

High Altitude Lidar Observatory (HALO)

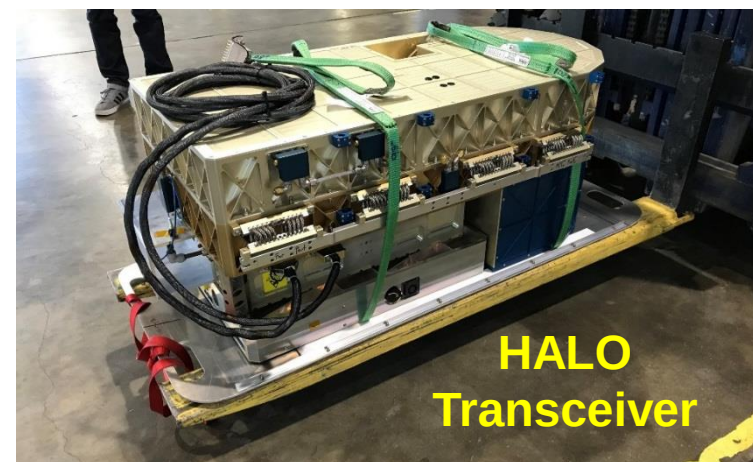
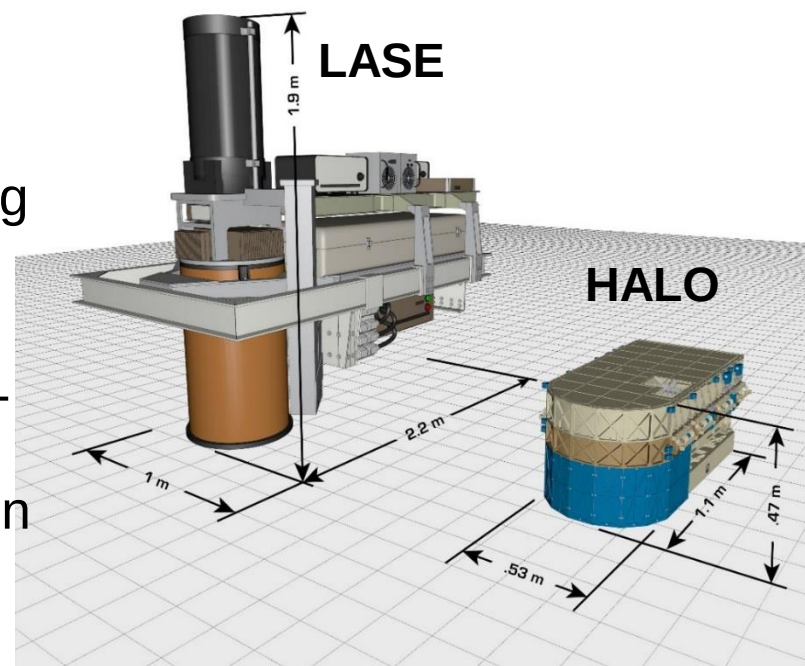
Preliminary Results from the HALO Water Vapor DIAL Test Flights During the ADM Cal/Val Field Campaign

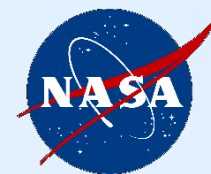
**Amin Nehrir
&
HSRL/DIAL Team**

NASA Langley Research Center, Hampton, Virginia, USA

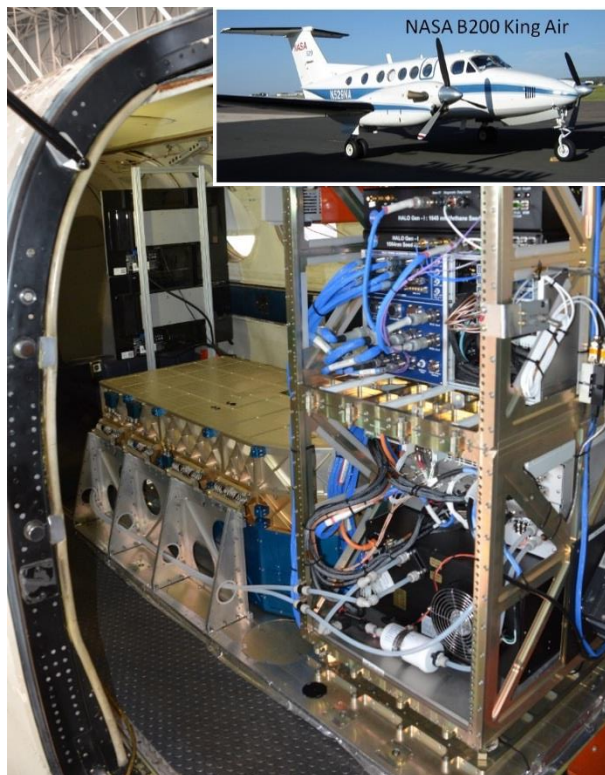
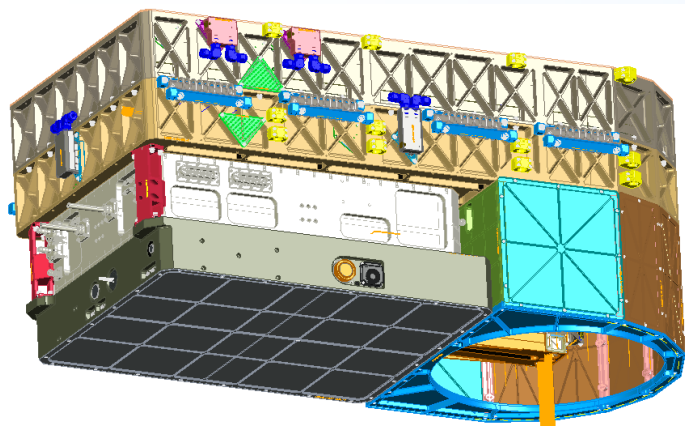
Advanced Airborne Demonstrator

- 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
- Transceiver capable of rapid reconfiguration to support H_2O /HSRL or CH_4 /HSRL or H_2O / CH_4
- 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 algorithms required for future DIAL missions





HALO Attributes and Development Cycle



- **H₂O DIAL Capabilities: 4 λ DIAL**
 - Accuracy: <5%
 - Precision: <10%*
 - Vertical resolution: 100-330 m*
 - Horizontal resolution: 1-12 km*
 - Sensitivity: .001-30 g/kg
 - TPWV: $\sigma \sim 1\%$, bias $\sim 1\%$, 200 m res.
 - **HSRL Capabilities: 1- α , 2- β , 2- δ**
 - HSRL at 532 nm
 - Backscatter 1064 nm
 - Depolarization at both 532, 1064 nm
 - **History**
 - 2015-2018: instrument development
 - May 2018: first test CH₄ flight on UC-12
 - April 2019: first test H₂O flight on DC-8
 - 2018: 1 field campaign (CH₄)
 - 2019: 2 field campaigns (H₂O & CH₄)
- *Vertical and horizontal averaging can be traded for precision and adapted for different applications. Nominal resolution is 315 m and 6 km.

Important System Characteristics

■ Calibration

- **Self calibrating** water vapor profiles using the DIAL technique
- **Large H_2O dynamic range** enabled by multi-wavelength transmitter
- **Internal calibration** of electro-optic gains between parallel and perpendicular polarization HSRL channels
- **Internal calibration** of “molecular” to parallel backscatter channel at 532 nm
 - 532 nm aerosol backscatter, depolarization, and extinction retrieved **without external calibration** to atmospheric target
- 1064 nm backscatter calibrated using information from 532 nm aerosol backscatter

■ **Rapidly reconfigurable** to support different science objectives from different airborne platforms

- H_2O +HSRL or CH_4 +HSRL or H_2O + CH_4
- Compatible to fly on most NASA Airborne Science aircraft including ER-2

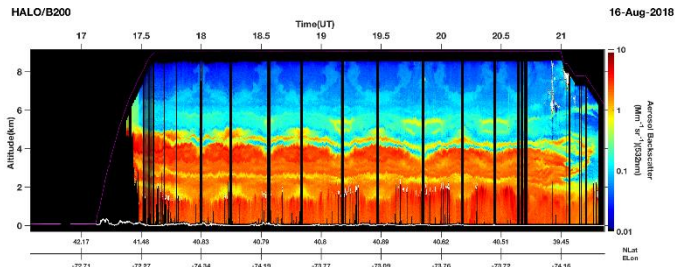
■ **1.25 meter** vertical resolution on all HSRL channels for cloud studies and future ocean profiling

Aerosol Products

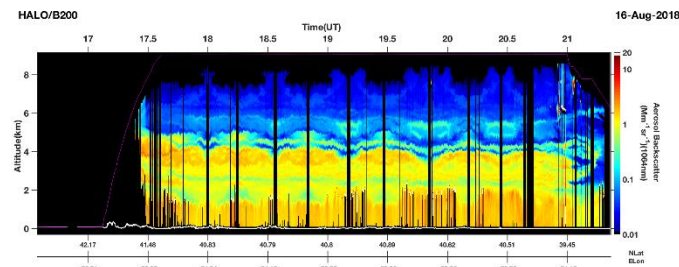


Aerosol Extensive Parameters

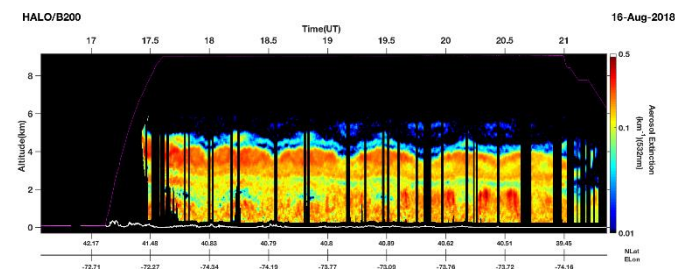
532 nm
Backscatter



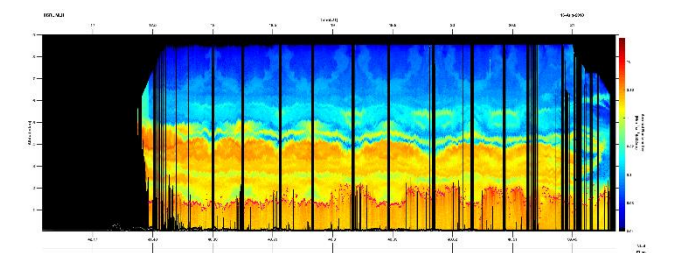
1064 nm
Backscatter



532 nm
Extinction

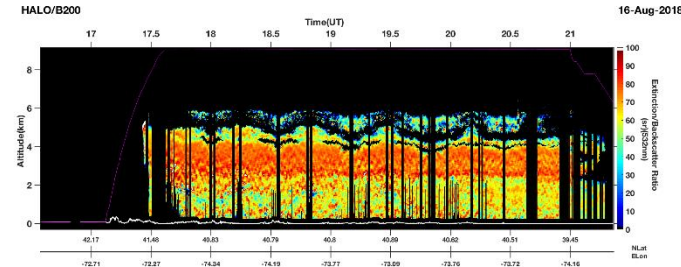


Mixed Layer
Heights

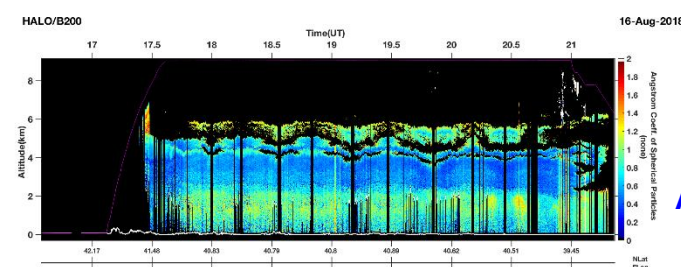


Aerosol Intensive Parameters

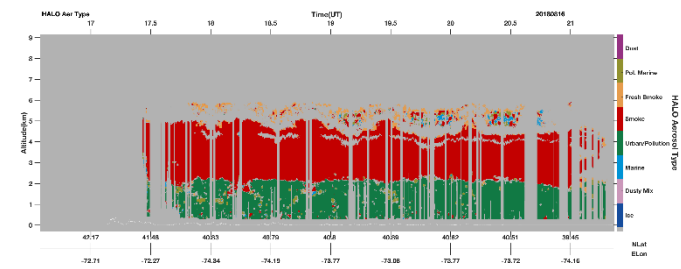
532 nm
Lidar Ratio



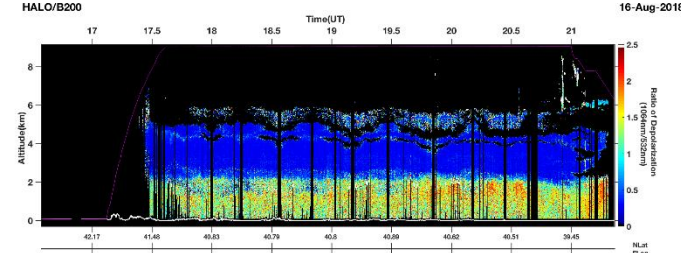
1064/532 nm
Backscatter
Angstrom Coeff.
(particle size)



