Differential Absorption Lidar (DIAL) for Profiling Water Vapor within and above the PBL

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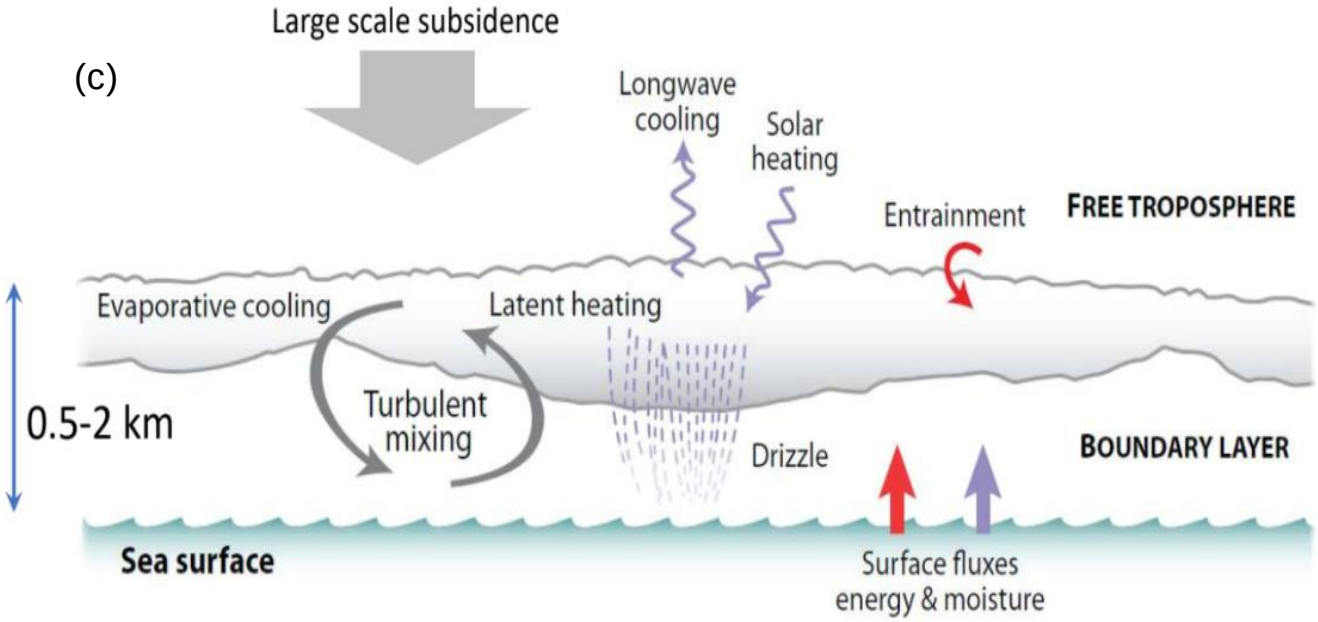
The PBL and Grand Challenges

The 2017 Decadal Survey[(a)] and the WCRP Grand Challenges[(b)] highlight:

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



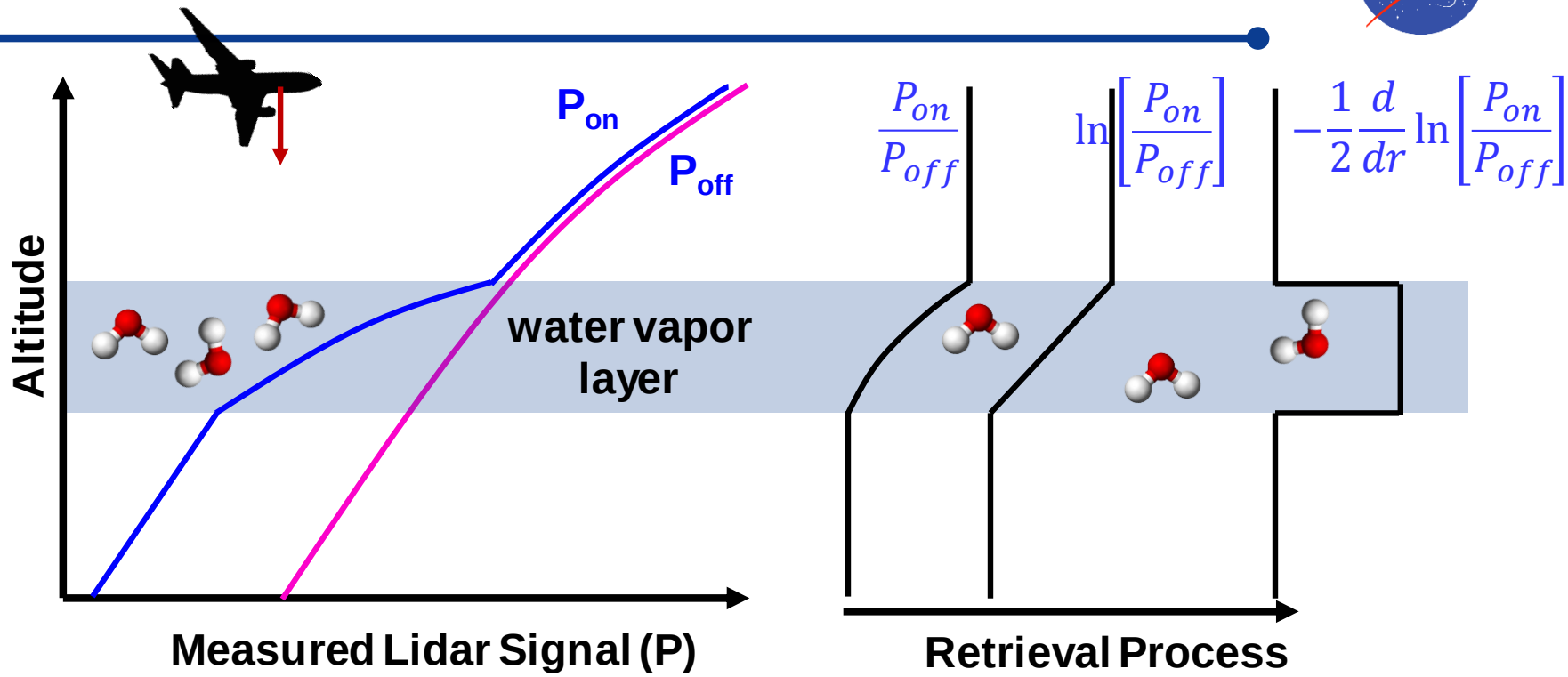
(a) National Academies of Sciences, Engineering, and Medicine (2018). Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space. Washington, DC: The National Academies Press. https://doi.org/10.17226/24938.

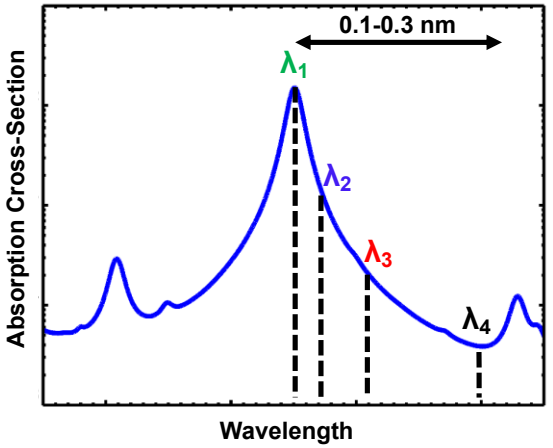
(b) Bony, S., Stevens, B., Frierson, D. M. W., Jakob, C., Kageyama, M., Pincus, R., … Webb, M. J. (2015). Clouds, circulation and climate sensitivity. Nature Geoscience, 8(4), 261–268.

