Multi-Spectra Multi-Species team

# Tropospheric HDO/$H_2O$ from AIRS and CrIS:

## Comparisons with Aircraft and Model HDO/$H_2O$

Robert Herman[1], John Worden[1], David Noone[2], Dean Henze[2], Mingjie Shi[1], Kevin Bowman[1], Susan Kulawik[3], Vivienne H. Payne[1], Karen Cady-Pereira[4]

1. Jet Propulsion Laboratory / California Institute of Technology

2. Oregon State University. 3. BAERI, 4. Atmos. and Environ. Research, Inc.

Jet Propulsion Laboratory
California Institute of Technology

# AIRS HDO

## Outline

1. Terminology
2. Scientific Motivation
3. HDO Retrieval
4. $HDO/H_2O$ Comparisons, AIRS vs aircraft
5. $HDO/H_2O$ Comparisons, AIRS vs CAM model
6. New $HDO/H_2O$ from CrIS

# 1. Terminology

# Stable isotope terminology

*Isotopologues*: molecules differing in isotopic composition, e.g., $H_2O$ versus HDO. These have slightly different physical properties, including molecular weight (18 versus 19) and vapor pressure.

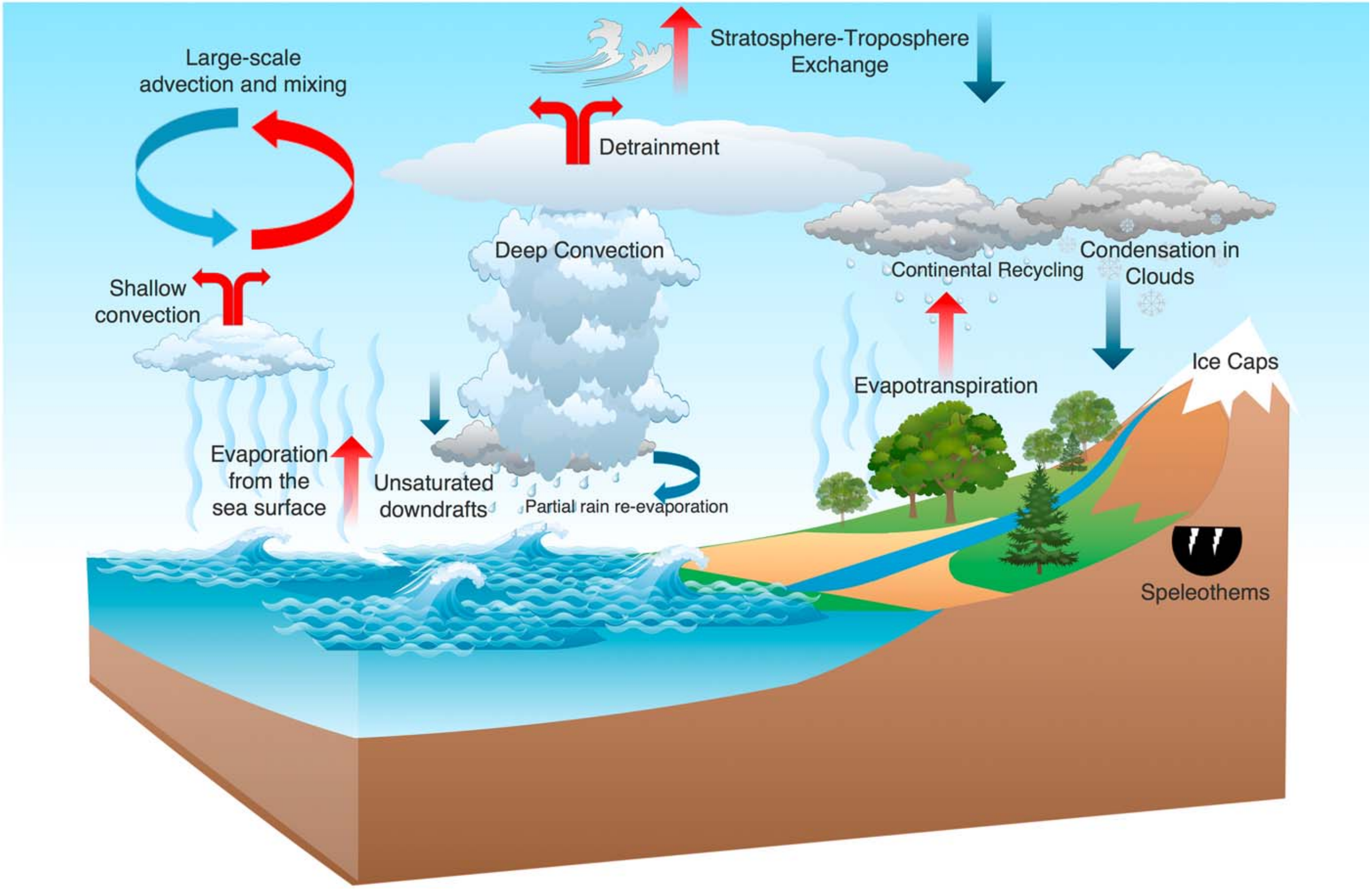
Water has several stable isotopologues, most abundant $H_2O$, HDO, $H_2{}^{18}O$.