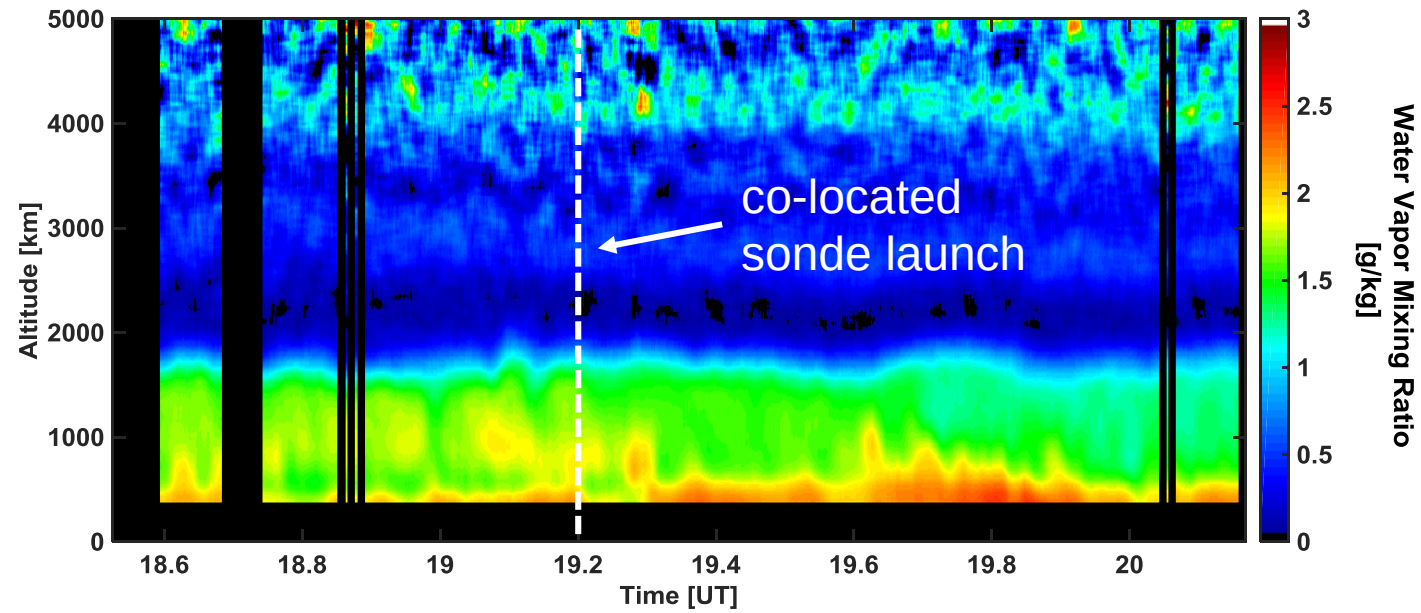
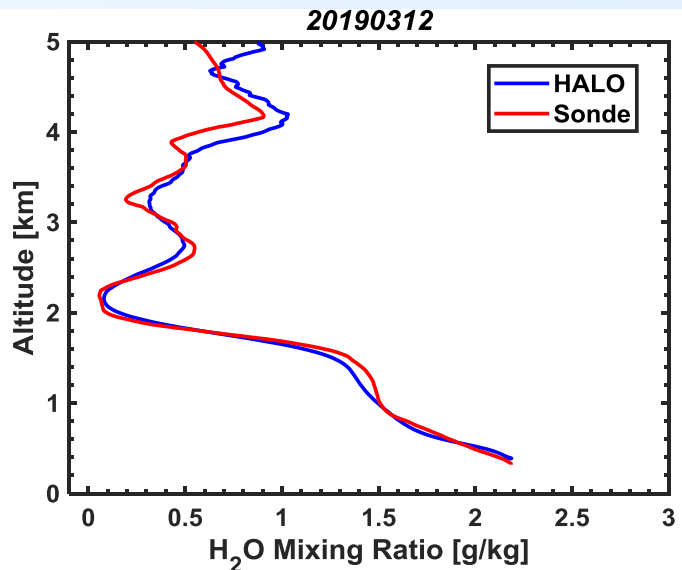
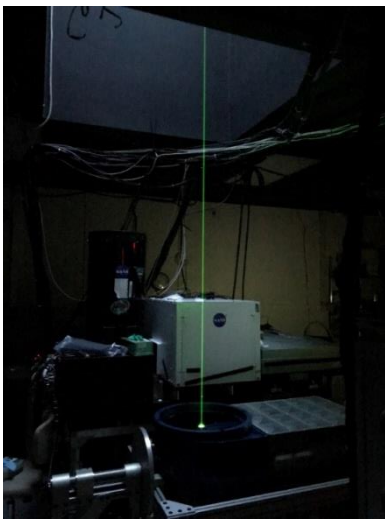
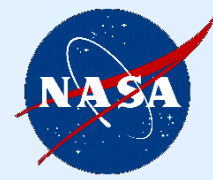
Aerosol Typing



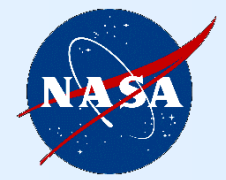
1064/532 nm
Depolarization
Ratio



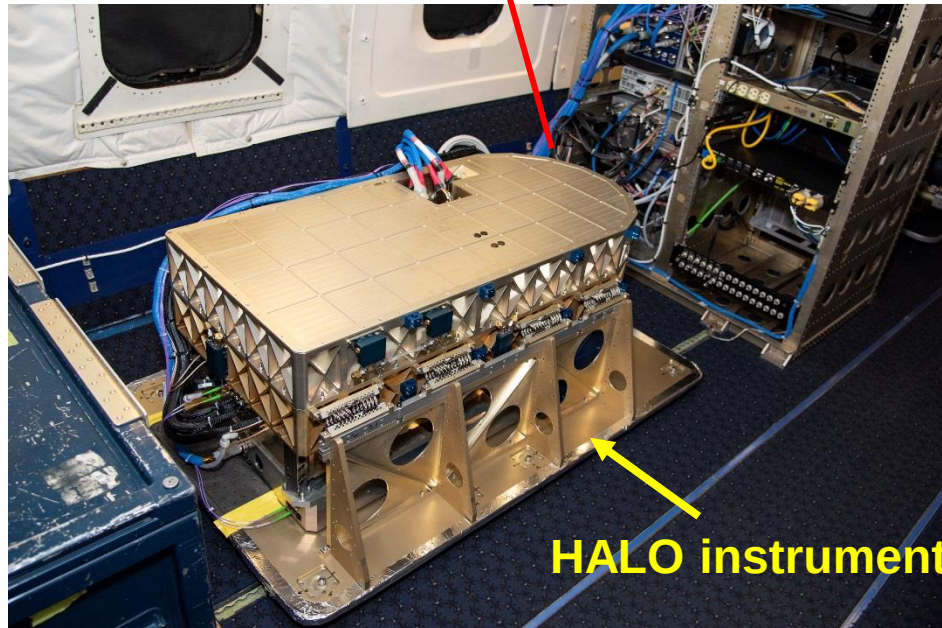
Ground Testing at LaRC March 2019



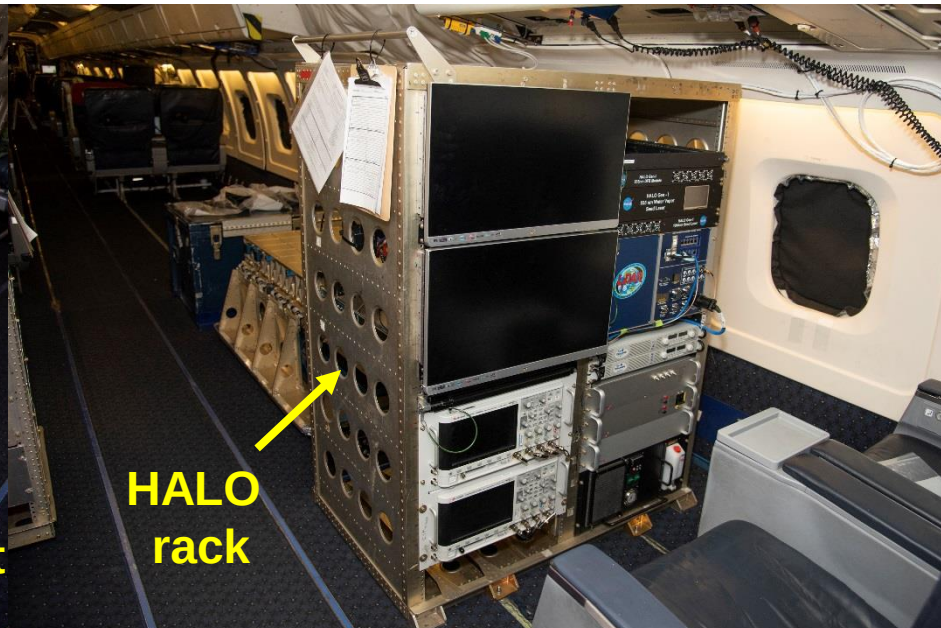
HALO Water Vapor configuration on NASA DC8-ADM Aeolus Validation Campaign



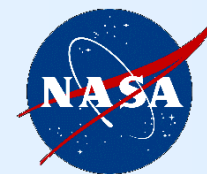
- HALO was installed over the nadir 9 portal on the NASA DC-8 during April 2019
- ADM Aeolus cal/val mission served as maiden test flights for water vapor measurements
- >45 flight hours with varying atmospheric conditions
- Demonstrated capability to tune transmitter to adapt to varying atmospheric conditions
- Demonstrated feasibility of state of the art laser transmitters on NASA airborne platforms



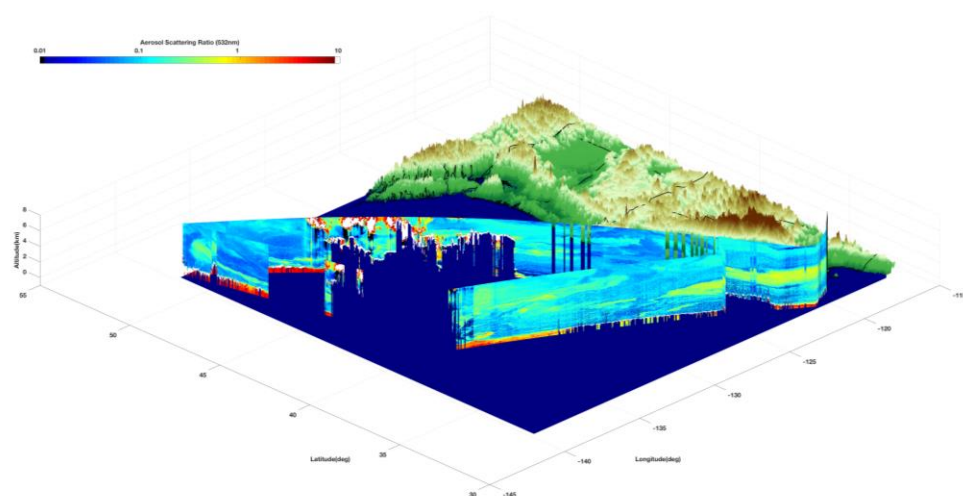
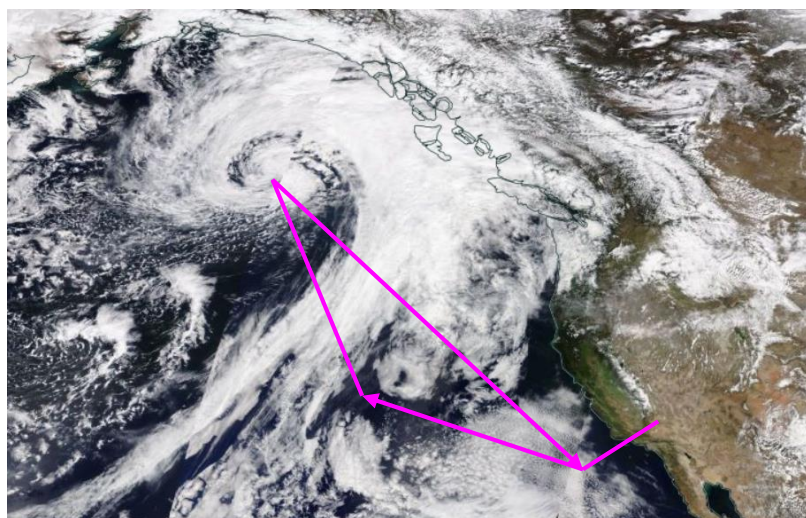
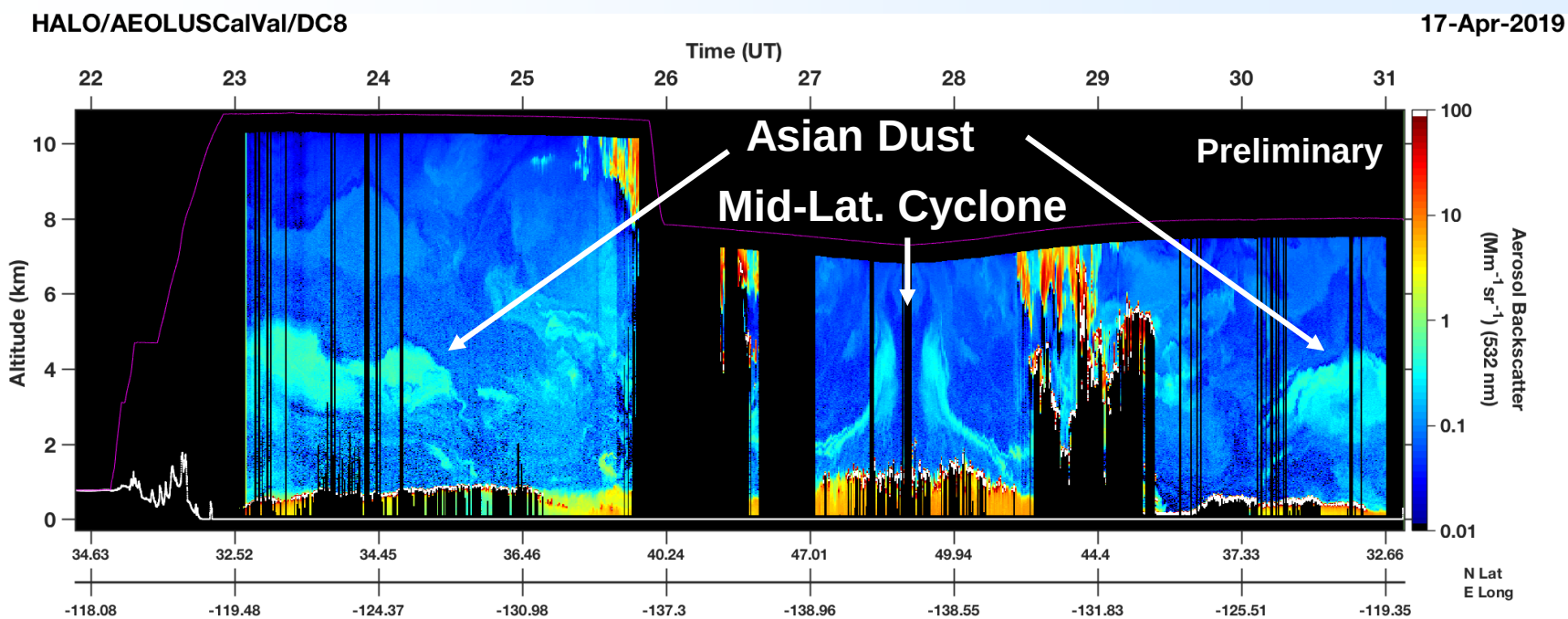
HALO instrument

