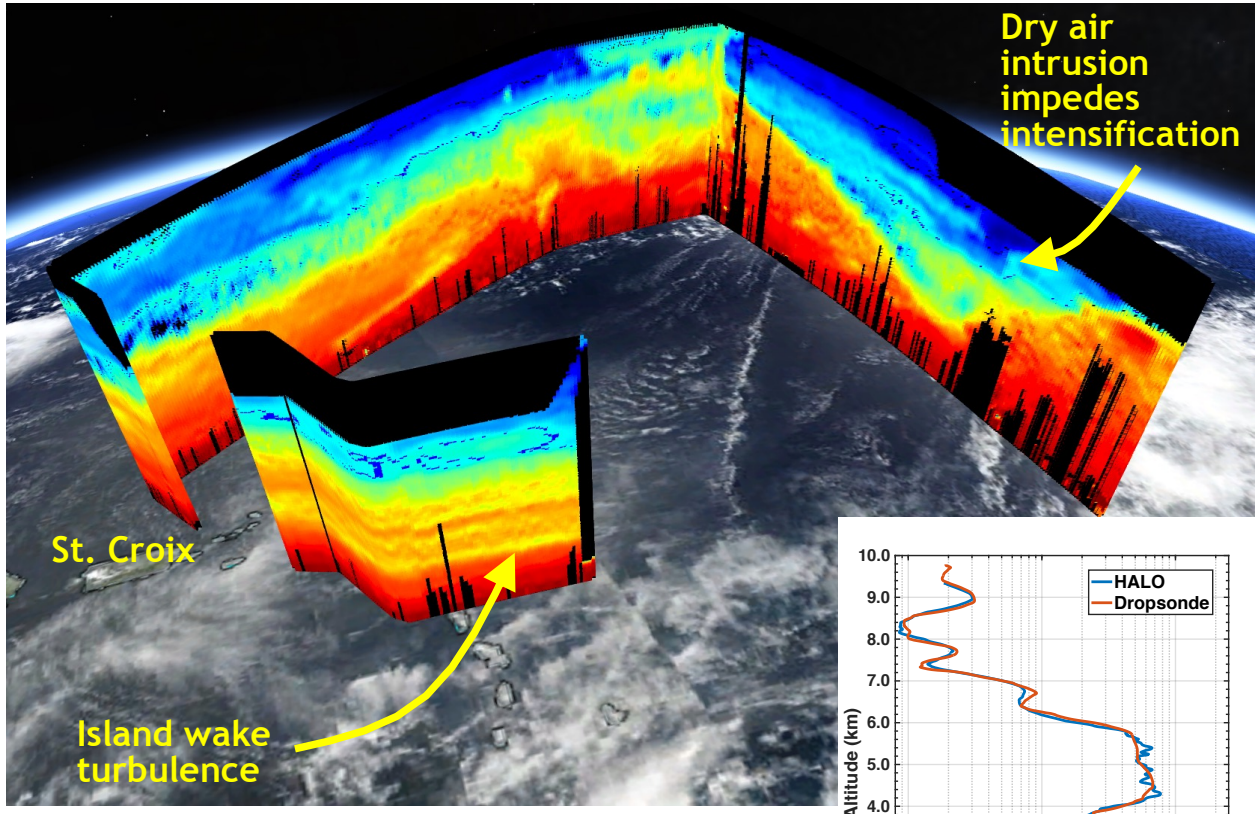


HALO Water Vapor DIAL Observations – Tropical Dynamics



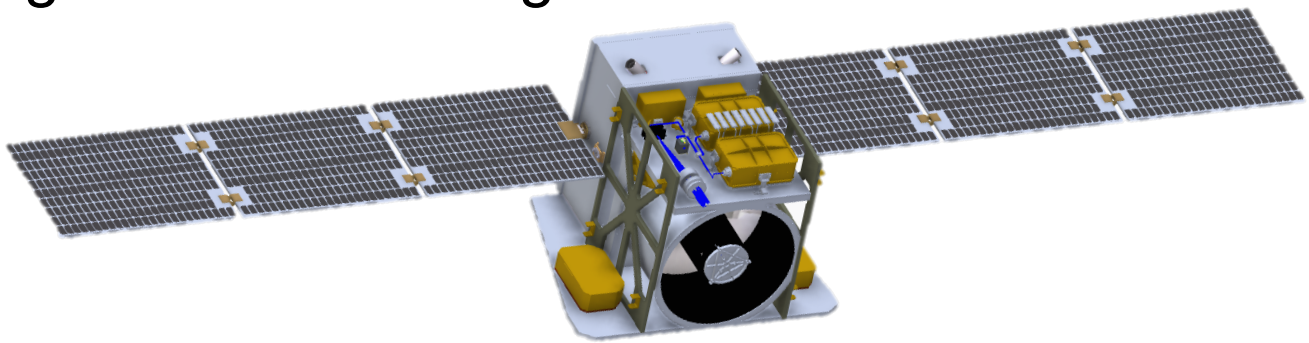
HALO Water Vapor DIAL Observations – Tropical Dynamics