Standard Mean Ocean Water (SMOW) has the isotopic ratio $(HDO/H_2O)_{SMOW} = 3.115\times10^{-4}$.

*Delta notation:* $\delta D_{sample} = [(HDO/H_2O)_{sample}/(HDO/H_2O)_{SMOW} - 1]*10^3$ (per mil or ‰).

# 2. Scientific Motivation

**How water vapor isotopologues help evaluate hydrological processes (Galewsky et al., Rev Geo., 2015)**




Red arrows describe "enriching" process

Blue arrows describe "depleting" process

Lighter isotopologues of water preferentially evaporate. Heavier isotopologues (HDO) preferentially condense. Different moisture sources have different isotopic composition

Tropical Transpiration ~-65 to 0 ‰
Tropical Ocean Source ~-65 to -120 ‰
Tropical bare soil ~ -240 to -180 ‰

1) Quantifying rainfall evaporation in tropical monsoons (Worden et al., Nature 2007)
2) Partitioning transpiration and river run-off (Good et al., Science 2015)
3) Amazon transpiration initiates rainy season (Wright et al., PNAS 2017)

# 3. HDO/$H_2O$ Retrieval

# HDO Retrieval

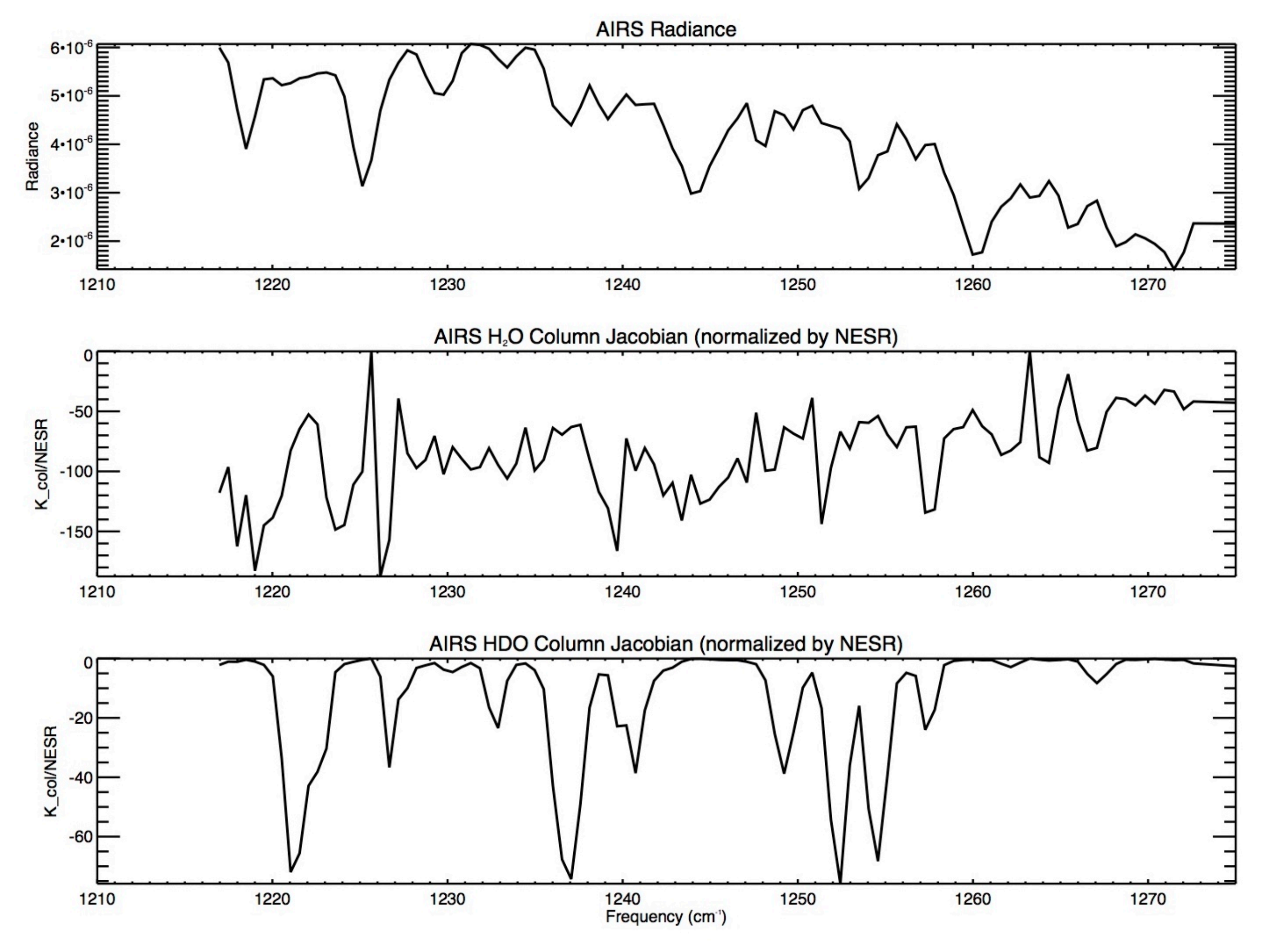
## J. Worden et al., Atmos. Meas. Techniques (2019)*