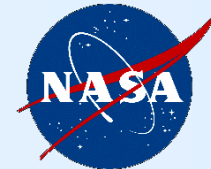


HALO rack

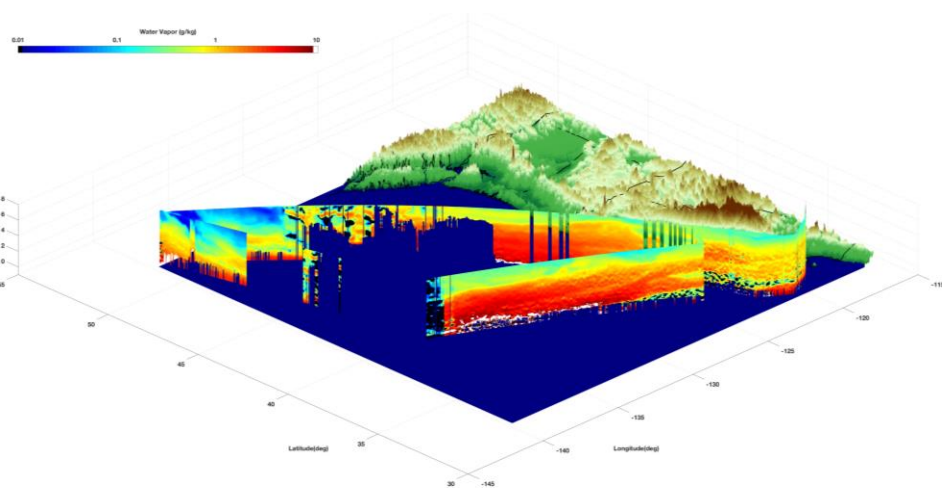
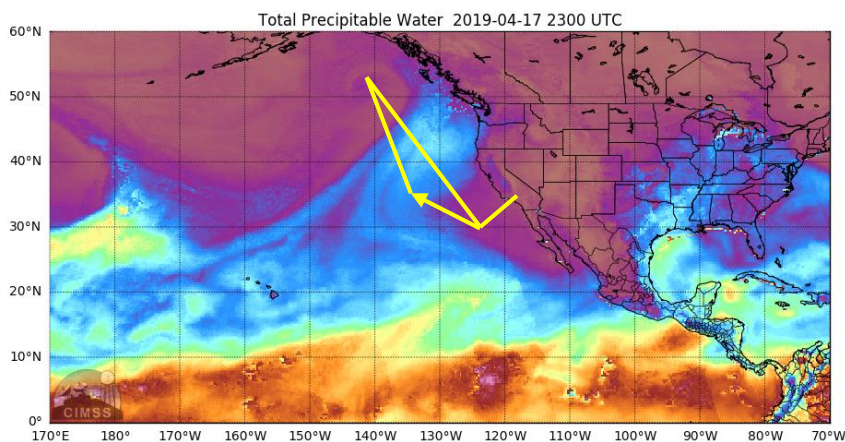
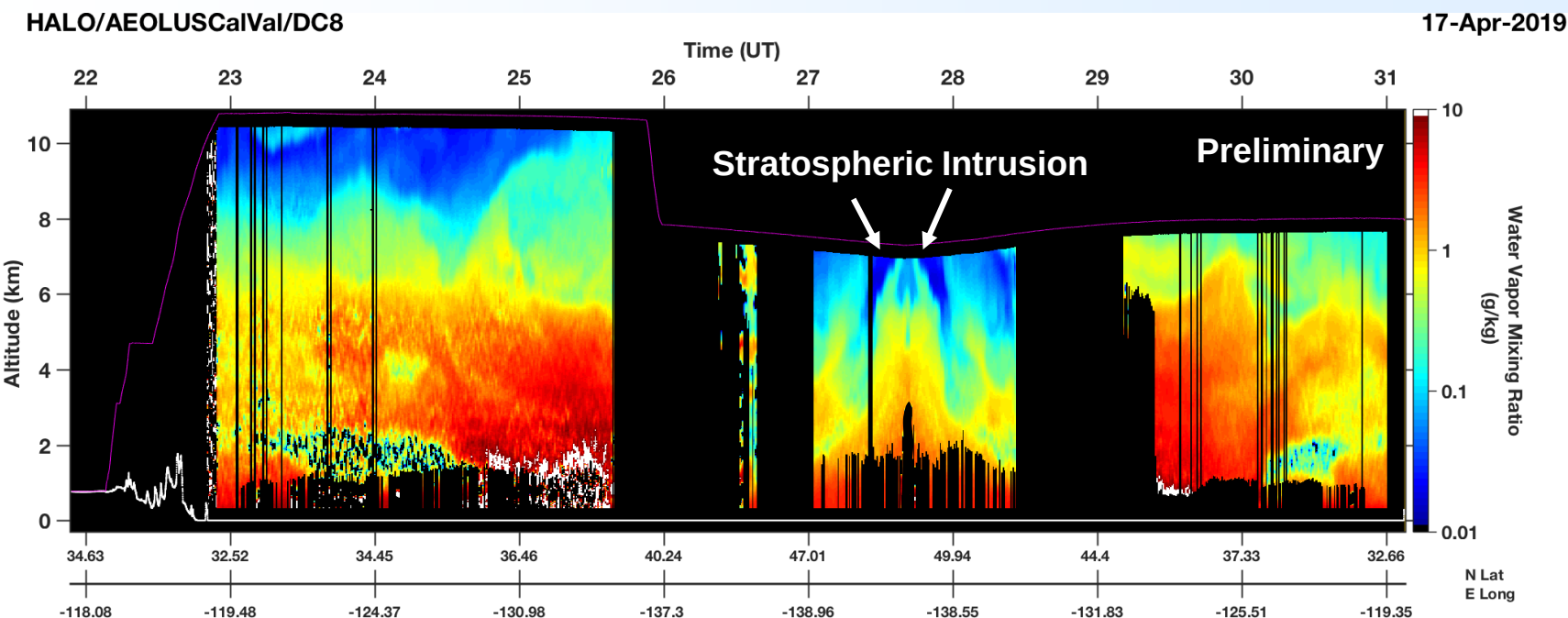


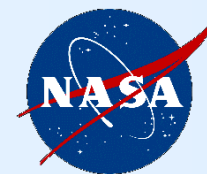
Flight #1, April 17: 532 nm Aerosol Backscatter



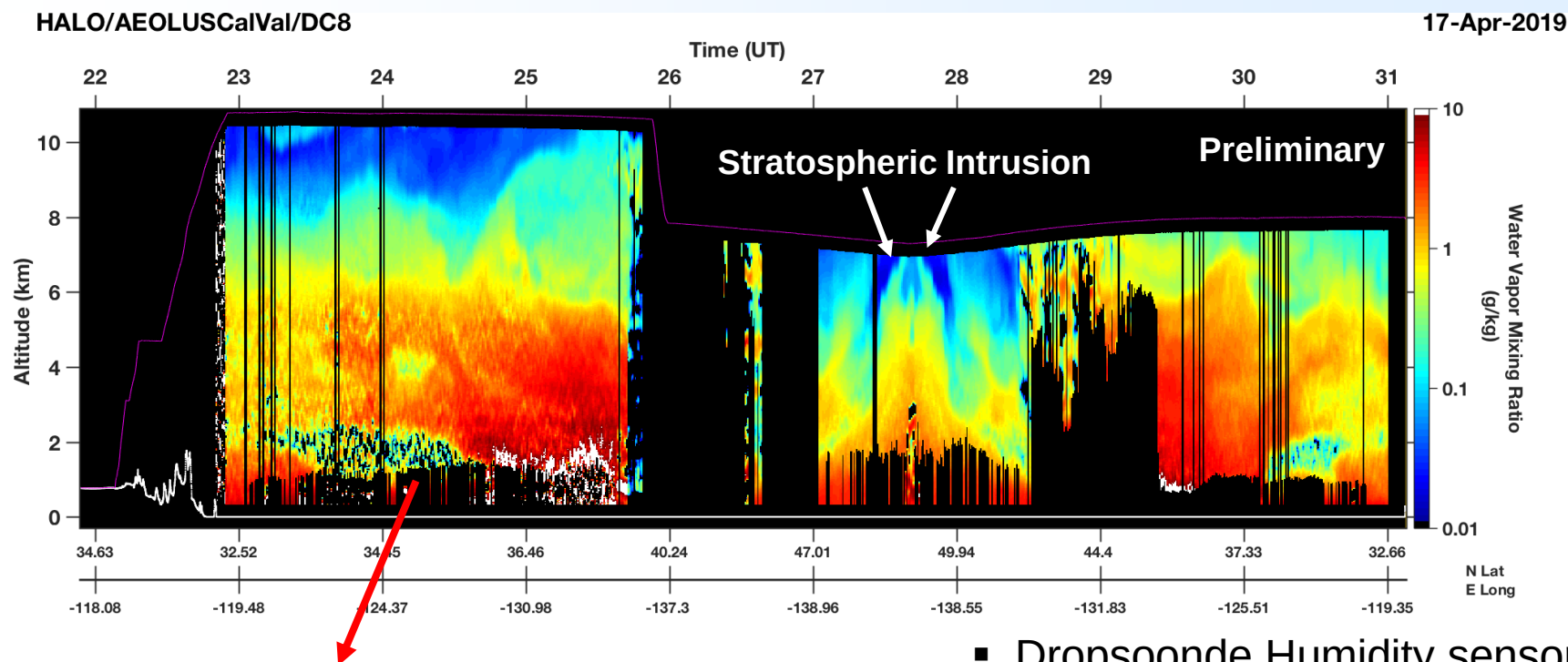


Flight #1, April 17: Water Vapor Mixing Ratio

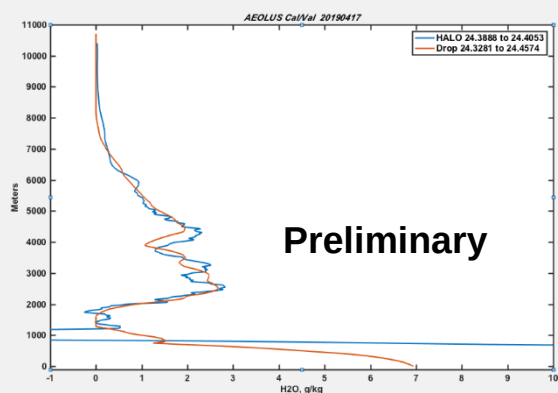




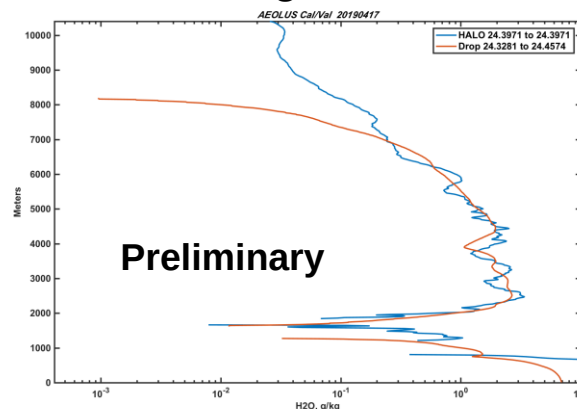
Flight #1, April 17: Dropsonde Comparisons