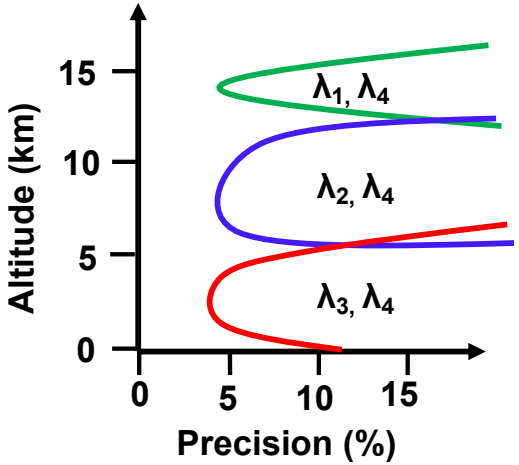
(c) Wood, R. (2012). Stratocumulus clouds. Monthly Weather Review, 140(8), 2373-2423. © American Meteorological Society. Used with permission.

The DIAL measurement

- Water vapor number density is proportional to the differential absorption at two wavelengths
- A direct, calibration-free measure of water vapor
- Direct measurement of uncertainty for each retrieval
- Multiple wavelengths provide sensitivity to different parts of the atmosphere
- Some limitations include
  - Lack of observations below opaque clouds
  - Small footprint
- Limitations can be addressed with other synergistic remote sensing observations







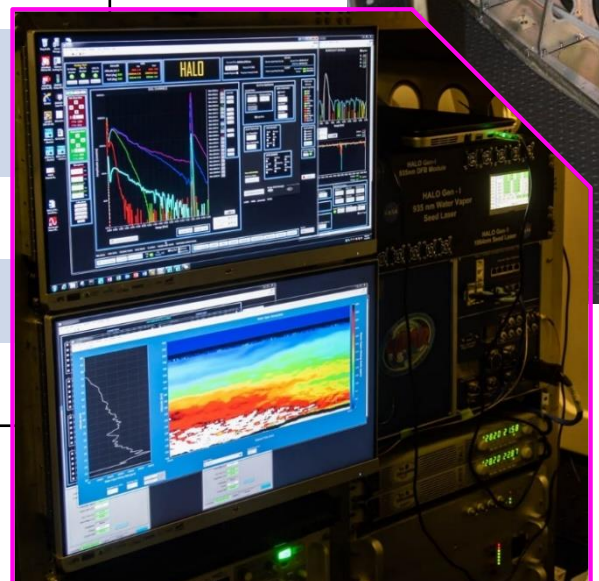
Random Error

$$\frac{\Delta n}{n} \propto (\Delta t)^{-0.5}(\Delta r)^{-1.5}$$

High Altitude Lidar Observatory (HALO)

HALO has flown on the NASA B200, UC-12, DC-8, and C130. Also compatible with P3, GV, and ER-2.

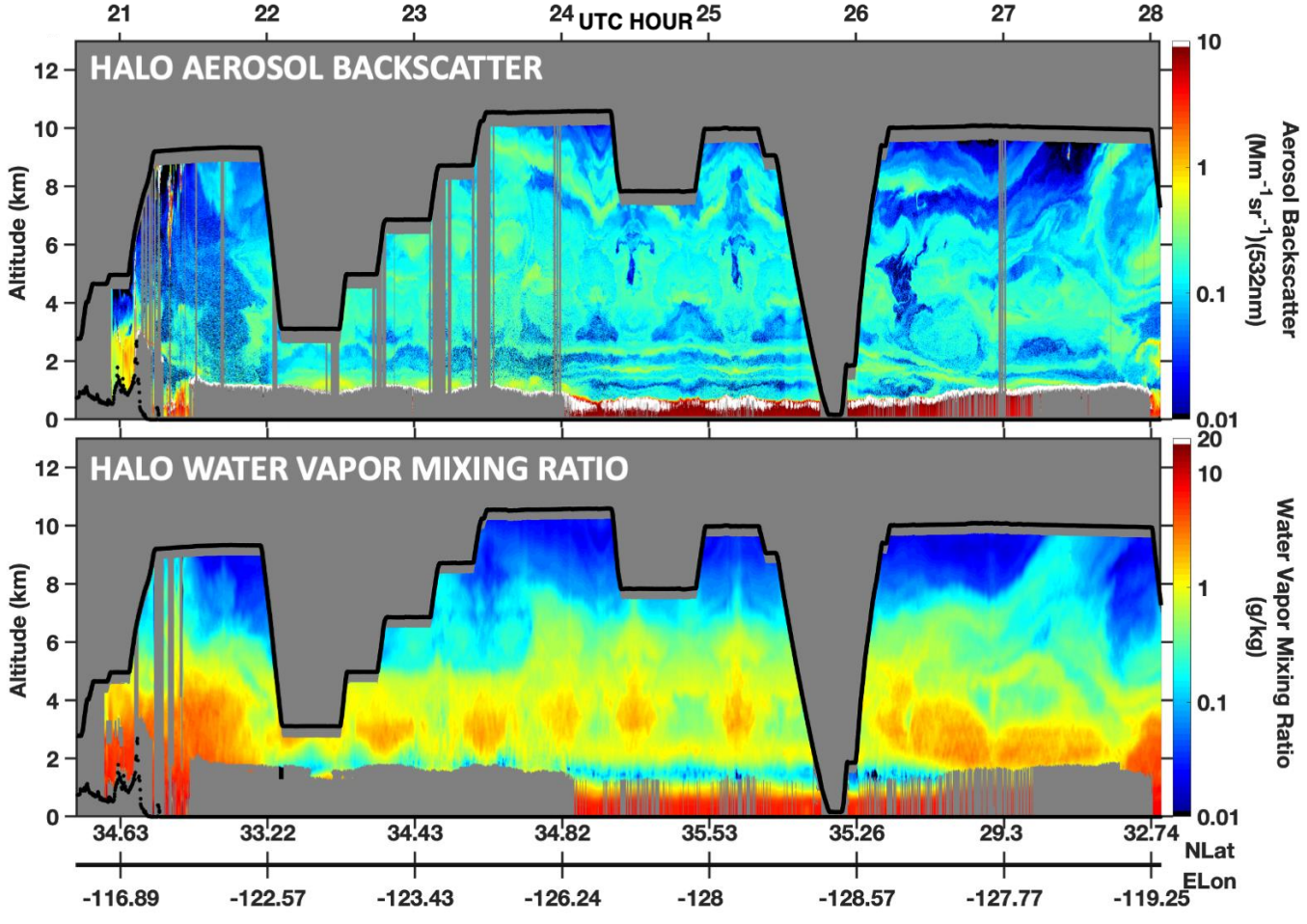
HALO, water vapor configuration	
Products	Profiles of water vapor mixing ratio Profiles of aerosol/cloud optical properties
Operation	Day, night, any altitude
Spatial Resolution*	1-12 km horizontal, 100-600 m vertical
Water vapor sensitivity	0.001-25 g/kg
Timeliness	Realtime reporting Several hours after flight
Wavelength	935 nm (532 nm, 1064 nm for HSRL)
Instrument Mass	400 lbs + aircraft fixture
Support Equipment	1 bay aircraft electronics rack