- These retrievals use the AIRS single footprint IR geolocated and calibrated radiance data (Aumann et al., 2003).
- The Retrieval Framework is an Optimal Estimation retrieval algorithm (TES heritage) in which HDO is retrieved from AIRS.
- AIRS and TES show a small bias for the $HDO/H_2O$ ratio of $0.32 \pm 2.3$ per mil.

*Worden, J. R., Kulawik, S. S., Fu, D., Payne, V. H., Lipton, A. E., Polonsky, I., He, Y., Cady-Pereira, K., Moncet, J.-L., Herman, R. L., Irion, F. W., and Bowman, K. W.: Characterization and evaluation of AIRS-based estimates of the deuterium content of water vapor, Atmos. Meas. Tech., 12, 2331-2339, https://doi.org/10.5194/amt-12-2331-2019, 2019.

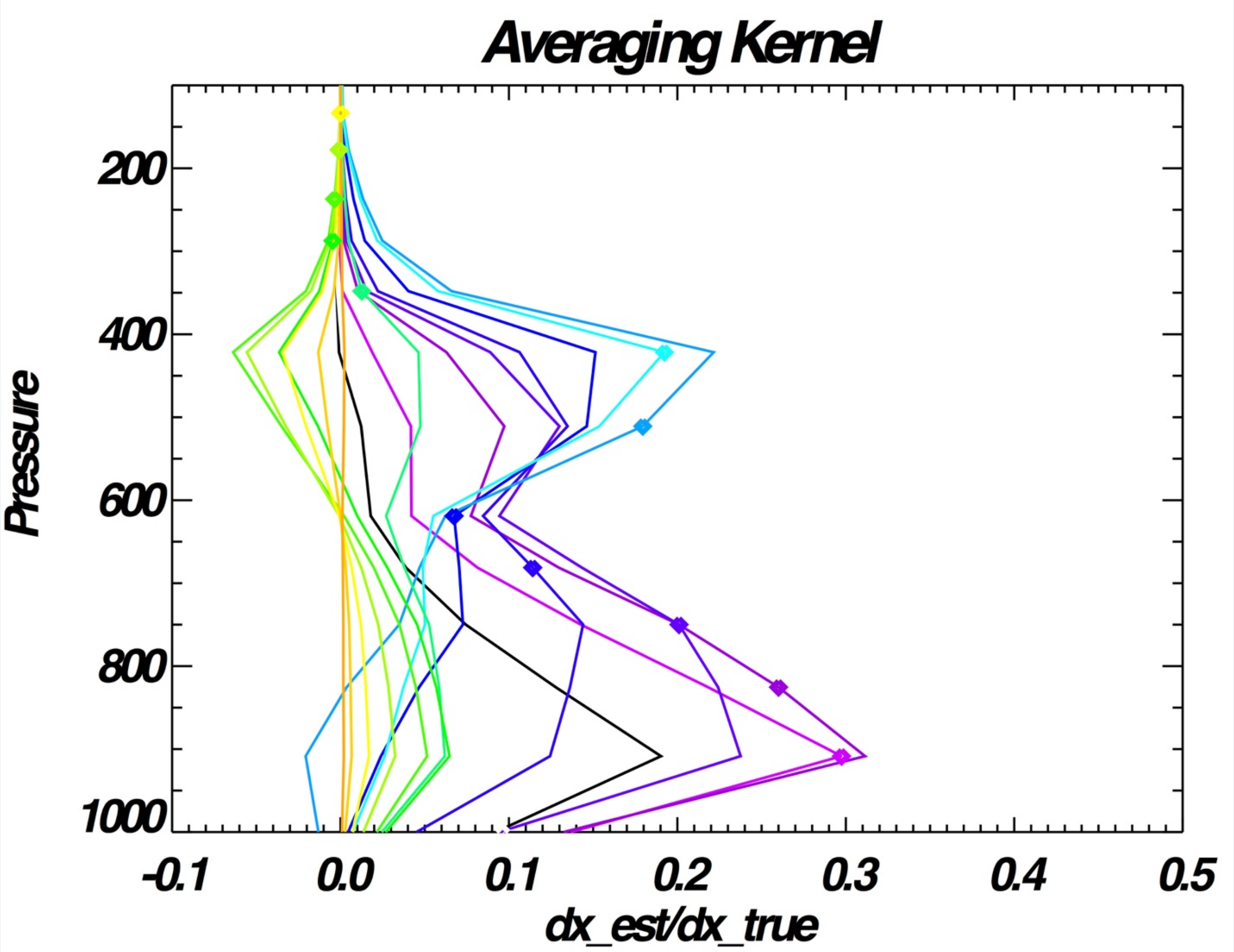
# AIRS HDO/$H_2O$ retrievals

## Radiance and Jacobians near 1240 $cm^{-1}$



# AIRS HDO

## Averaging Kernel traces



# 4. HDO/$H_2O$ Comparisons, AIRS vs aircraft, from:

Herman, R. L., Worden, J., Noone, D., Henze, D., Bowman, K., Cady-Pereira, K., Payne, V. H., Kulawik, S., and Fu, D.: Comparison of Optimal Estimation HDO/H2O Retrievals from AIRS with ORACLES measurements, Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2019-195, in review, 2019.