Linear Scale

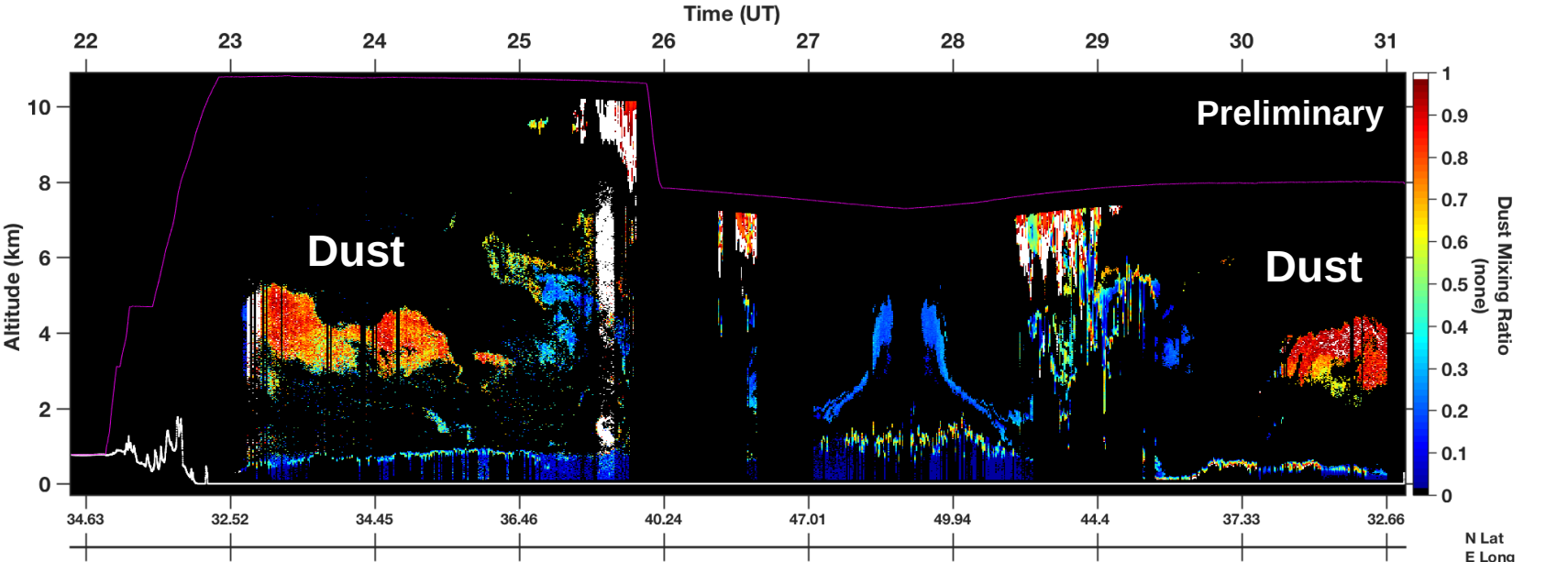
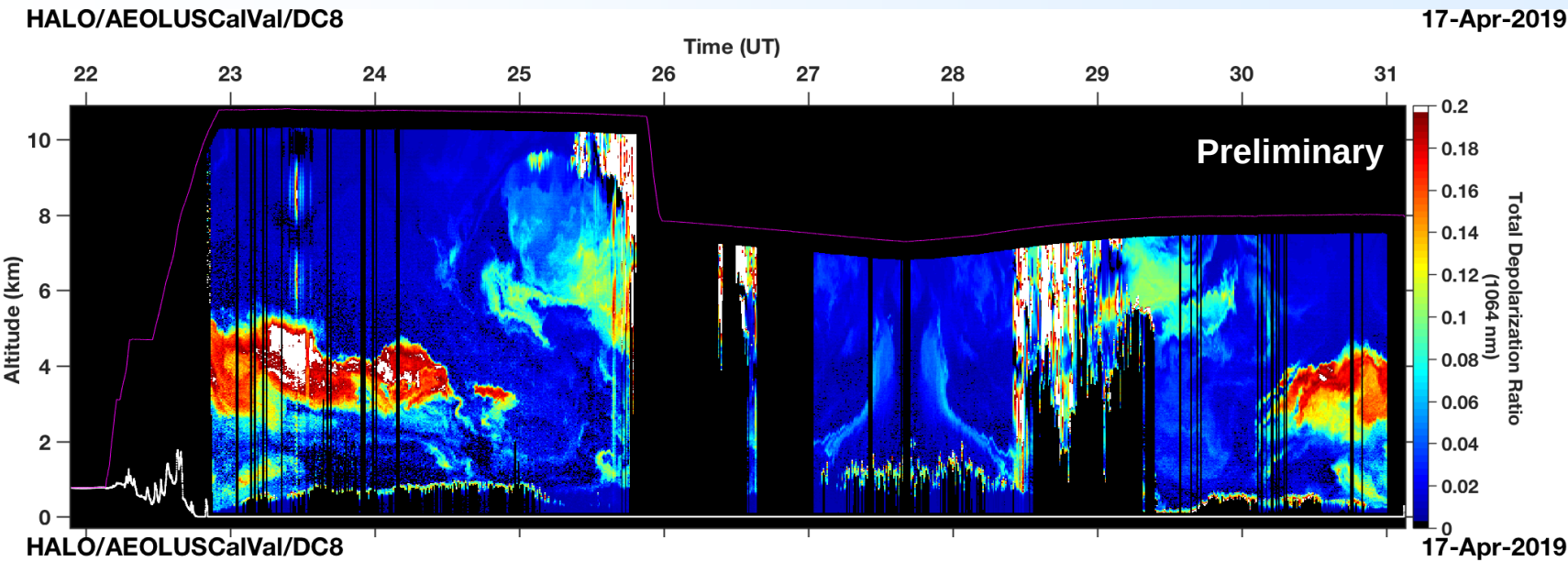


Log Scale



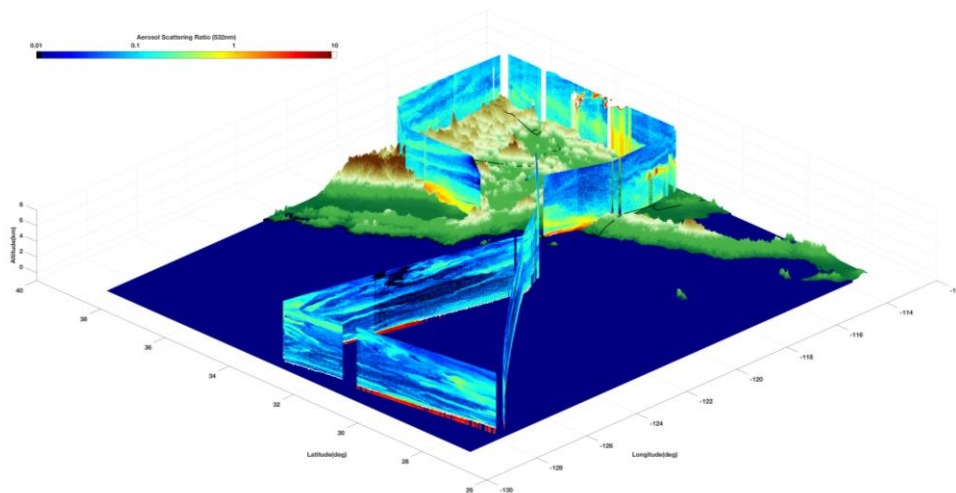
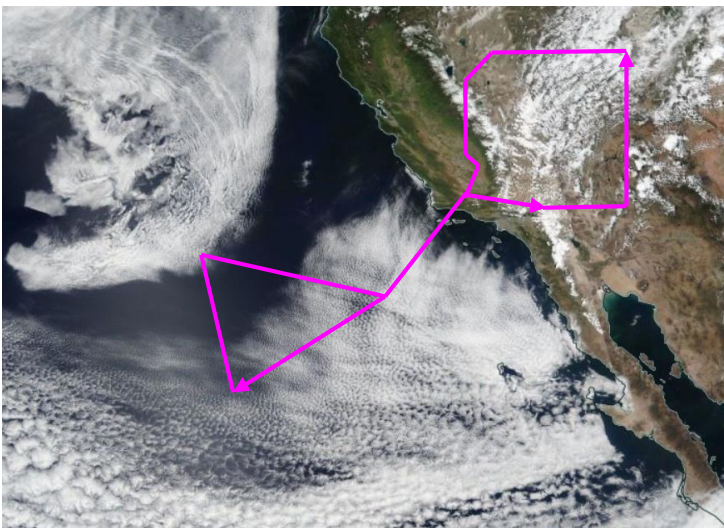
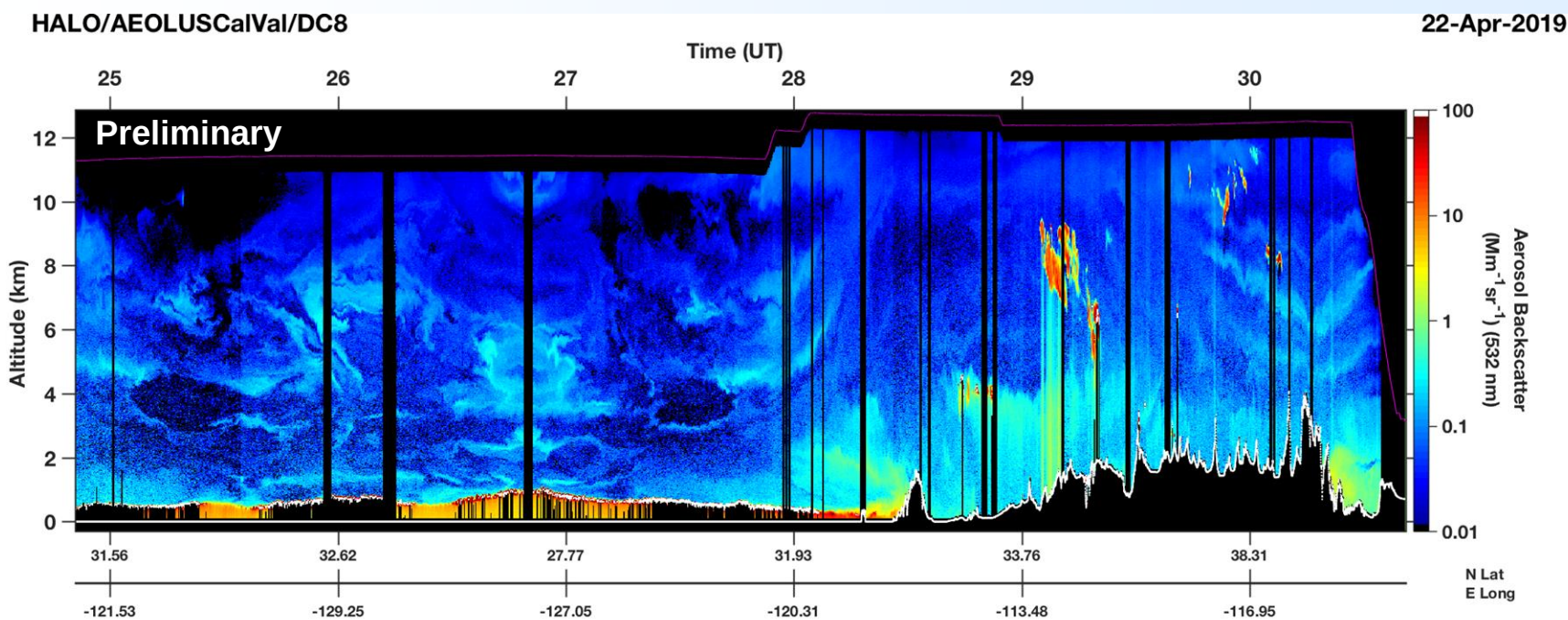
- Dropsonde Humidity sensor showed signs of large bias in the upper and mid trop.
- Humidity sensor also showed signs of damped response at all altitudes resulting in degraded spatial resolution and altitude registration
- Sonde performance under investigation