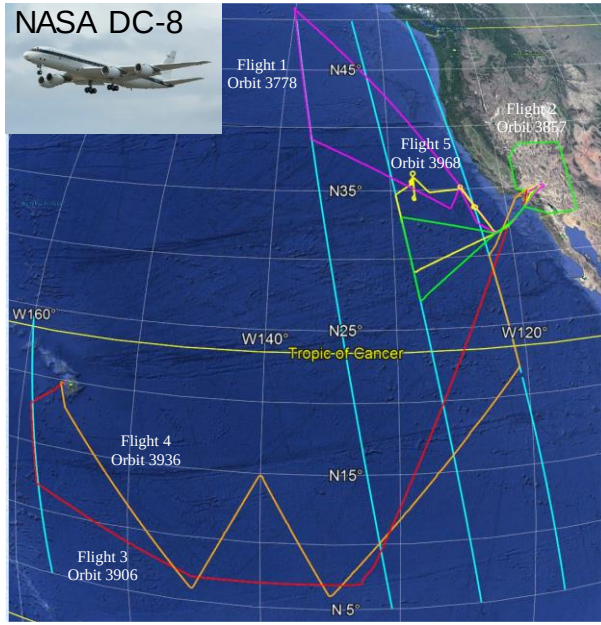


*Vertical and horizontal averaging can be traded for precision and adapted for different applications. Nominal resolution is 315 m vertical and 12 km horizontal from 10km altitude.

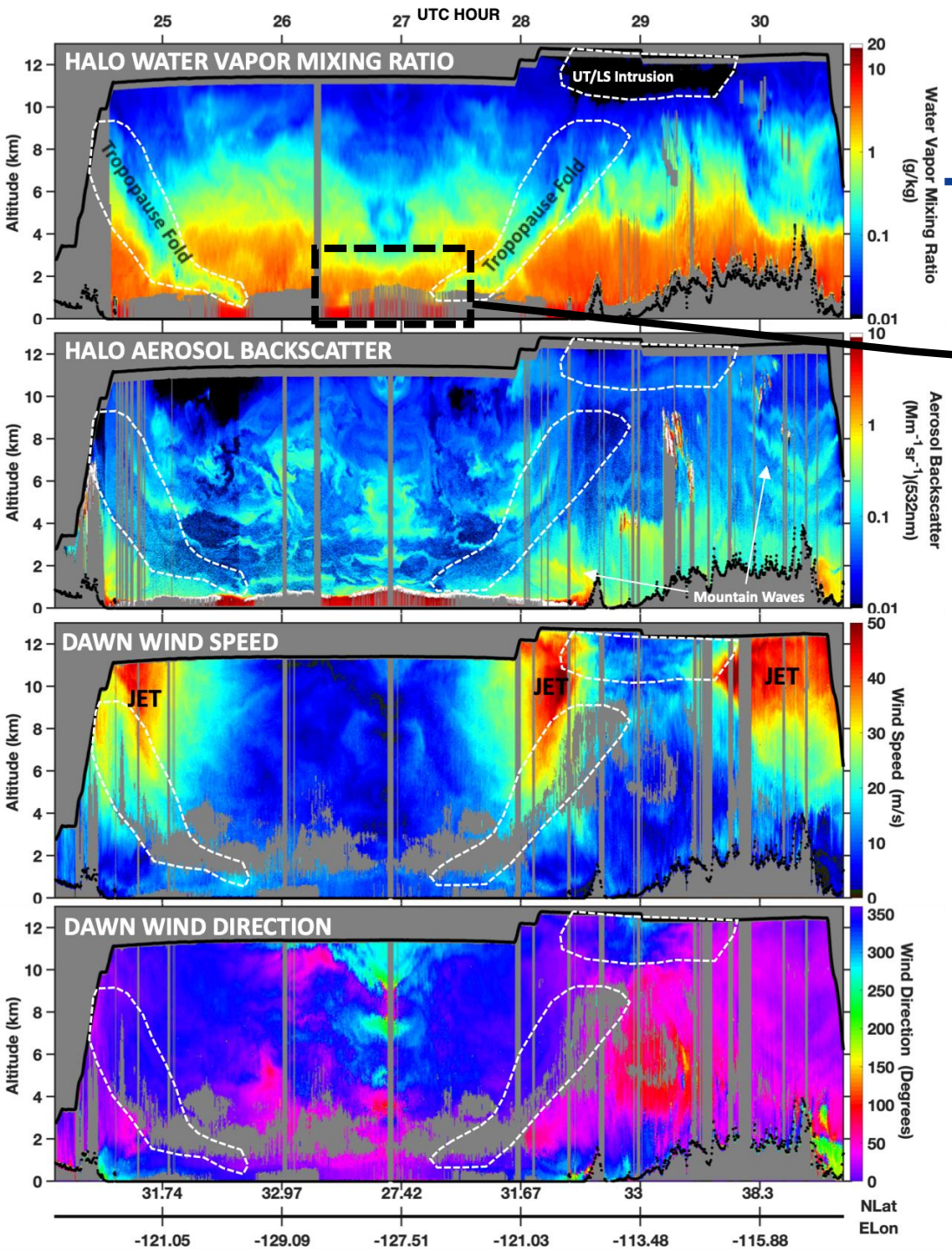
2019 AEOLUS cal/val campaign: 5 flights

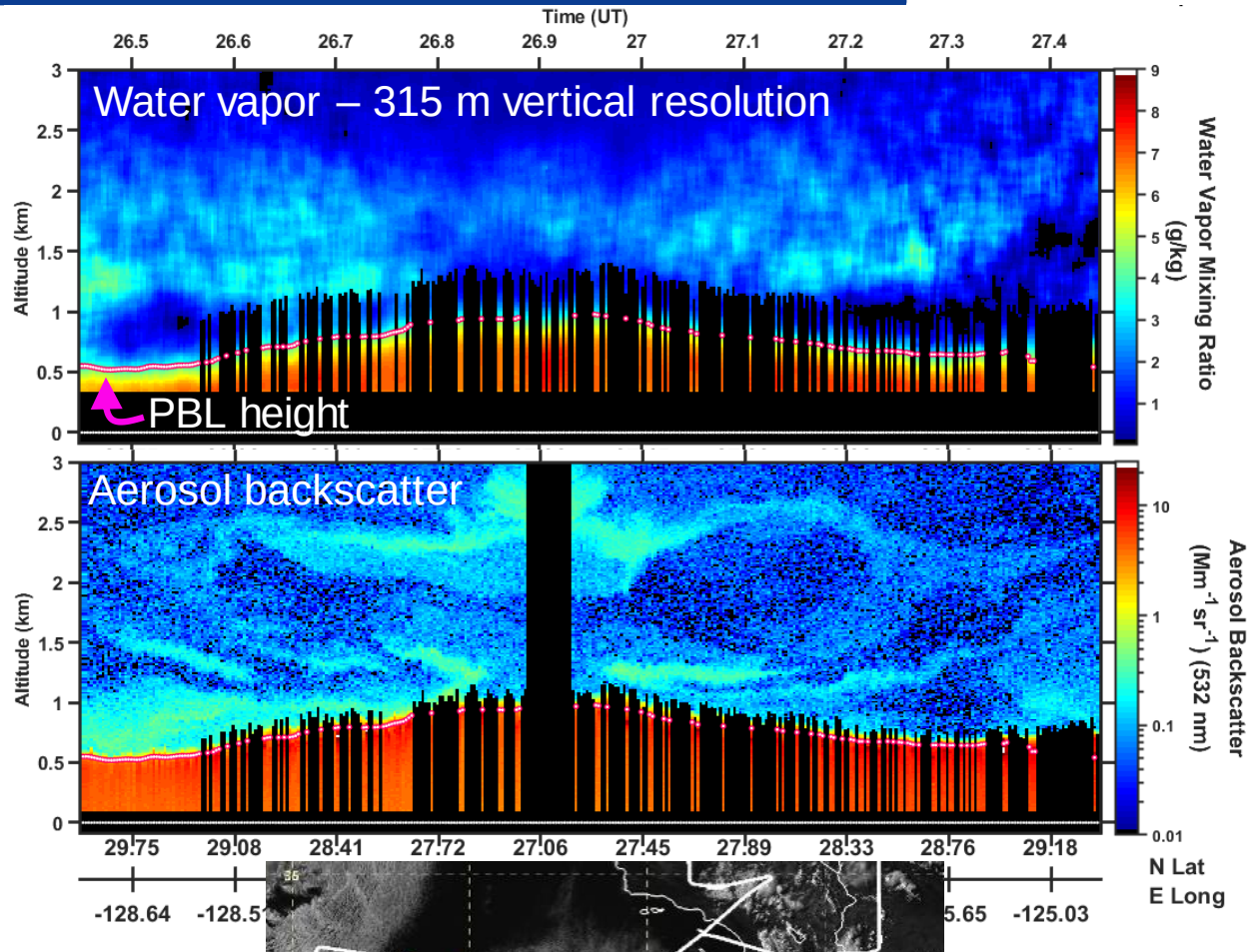
- Maiden HALO water vapor flights - Opportunity to evaluate performance of DIAL across a range of relevant atmospheric conditions
- Evaluate new algorithms to improve precision, spatial resolution and coverage
- Demonstration of combined HALO and DAWN (wind lidar) observations