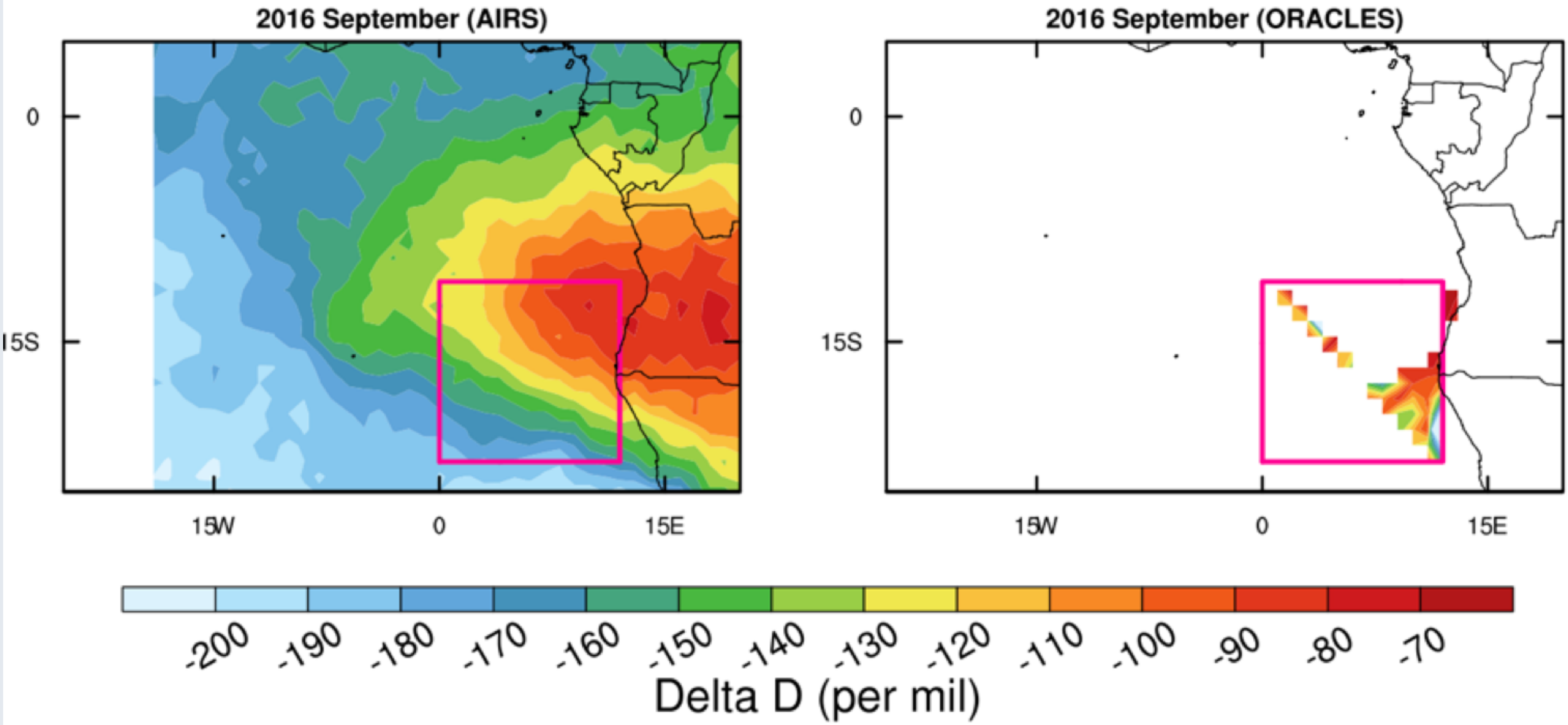
# ORACLES

## ObseRvations of Aerosols above CLouds and their intEractionS

- A 5-year EVS-2 investigation to study key processes that determine the climate impacts of African biomass burning aerosols.
- ORACLES provides multi-year airborne observations (2016-2018) over the complete vertical column of the key parameters that drive aerosol-cloud interactions in the SE Atlantic, an area with some of the largest inter-model differences in aerosol forcing assessments on the planet.
- Science question relevant to AIRS: How do biomass burning aerosols affect cloud droplet size distributions, precipitation and the persistence of clouds over the SE Atlantic?
- Water Isotopologue measurements from the WISPER instrument on the P-3 aircraft (Noone’s OSU group).