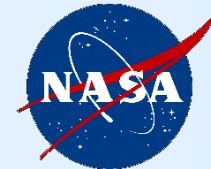
Flight #1, April 17: Aerosol Intensives



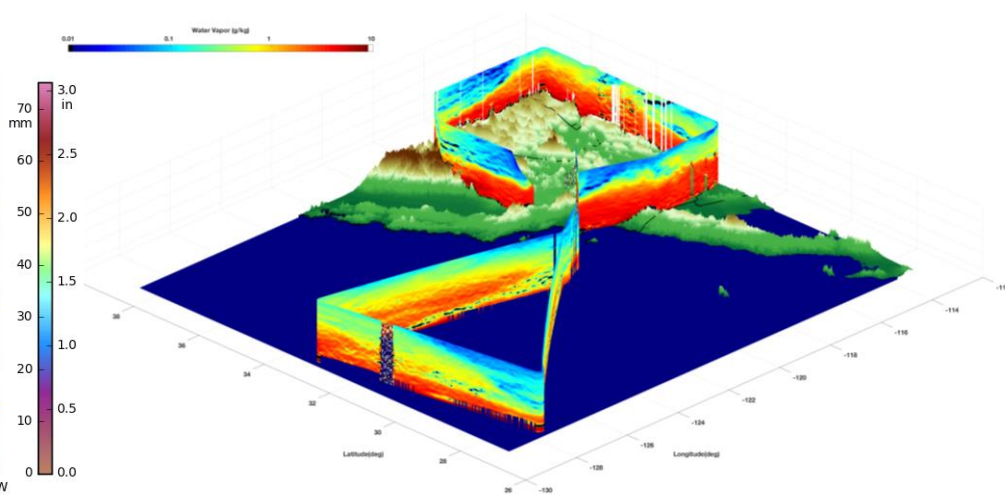
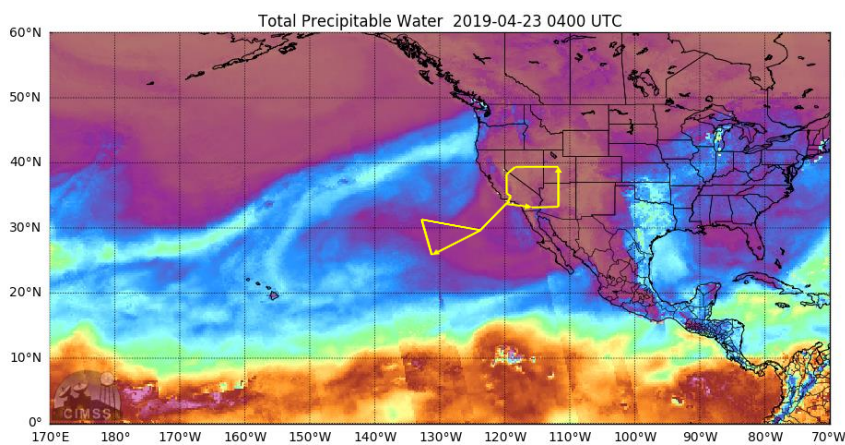
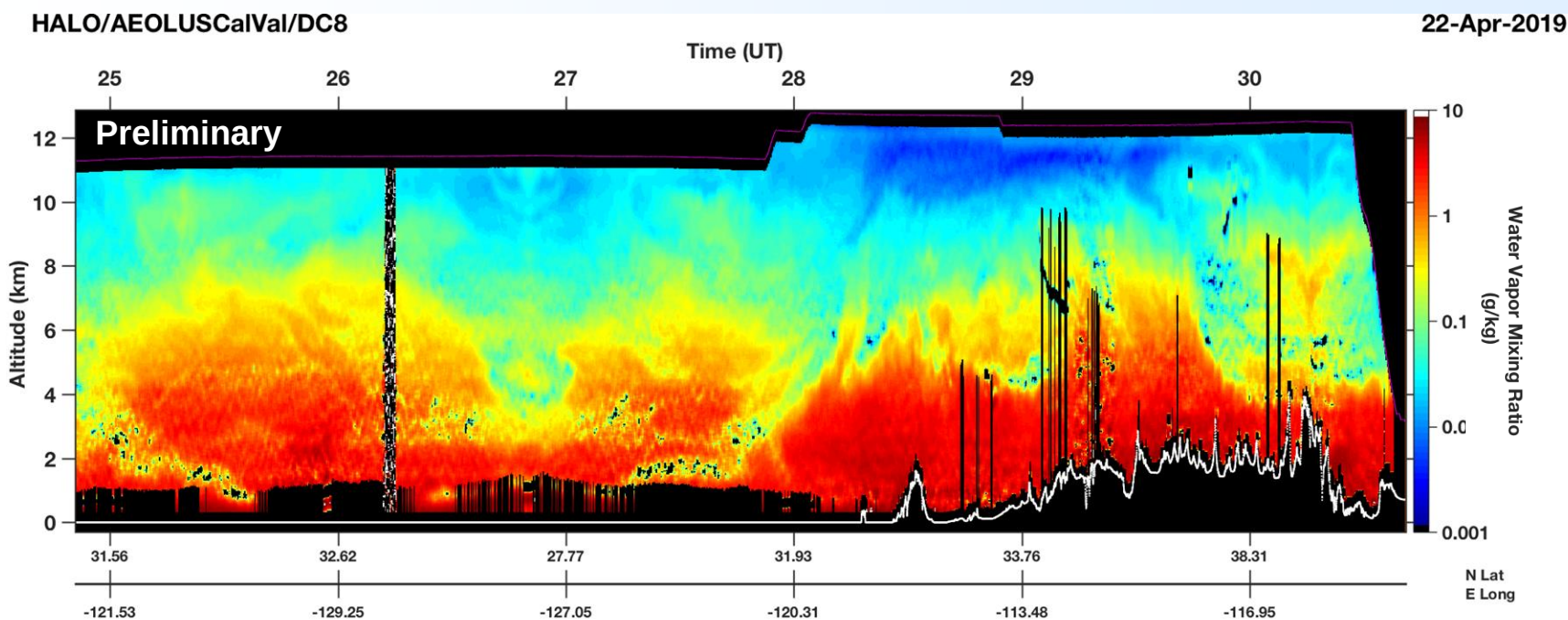


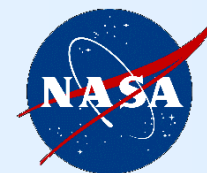
Flight #2, April 22: 532 nm Aerosol Backscatter



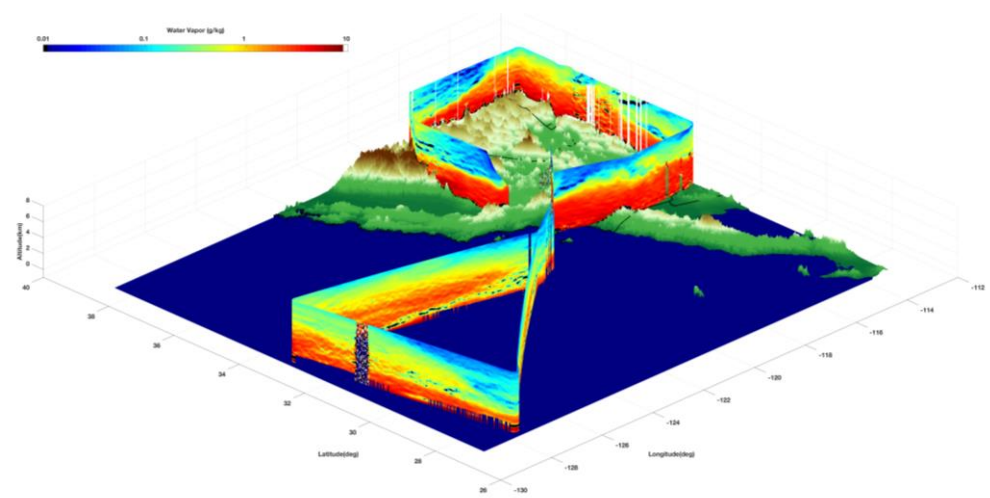
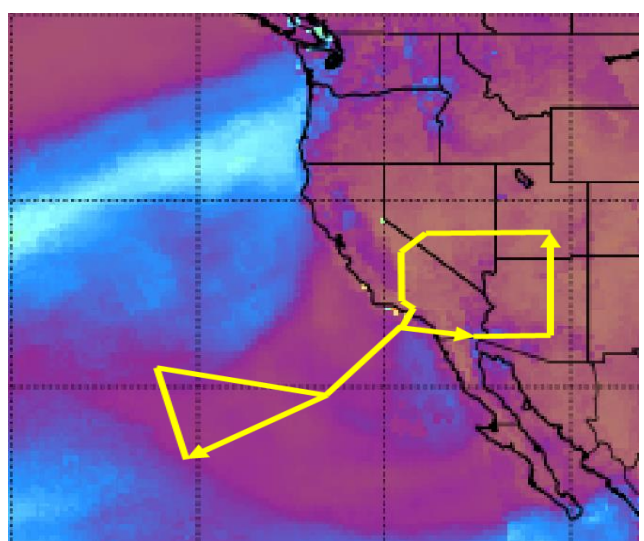
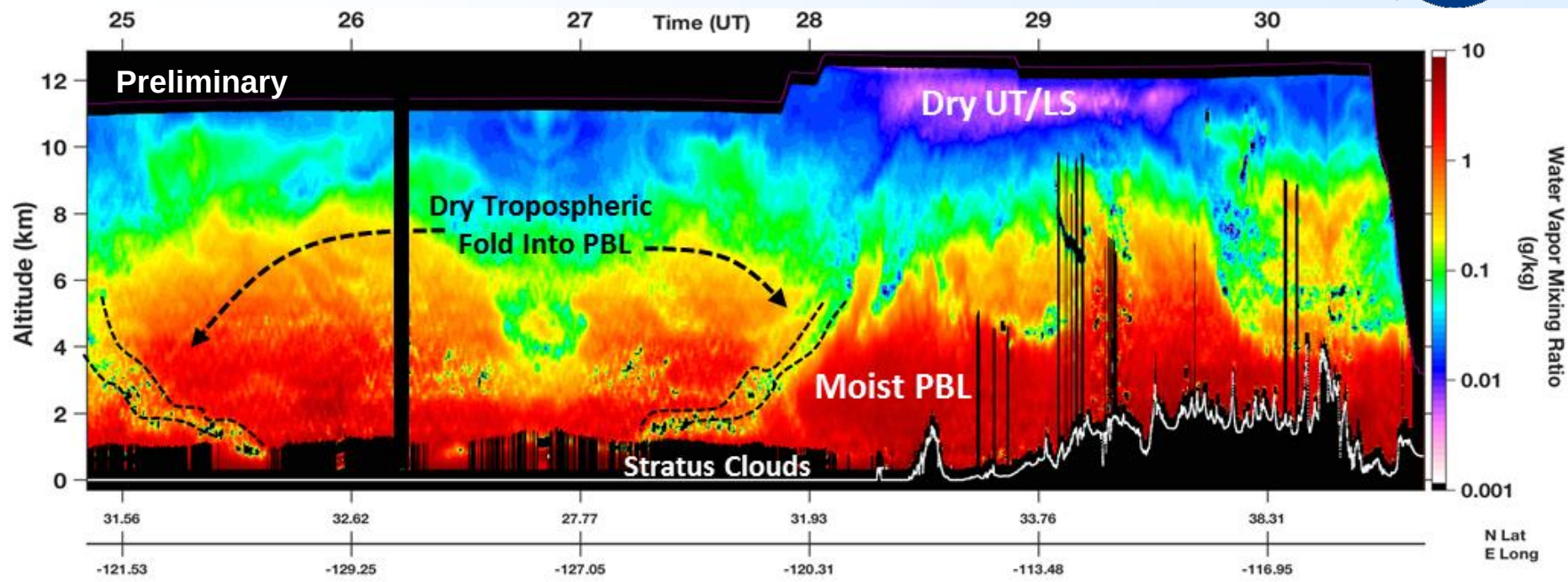


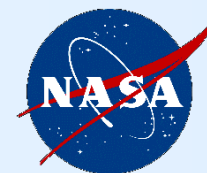
Flight #2, April 22: Water Vapor Mixing Ratios



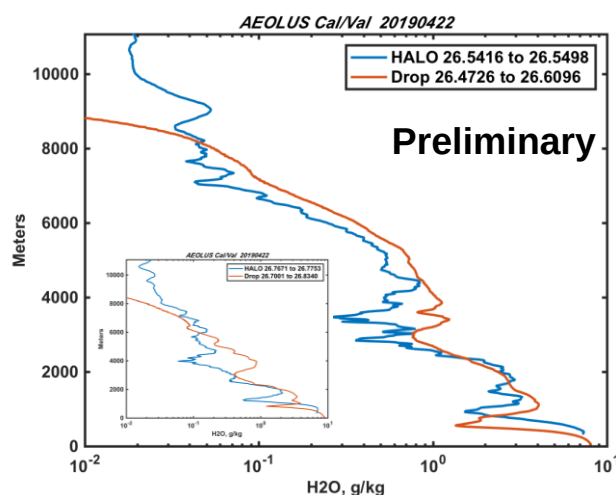
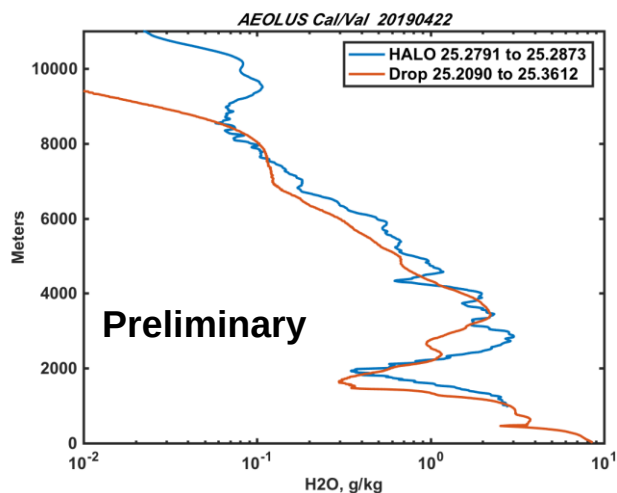
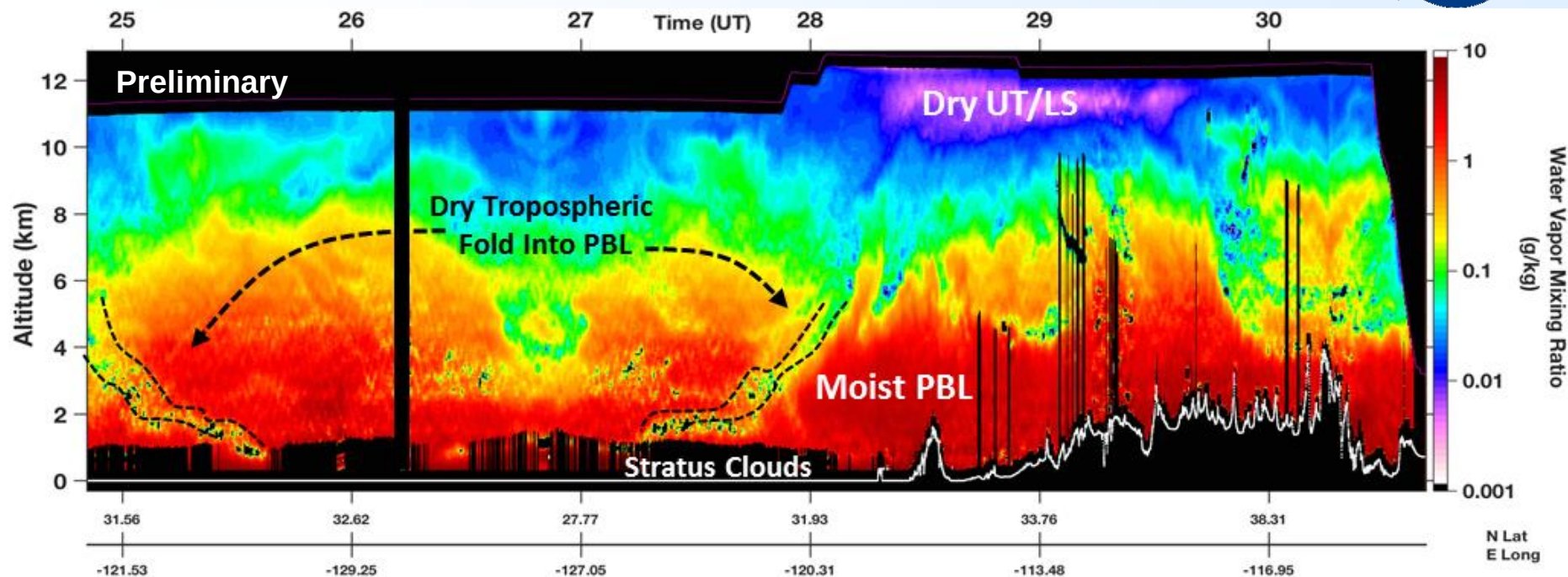