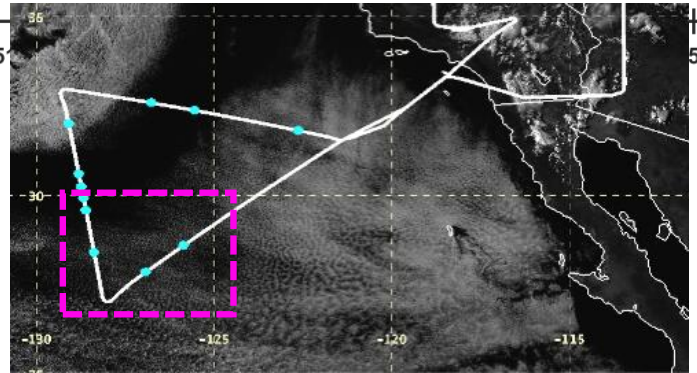




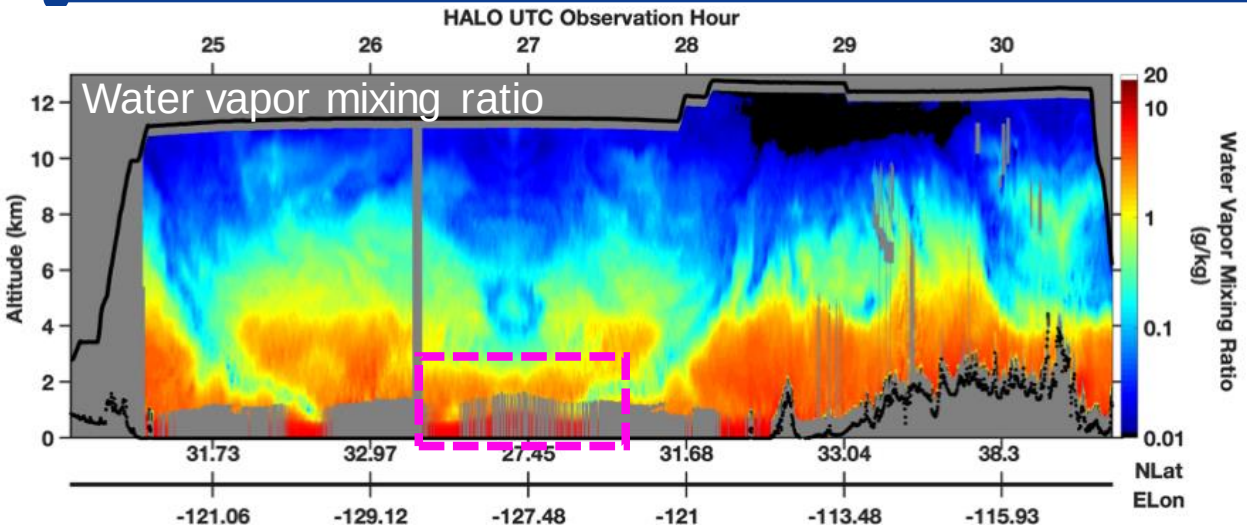
Observations from large scale circulation to clouds