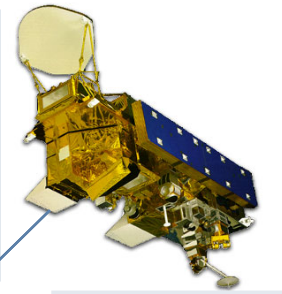
# Delta D over Southeast Atlantic Ocean

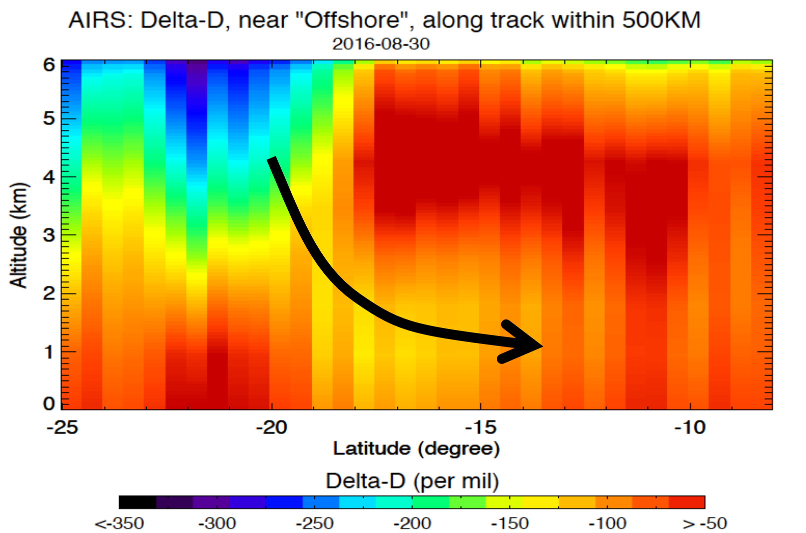
AIRS (left) and WISPER in-situ (right) average 825-562 hPa.