Path Forward

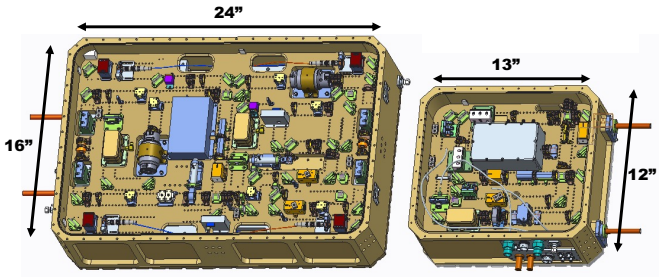
- NASA LaRC has developed HALO in collaboration with industry and funding from NASA Earth Science Technology Office (ESTO), NASA SBIR, and LaRC IRAD
- HALO is operational and routinely supporting the NASA composition, weather and dynamics, radiation sciences, and carbon cycle programs
- Pursuing opportunities for interagency collaboration
  - Workhorse instrument for the new NOAA Gulfstream 550 for hurricane research
  - Tropical and arctic research in support of national defense
  - Support basic research and model evaluation
- Emerging technologies allow for cross-cutting science (e.g. winds, CH_4 columns)
- Technologies are being advanced through ESTO to enable the first space-based DIAL

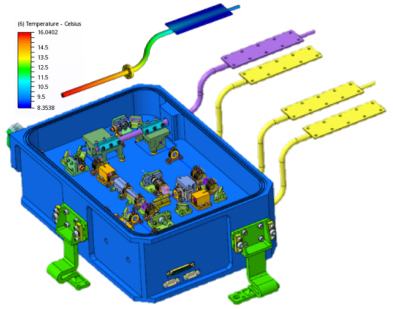


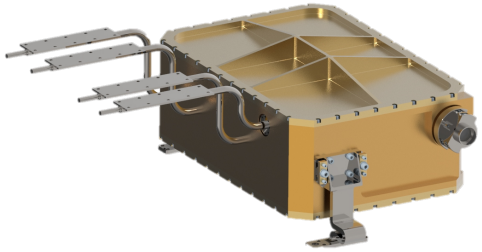
Research to Operations - Technology Advance for Space-borne DIAL