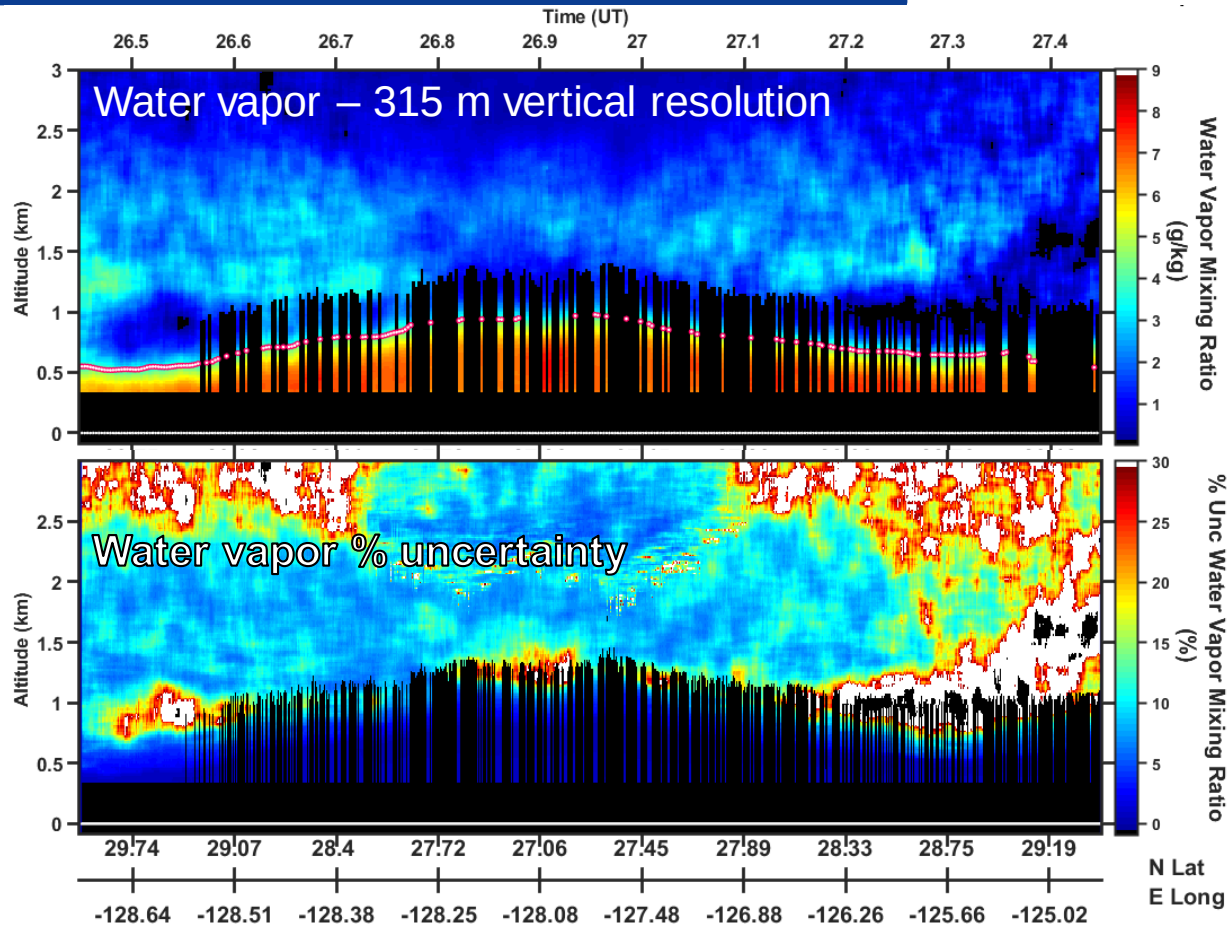




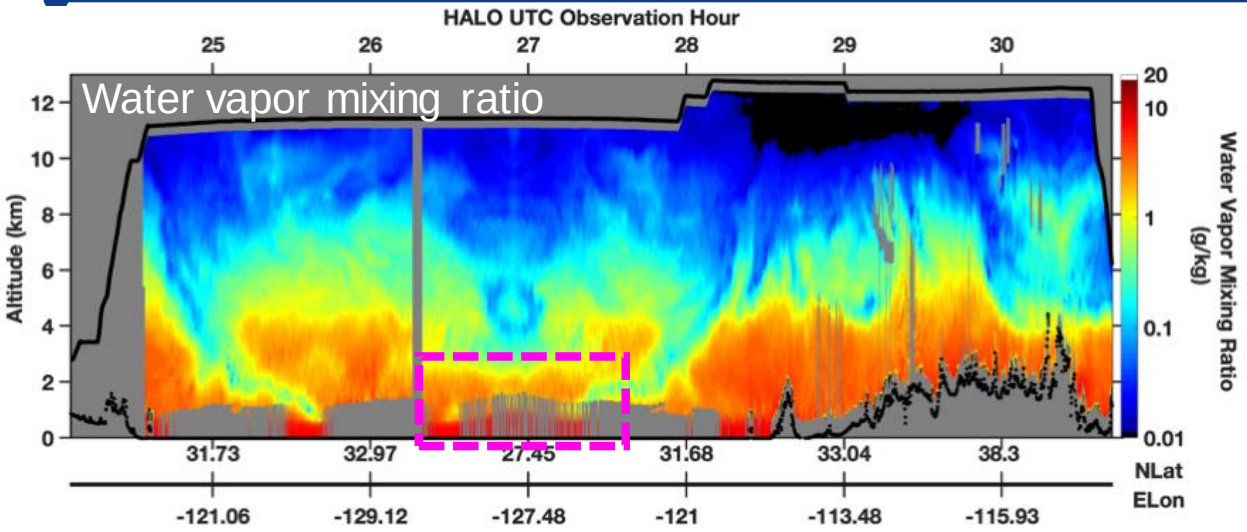
Balancing resolution and precision

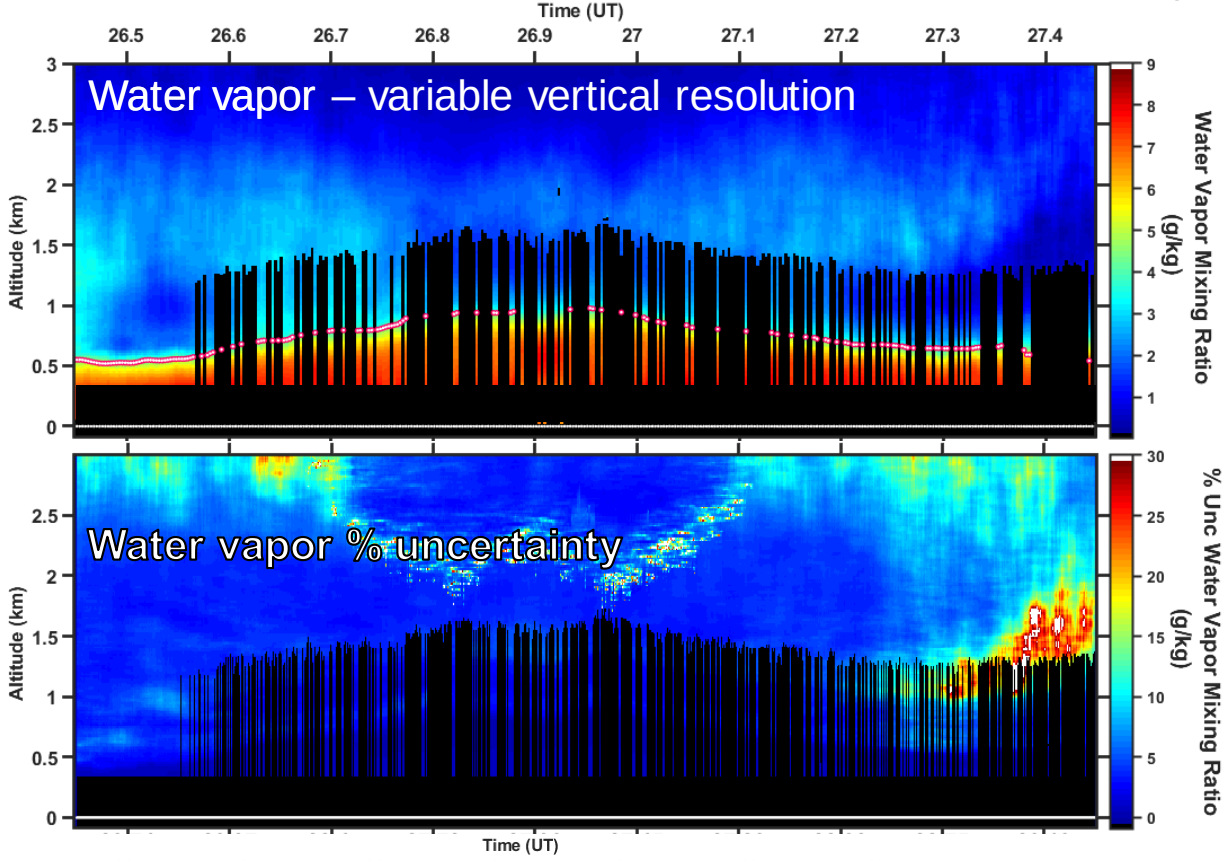


- DIAL precision is proportional to received signal strength and the differential absorption optical depth
- Enhanced aerosol signal allows higher resolution in PBL