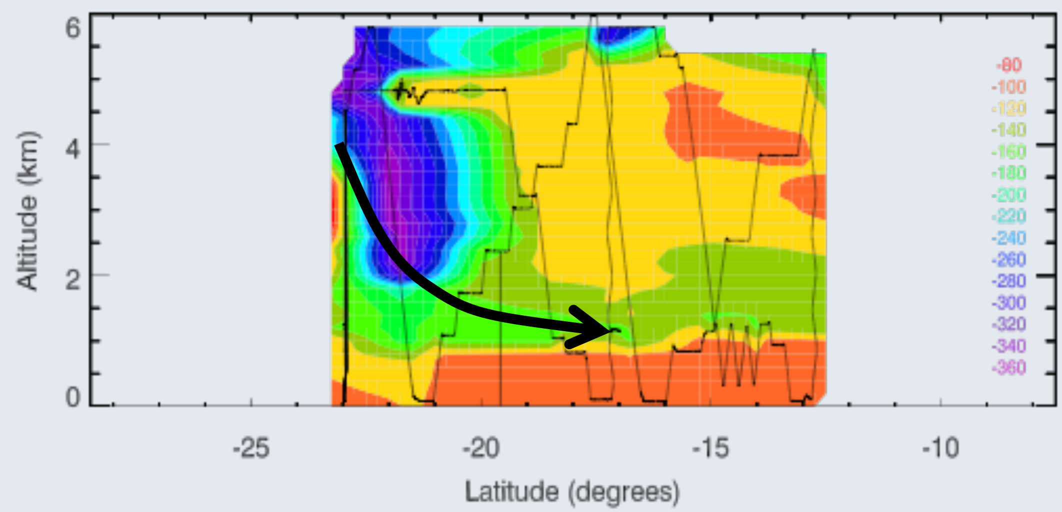


# Delta D Curtain Plots

## AIRS (left) and WISPER in-situ (right)