Flight #2, April 22: Mixing Ratio Dynamic Range



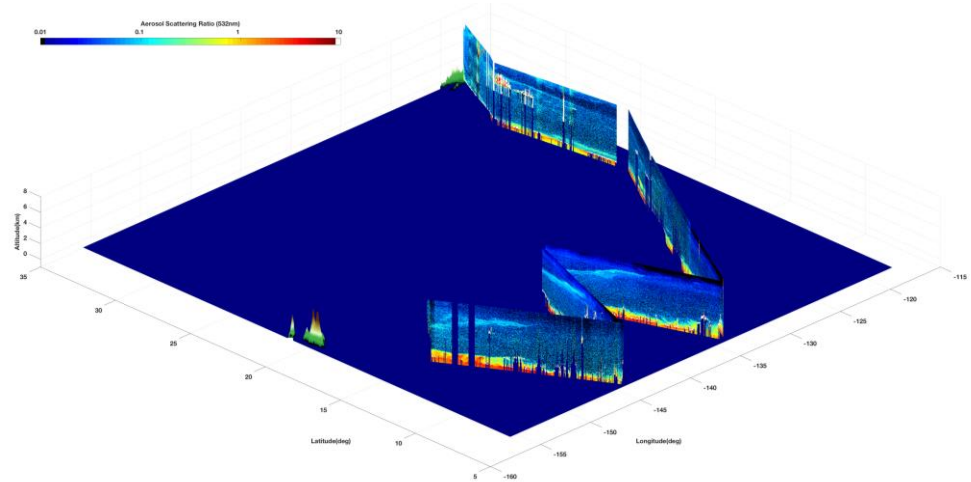
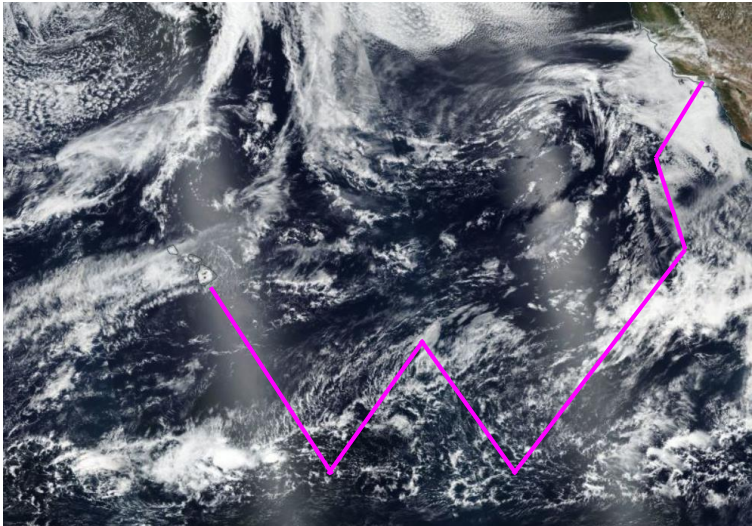
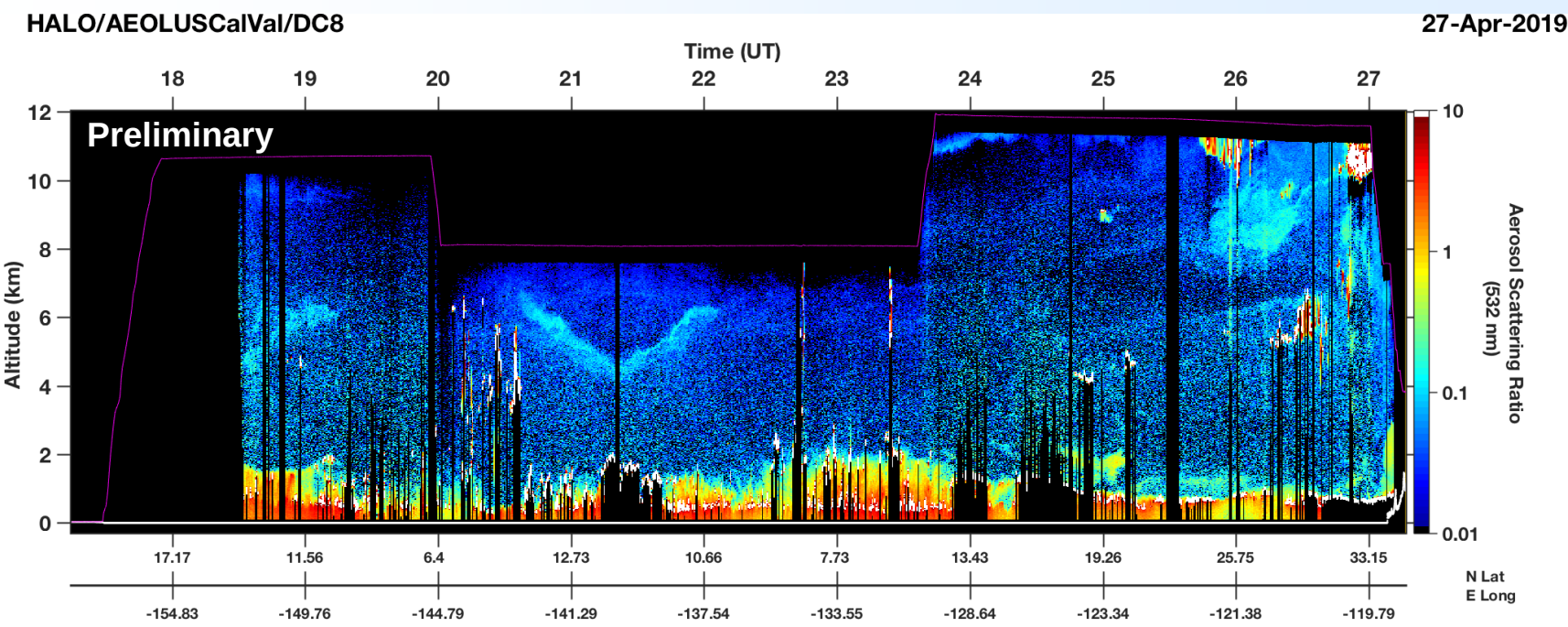


Flight #2, April 22: Dropsonde Comparisons

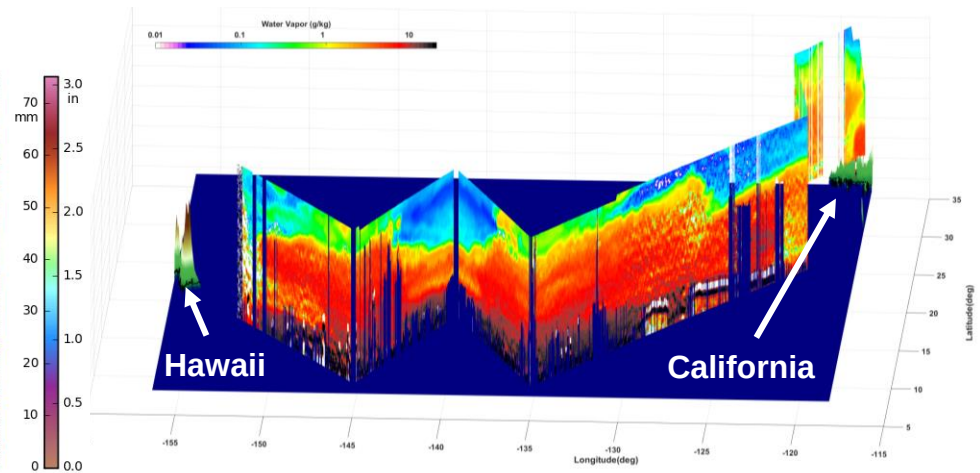
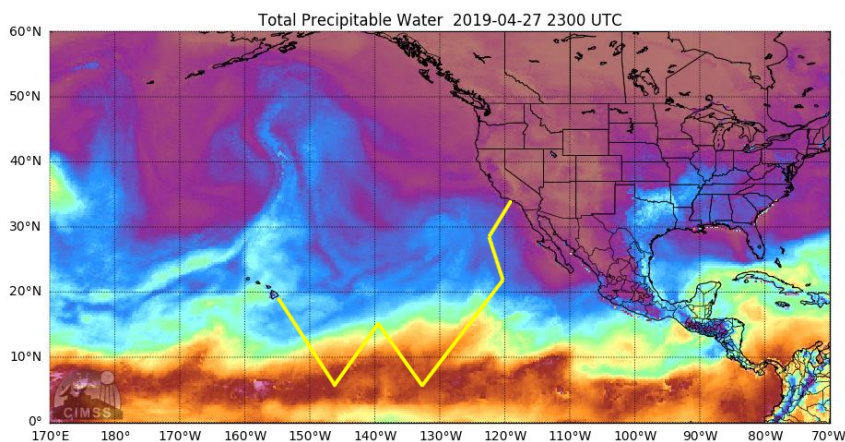
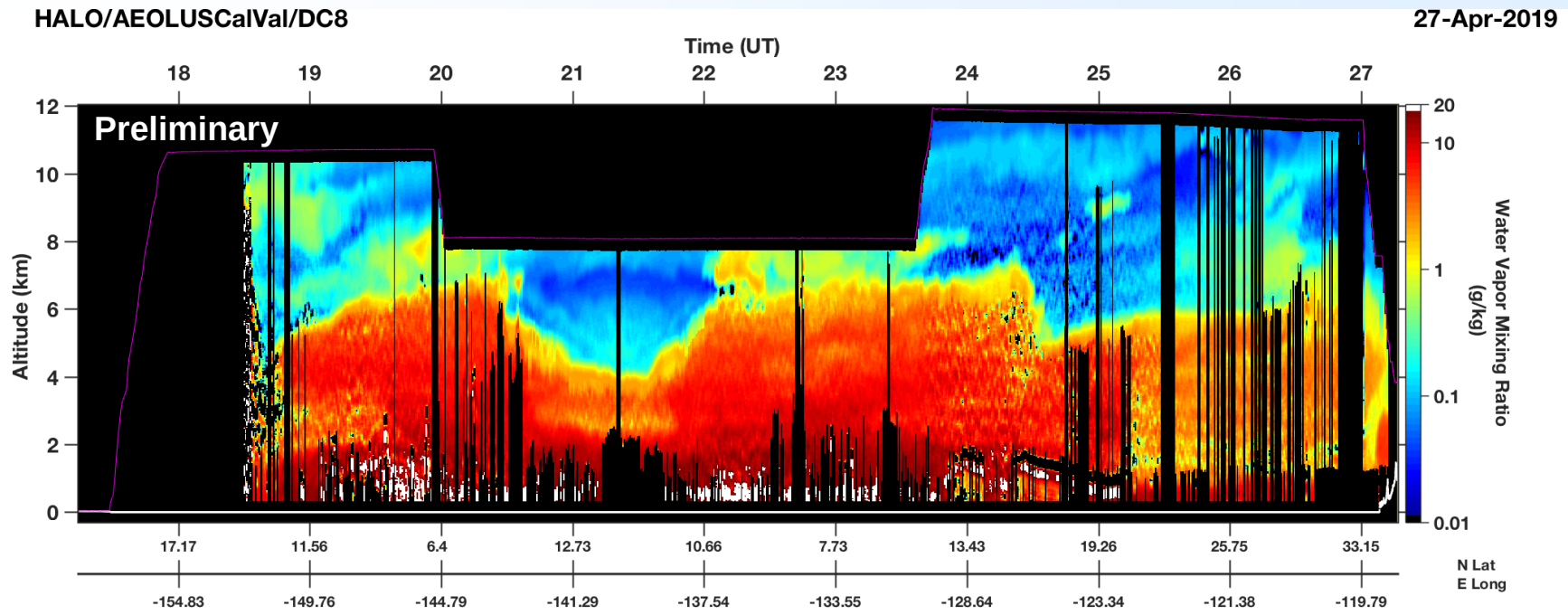
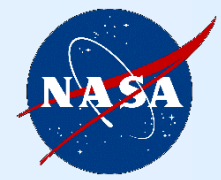


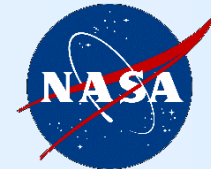
- HALO profiles show good general agreement with despite sonde dry bias and damped response
- This flight demonstrated capability to retrieve water vapor profiles over four orders of magnitude in a single profile