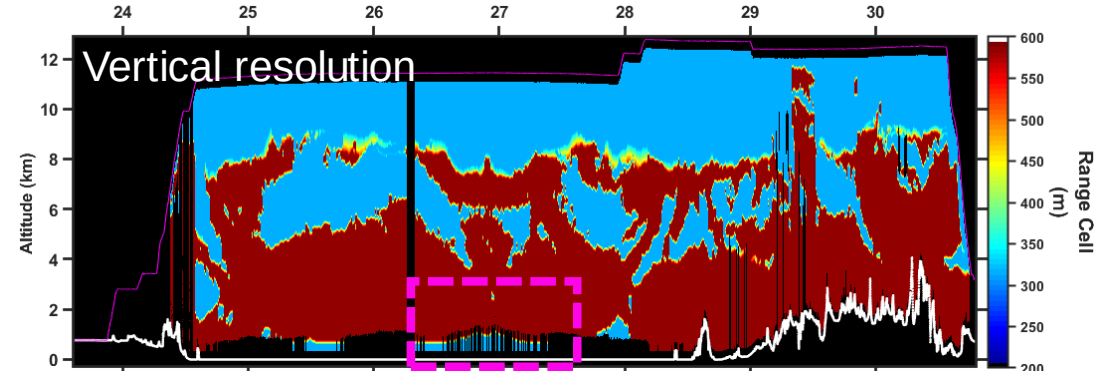


Variable Resolution Humidity Retrievals

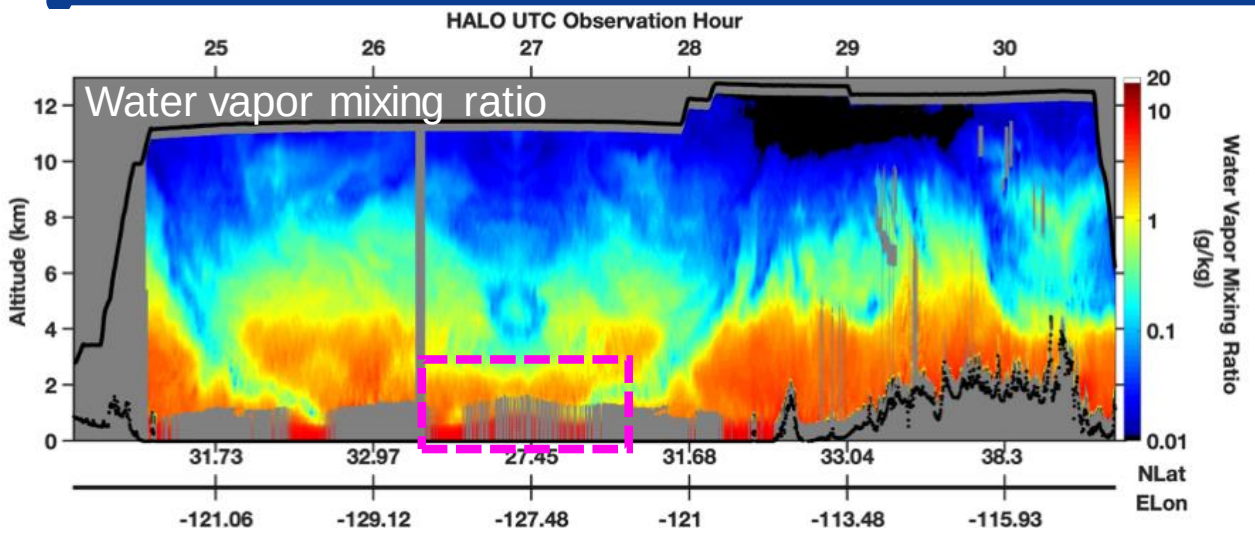


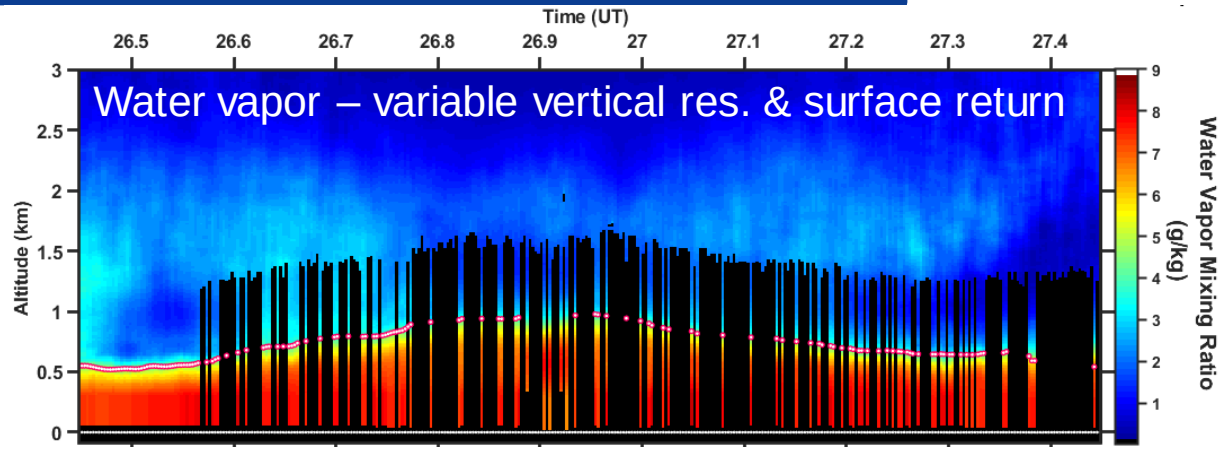


- DIAL precision is proportional to received signal strength and the differential absorption optical depth
- Enhanced aerosol signal allows higher resolution in PBL
- Larger averaging reduces uncertainty in free trop., but increases standoff distance to clouds and surface
- Variable resolution throughout troposphere reduces uncertainty in areas of low SNR while maintaining high resolution in PBL