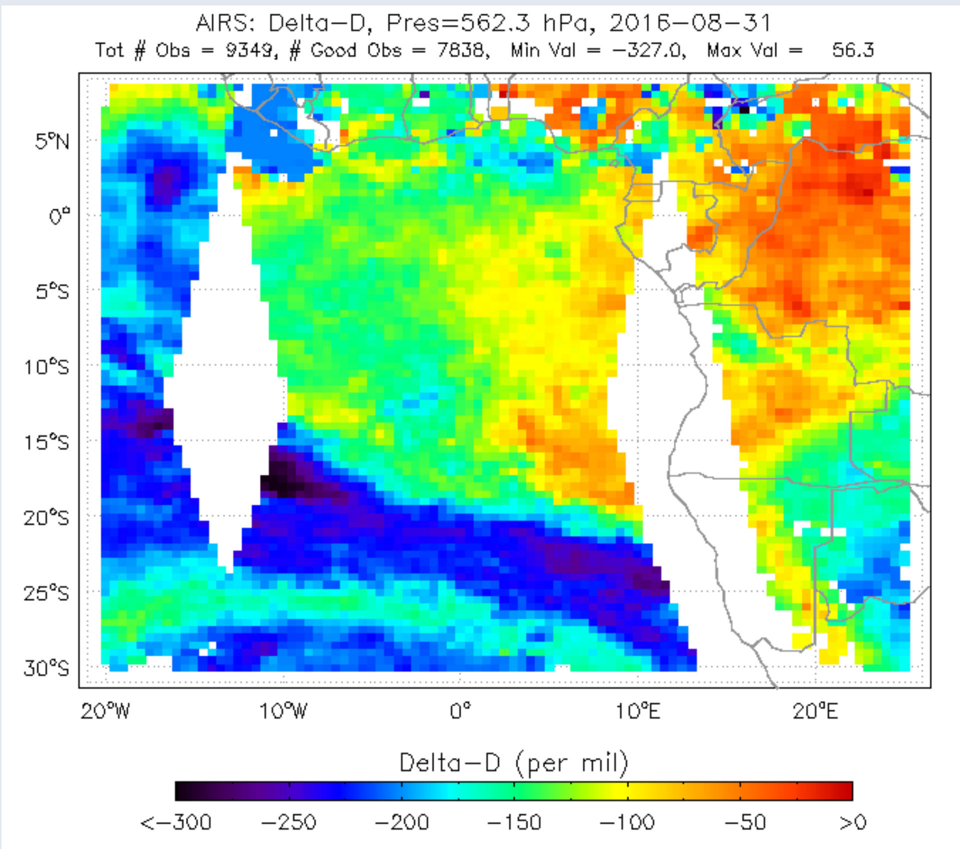


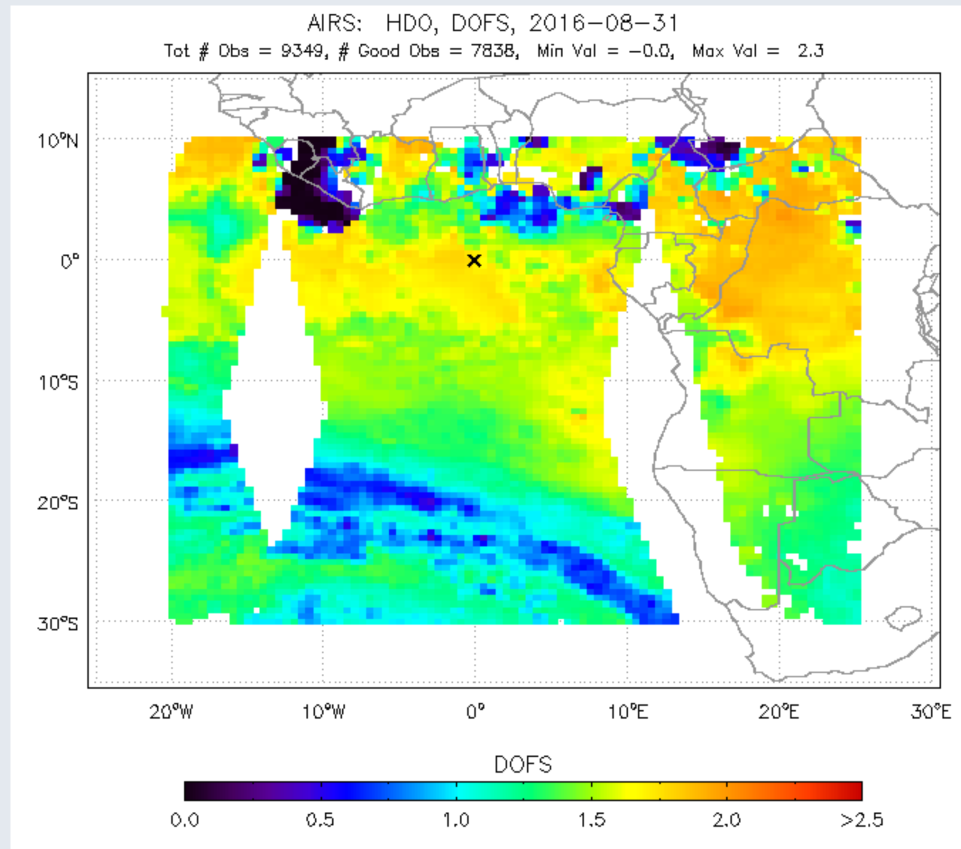




Courtesy D. Noone (OSU)