Flight #4, April 27: 532 nm Aerosol Backscatter

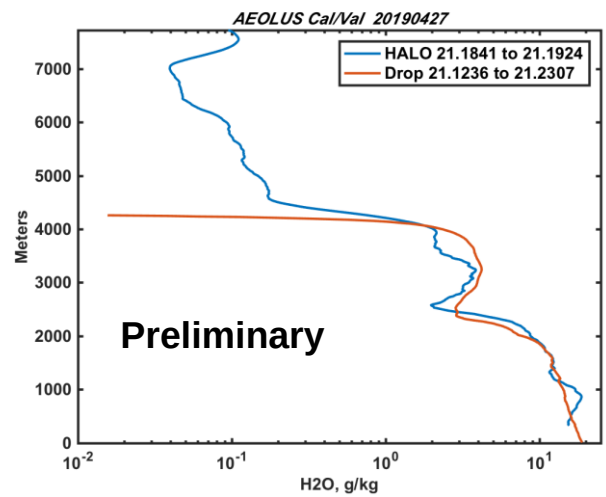
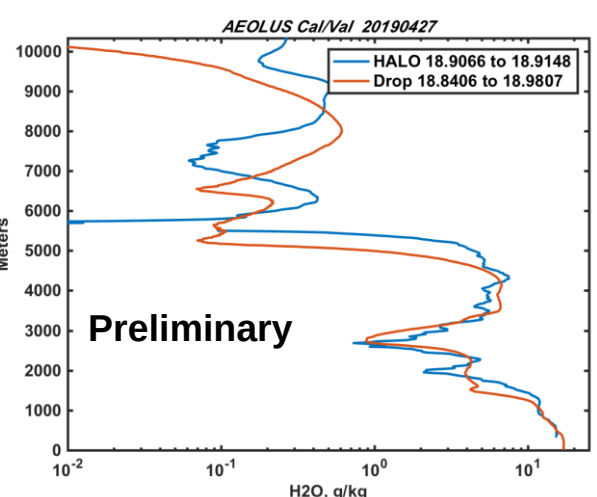
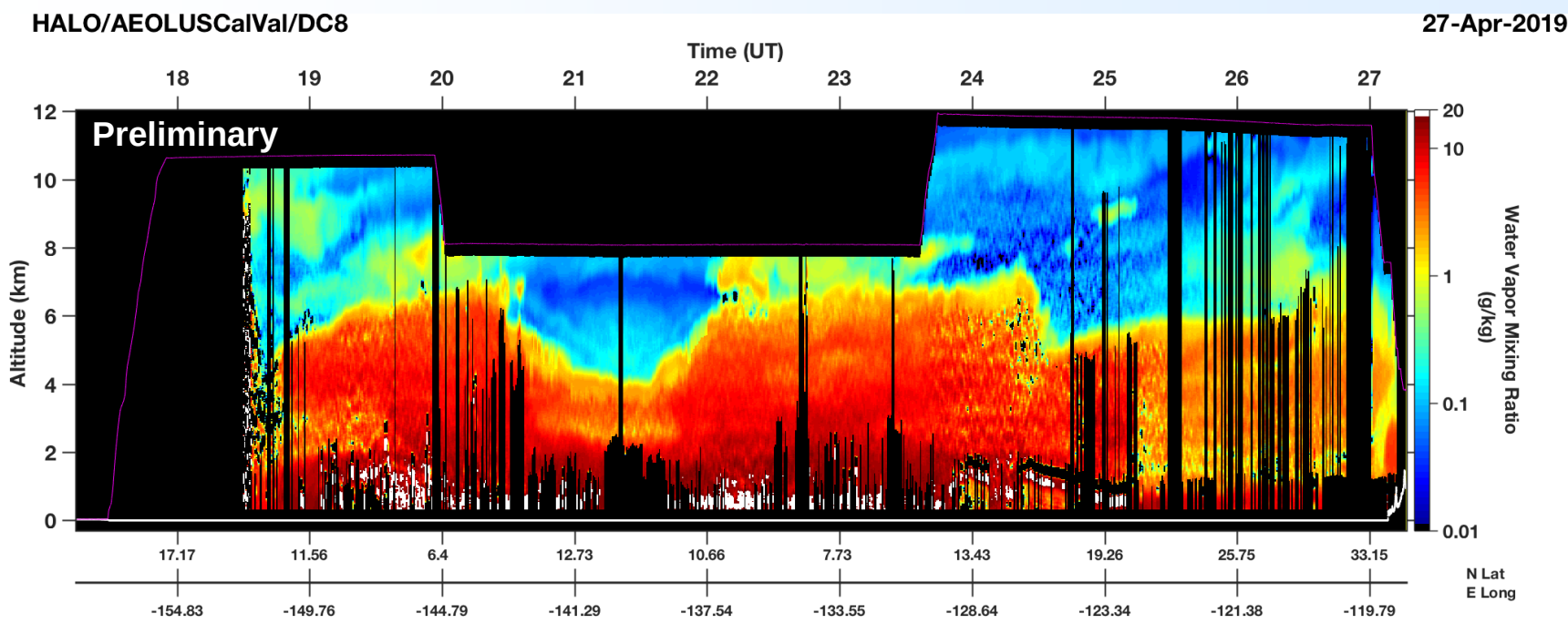


Flight #4, April 27: Water Vapor Distributions in the ITCZ



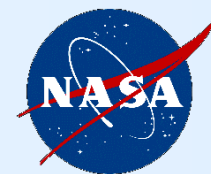


Flight #4, April 27: Dropsonde Comparisons



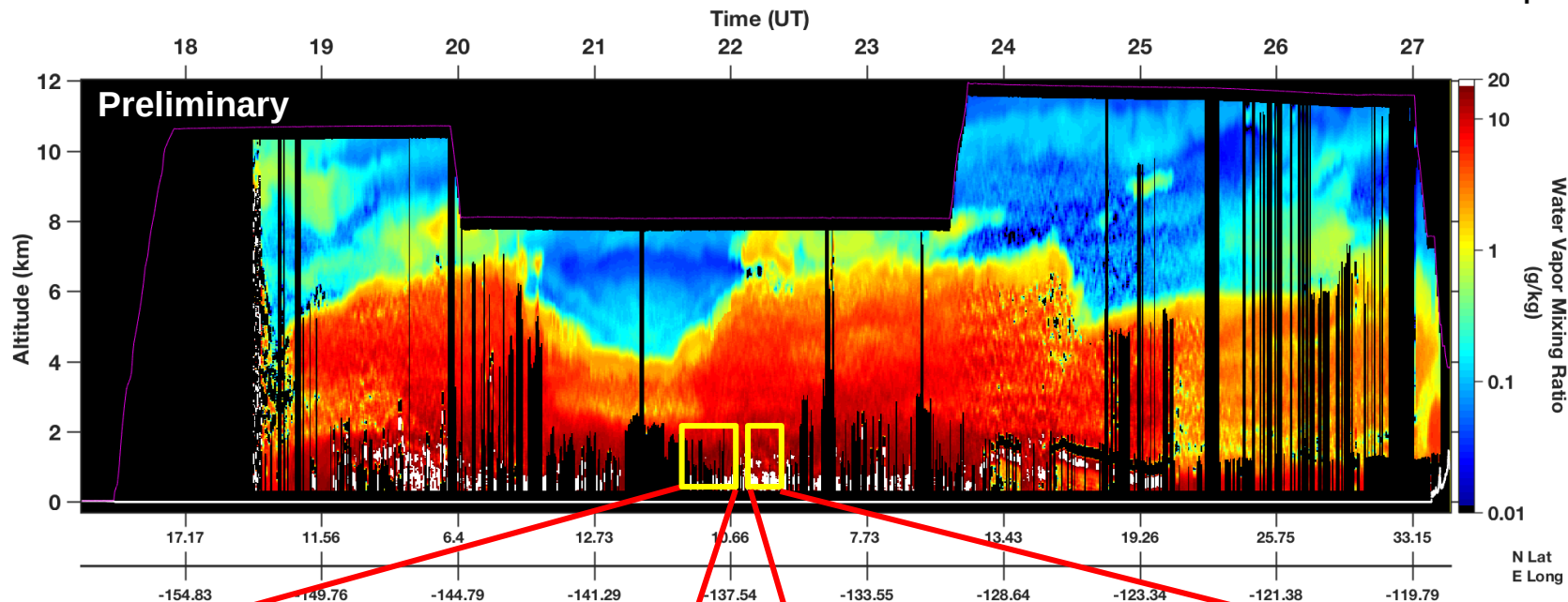
- HALO demonstrated capability to tune transmitter during flight to transition from dry mid-latitude to humid tropical conditions
- Good general agreement with sondes shows deep transport of moisture to mid troposphere
- Damped sonde response evident in left most figure

Flight #4, April 27: Boundary Layer Dynamics in the ITCZ



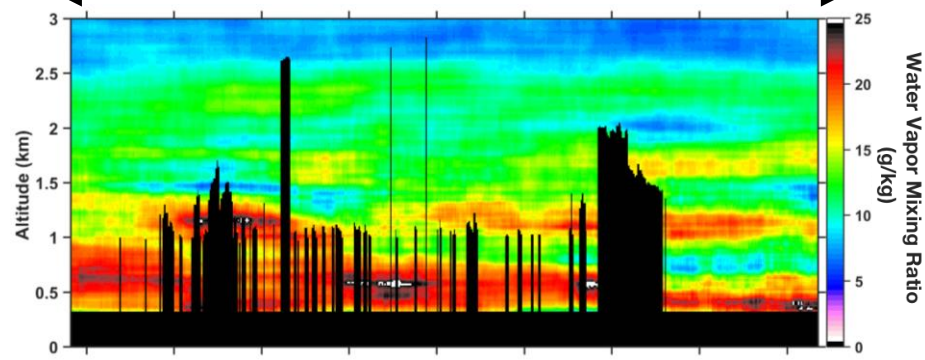
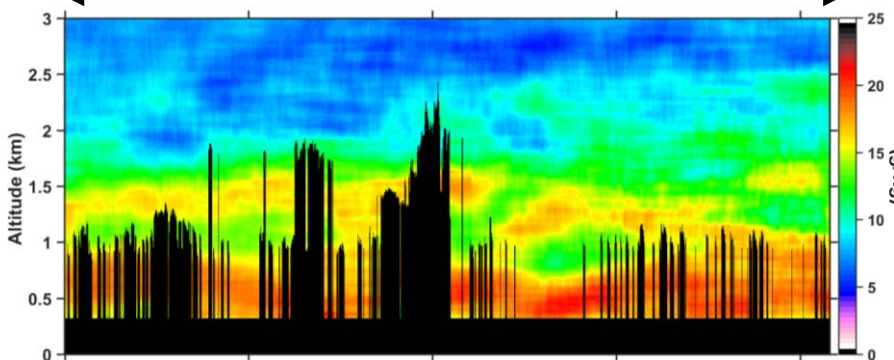
HALO/AEOLUS/CalVal/DC8

27-Apr-2019



~140 km

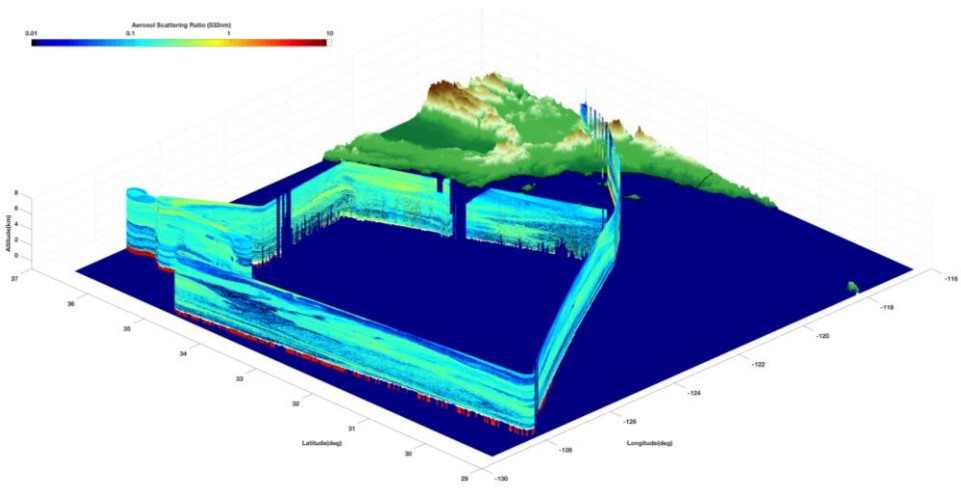
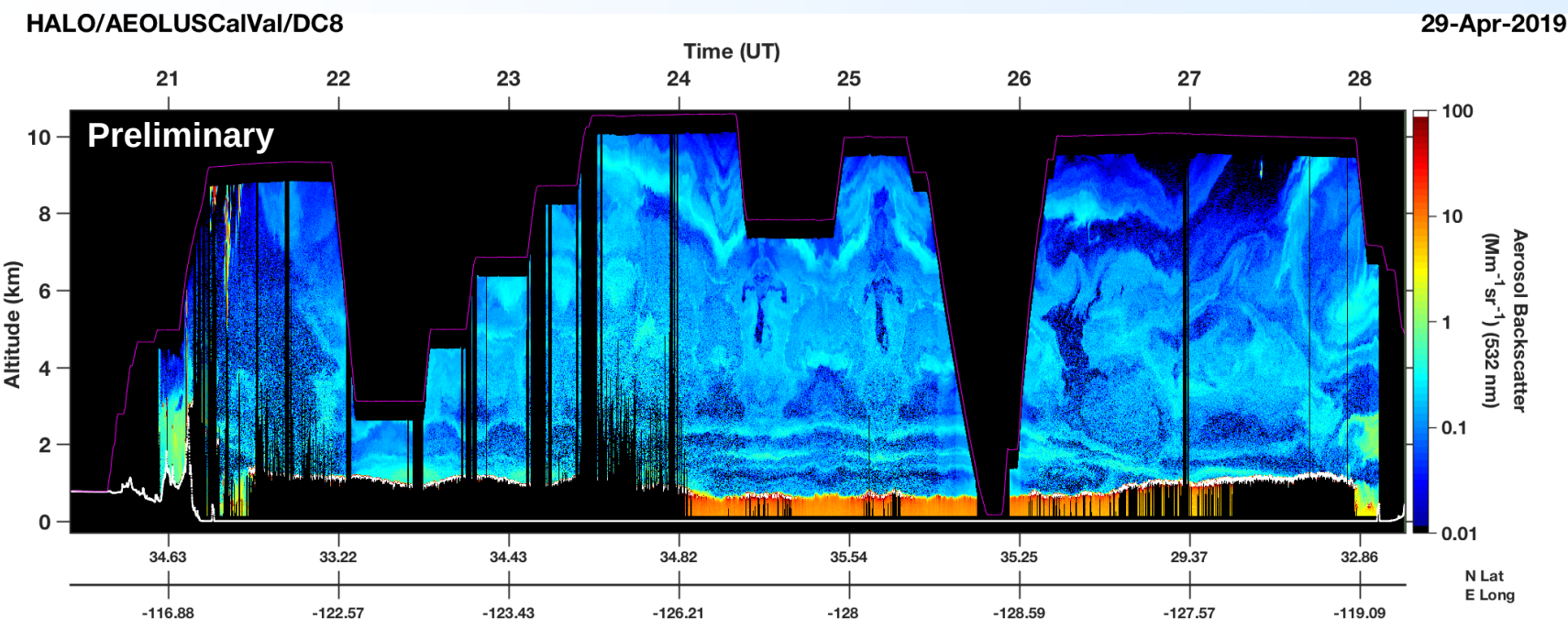
~60 km