TRL 9 Airborne → **Opto-Electronic Integration** → **TRL 5 Flight**

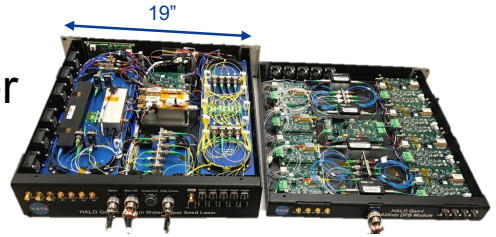
Pulsed Laser Advance

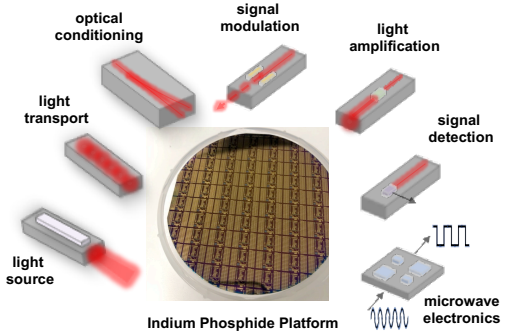


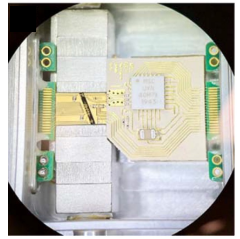


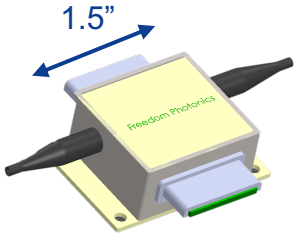


Seed Laser Advance



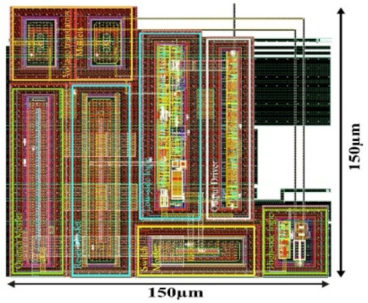


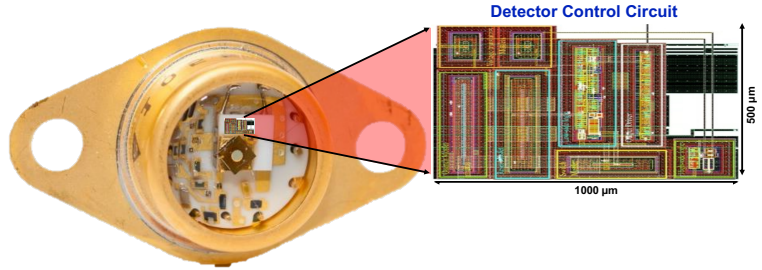




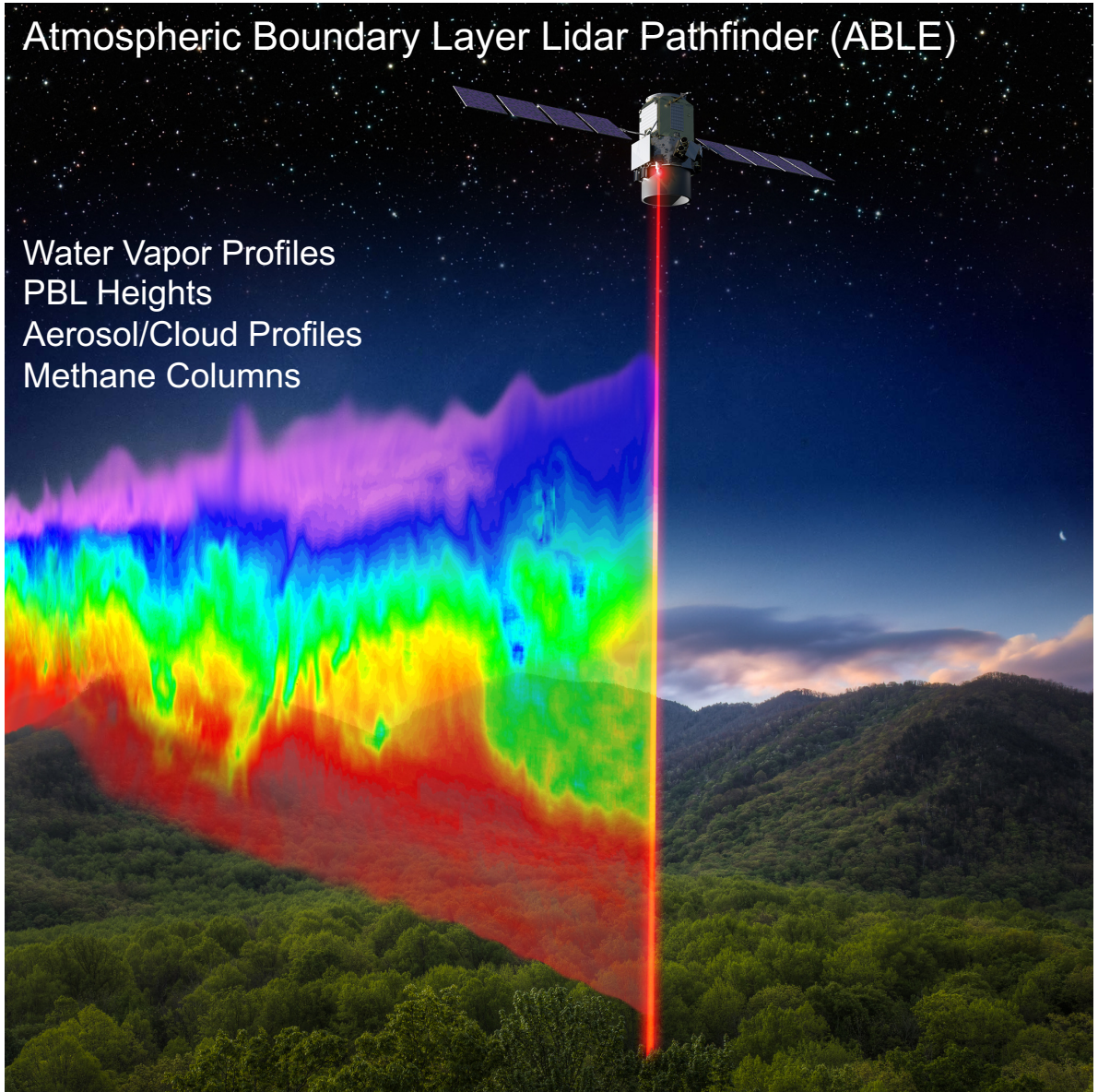
Detector Advance







Atmospheric Boundary Layer Lidar PathfindEr



- Develop a pathfinder mission concept and advance associated technologies to enable the first demonstration of DIAL in space
  - Water vapor profiling from mid-troposphere to PBL
  - 200-400 m resolution in the PBL, 1 km in mid-trop
  - 50-75km along track resolution
- Novel laser technologies enable *crosscutting science* spanning disparate science focus areas
  - Weather and dynamics (including PBL)
  - Atmospheric composition and radiation
  - Carbon Cycle
- Set stage for synergistic observing system with backbone observations
  - Hyperspectral Infrared Sounder
  - Microwave Sounder