Extending Measurements to Surface and Cloud Top





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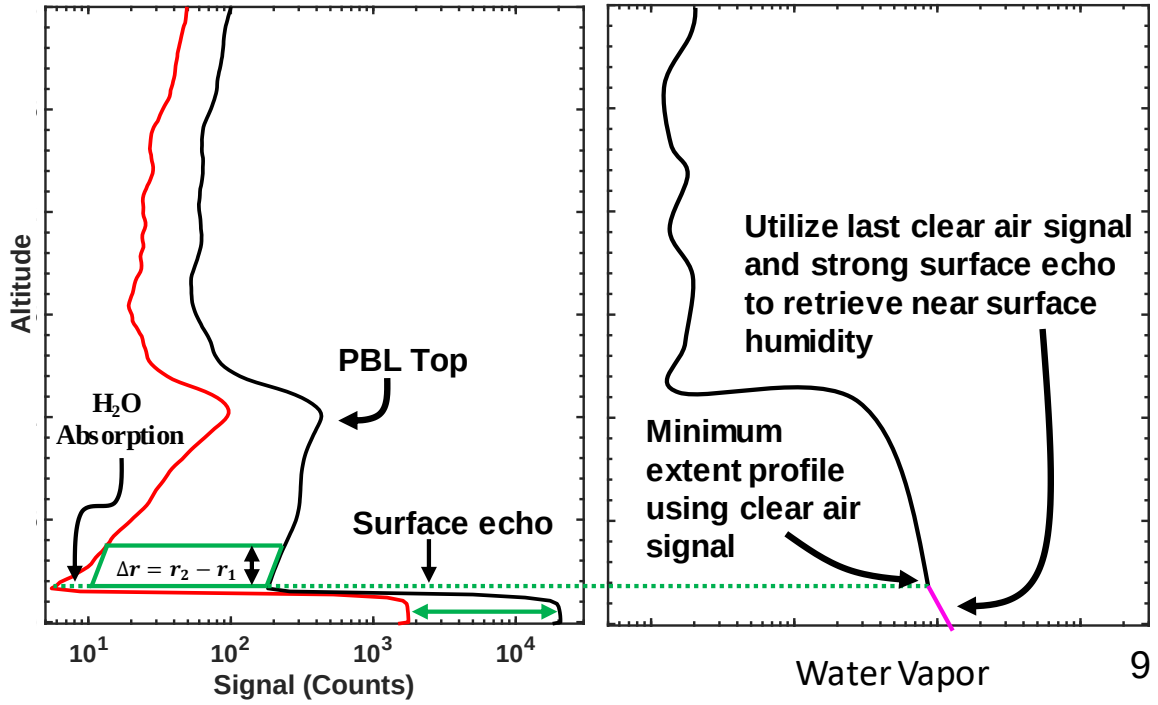
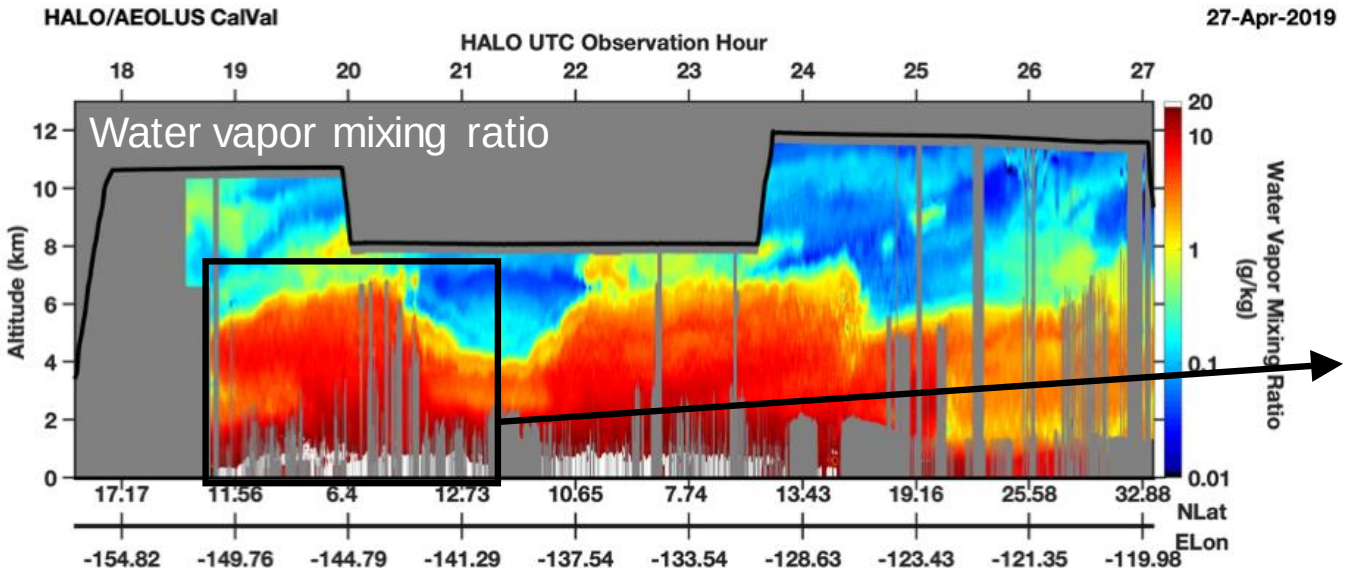
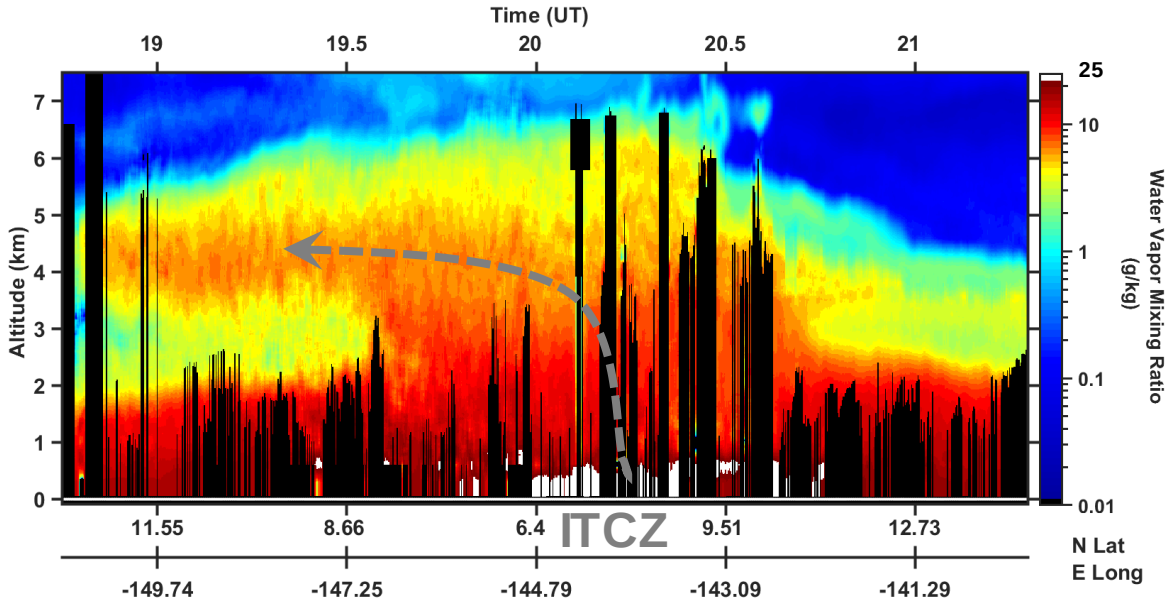
- Humidity profiles can be extended to the surface using differential attenuation from the strong surface echo
- Similar approach can be employed to extend measurements to cloud top