* bottom images are on a linear scale to highlight variability in moisture fields in and around the tropical boundary layer

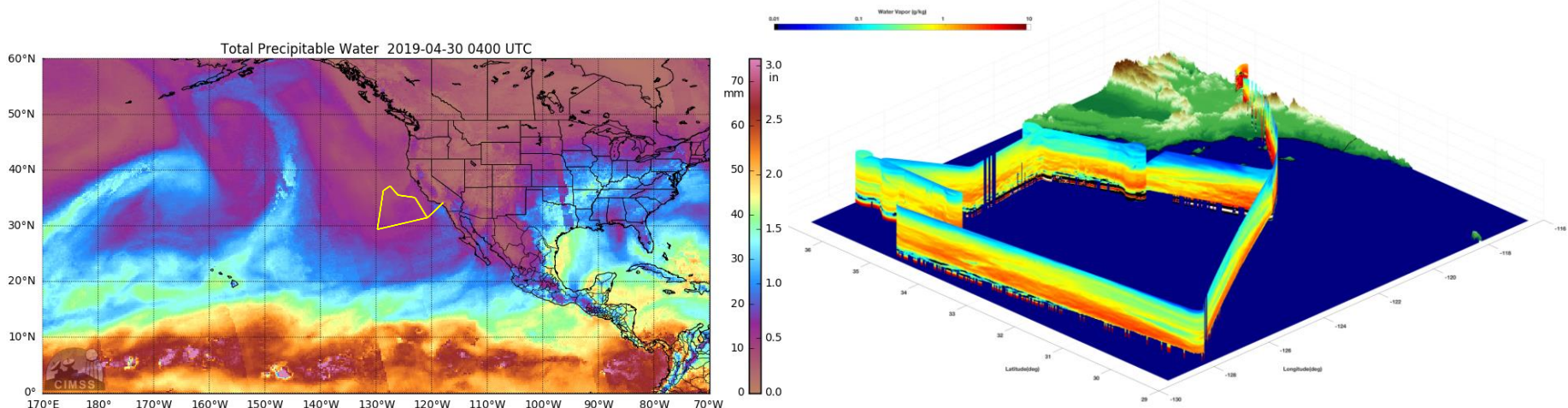
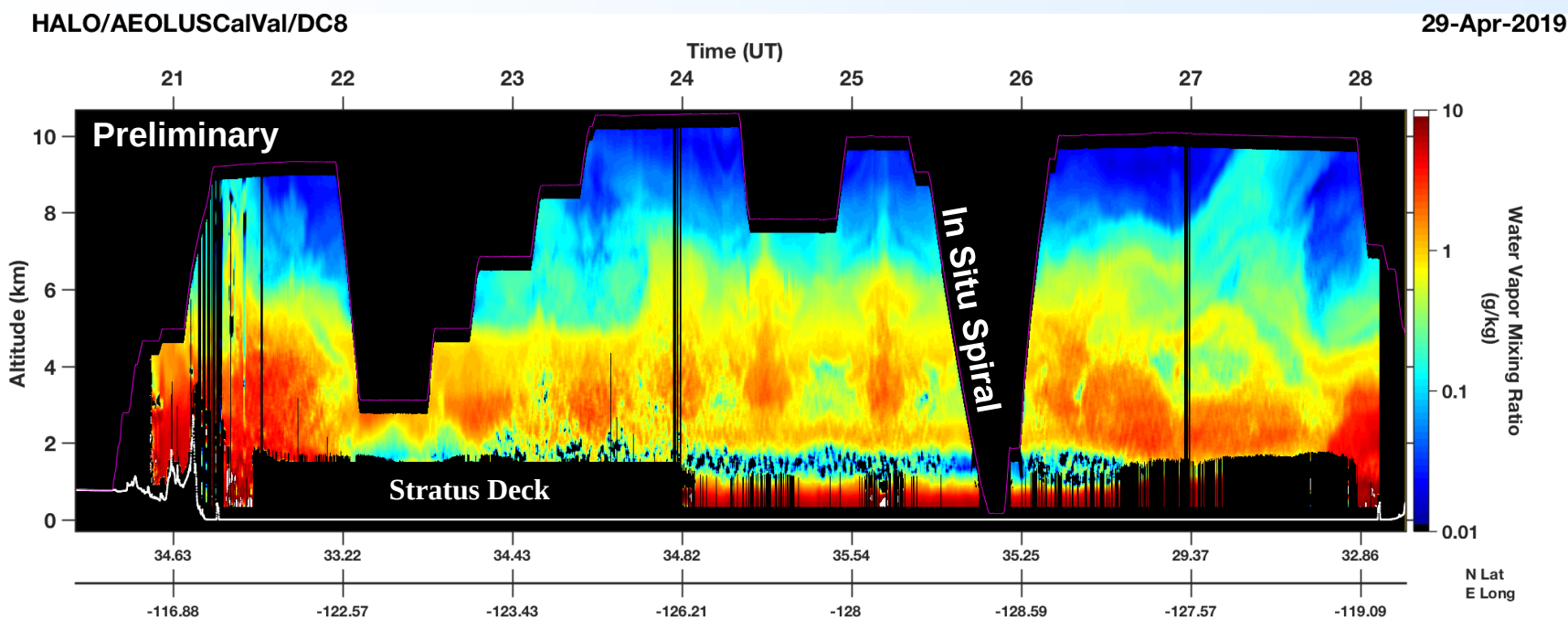


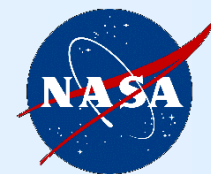
Flight #5, April 29: 532 nm Aerosol Backscatter



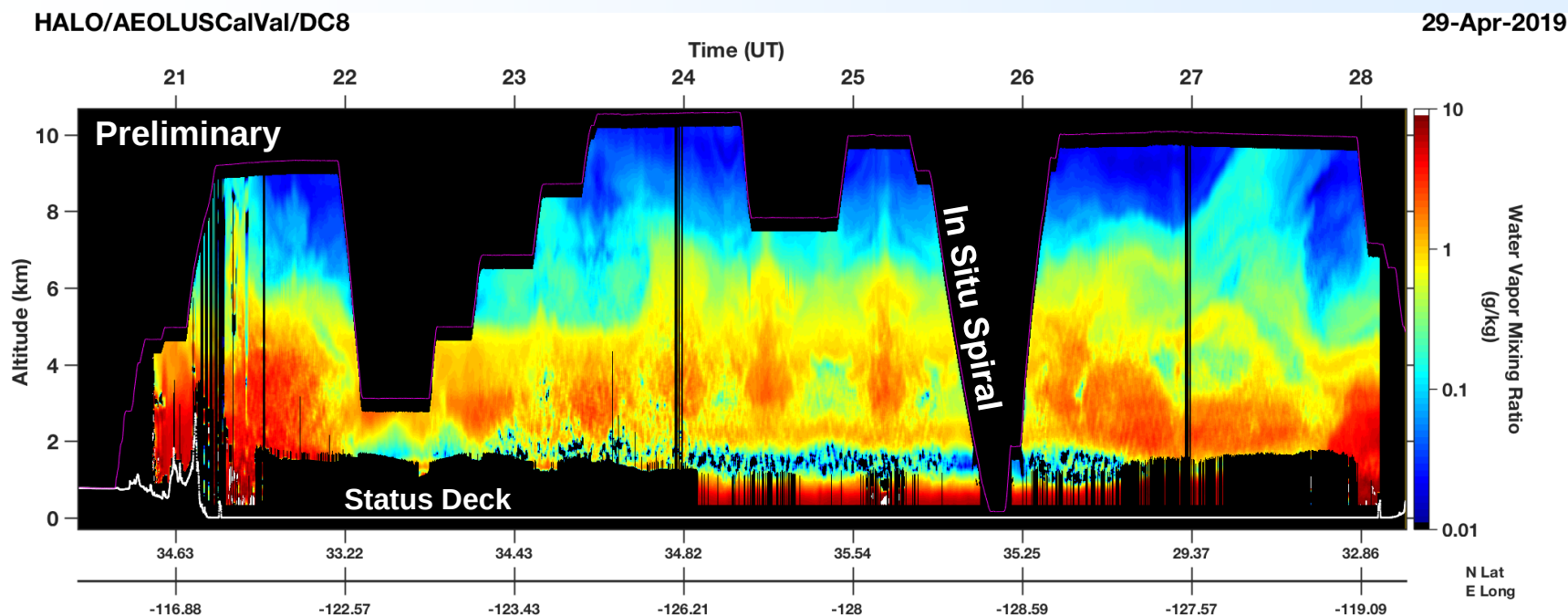


Flight #5, April 29: Water Vapor Mixing Ratios

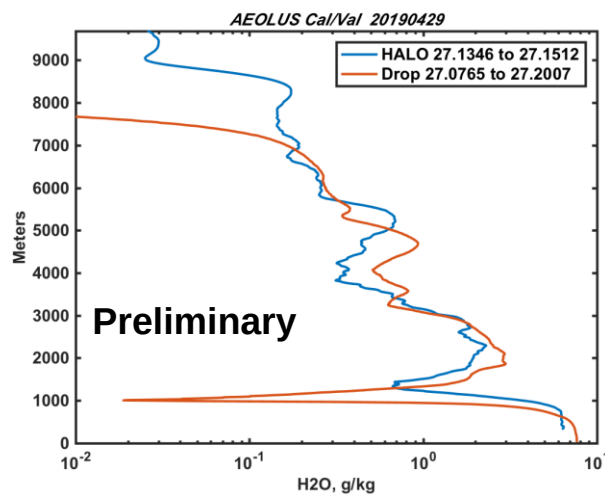
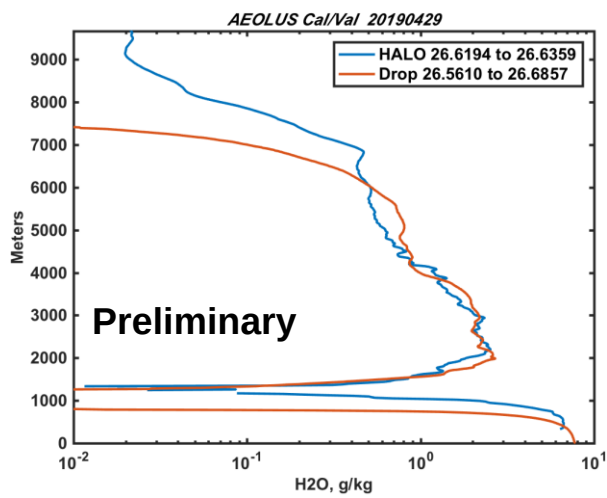


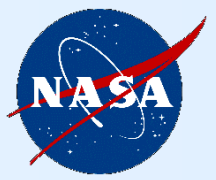


Flight #5, April 29: Dropsonde Comparisons



- HALO water vapor profiles show high spatial correlation with aerosol distributions
- HALO demonstrated capability to measure shallow dry layers above marine stratus important for aerosol cloud radiation studies
- Transport of moisture to upper troposphere observed near the end of the flight





- HALO deployed on the NASA DC-8 as a part of the ADM-Aeolus Cal/Val experiment
- This mission served as the maiden test flights for the HALO water vapor DIAL/HSRL configuration
- HALO was 100% operational for the duration of the 45 flight hours and demonstrated the feasibility of deploying new state-of-the-art laser technologies on airborne platforms
- Over 60 Yankee dropsondes were deployed over the duration of the mission
 - Primary focus was on accurate wind retrievals for ADM/DAWN validation
 - Humidity sensor showed signs of large bias in the upper and mid trop.
 - Humidity sensor also showed signs of damped response at all altitudes resulting in degraded spatial resolution and altitude registration
- Preliminary HALO water vapor mixing ratio profiles showed good general agreement despite problems with dropsondes.
- HALO will be a part of the ADM-Aeolus Cal/Val and tropical dynamics mission in 2020 out of Cape Verde
- HALO is ready for future deployments and looking for opportunities to fly with other partners/agencies