Moist tropical PBL and circulations



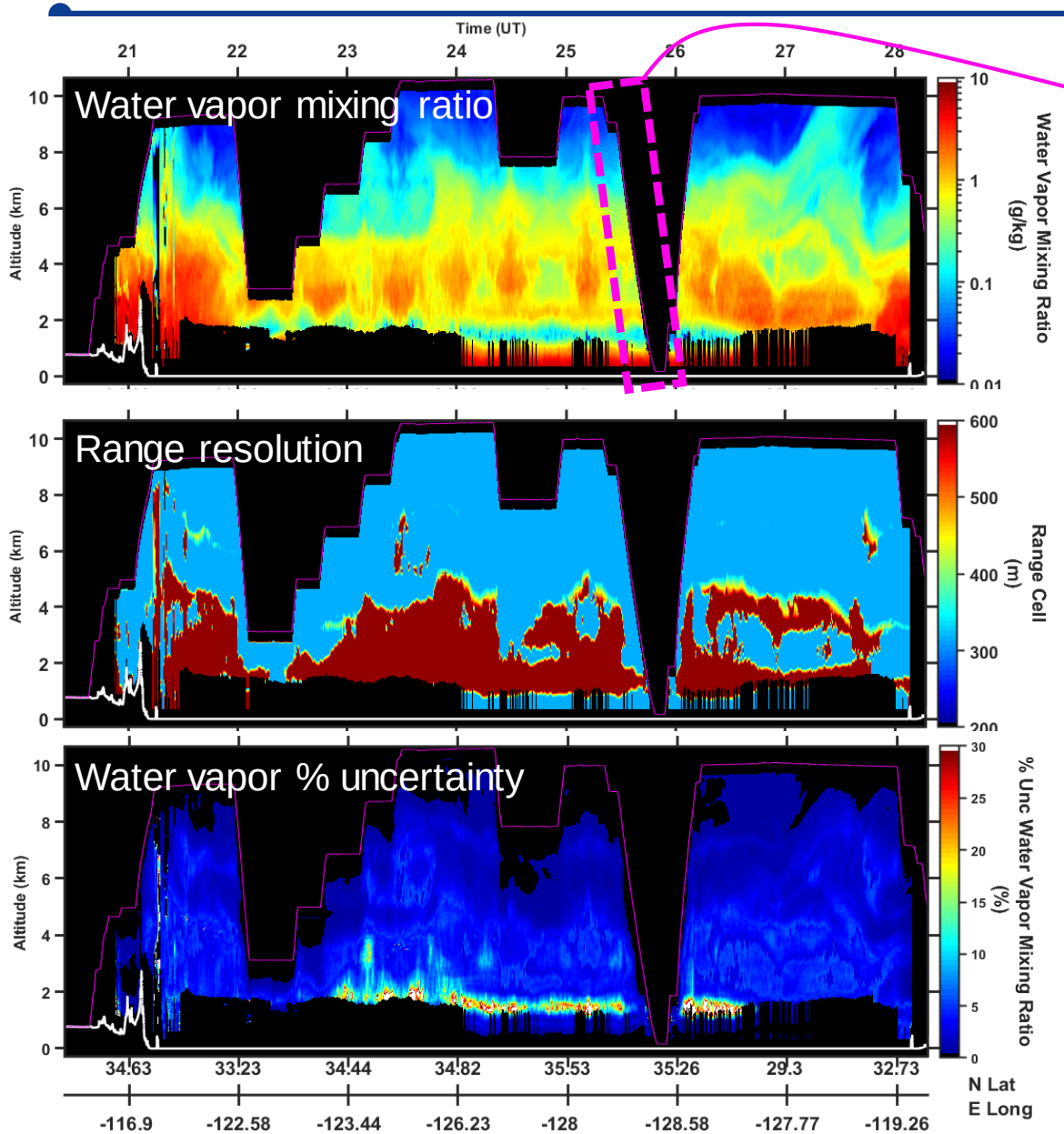


- More water vapor in the tropics causes more online signal attenuation. Loss of SNR is mitigated by tuning the online frequency.

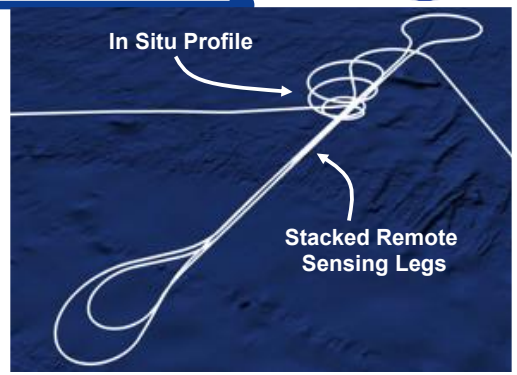
Observing processes across scales that are coupled to the PBL

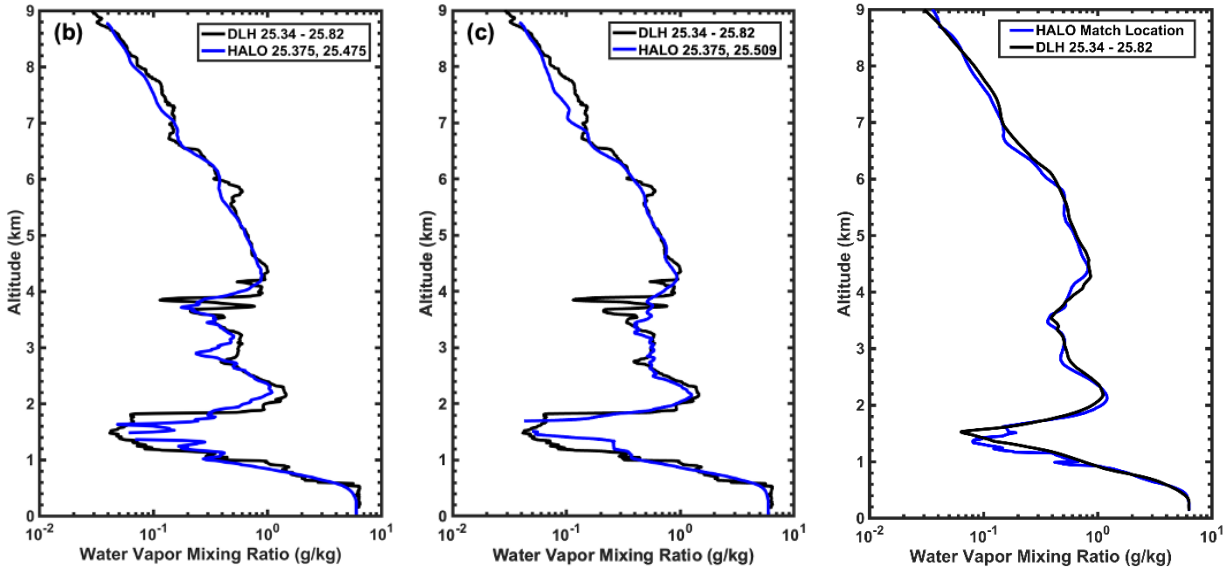
- Very moist ITCZ PBL
- Moisture plume lofted 4 km and advected northward, Hadley cell circulation
- Higher cloud top heights in ITCZ

HALO validation and variable resolution



Validation against diode laser hygrometer (DLH)





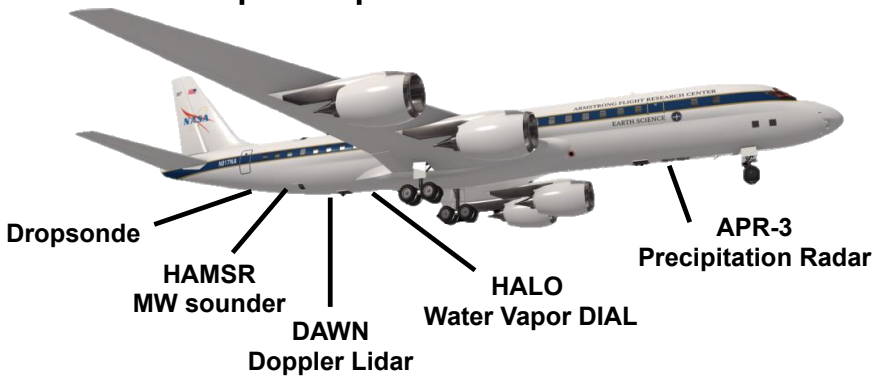
Native DLH resolution of ~5 m. High frequency variations near 4km in DLH are spatial variability within spiral volume

DLH smoothed to 315 m vertical resolution. HALO data matched to closest GPS location to DLH.

Ongoing and Future Activities

Suborbital

- Activities ongoing to increase laser power and frequency tunability to improve performance in tropics
- Suborbital campaigns provide a unique opportunity to demonstrate technologies, advance algorithms, and evaluate measurement synergies
- Joint observations with Differential Absorption Radar and Infrared Sounder have the potential to significantly increase information content and enable new PBL science
- CPEX-AW is a near term opportunity to evaluate PBL synergies using DIAL, Doppler lidar, microwave sounder, and cloud/precipitation radar



Convective Process Experiment
NASA CPEX-AW
Aerosols - Winds -

PBL Optimized Space-Based DIAL