# AIRS HDO/$H_2O$ retrievals

## Southeast Atlantic Ocean, 31 Aug 2016

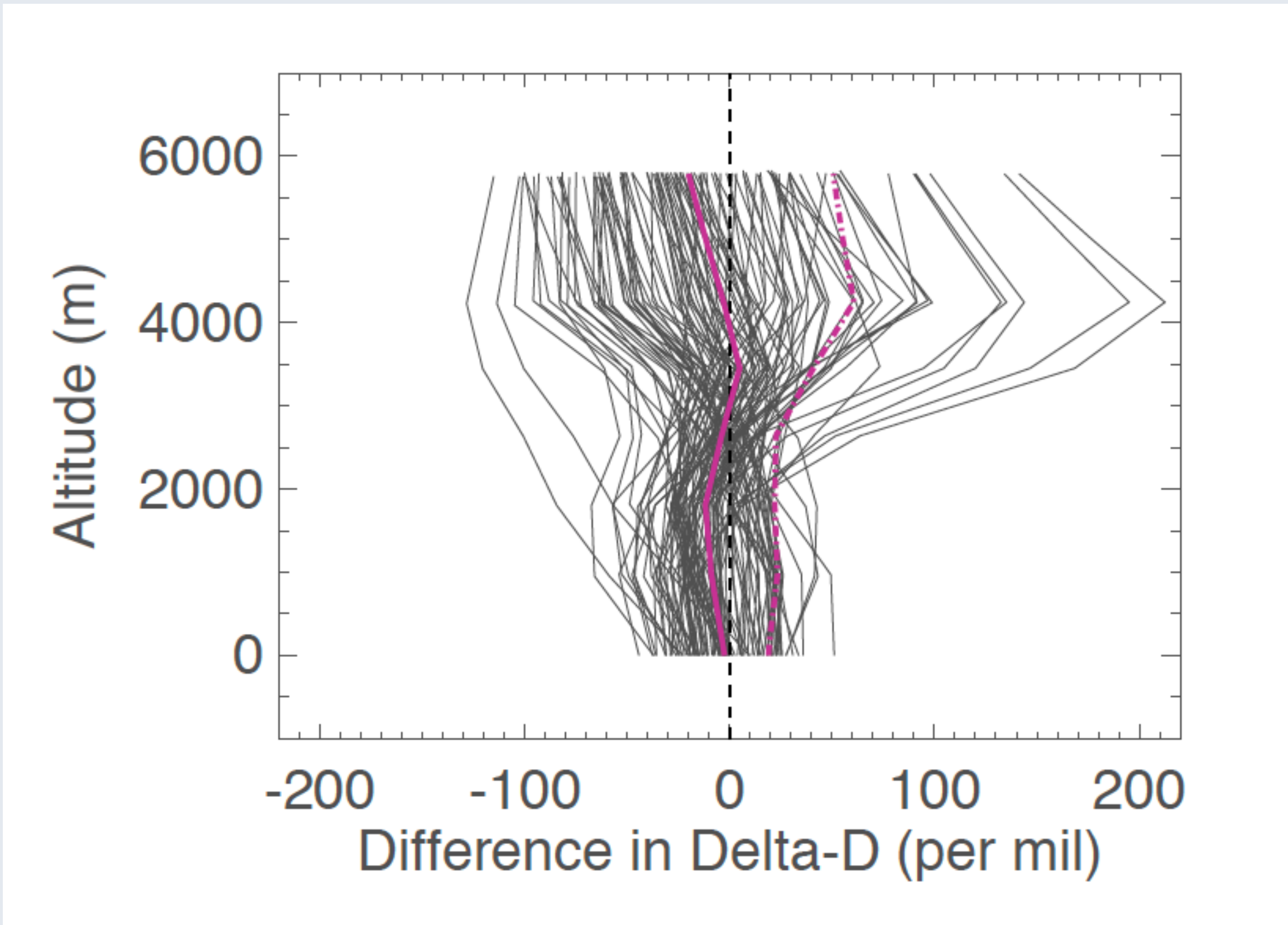



**AIRS tropical HDO/$H_2O$ estimates have ~1.5 Degrees of Freedom for Signal (DOFS).**

# Statistics of AIRS minus WISPER Delta D

## 446 pairs (black), mean (red solid) and rms (red dash dot)



# AIRS versus aircraft Summary:

Herman et al., AMTD (2019)*

- AIRS HDO/$H_2O$ retrievals are very well characterized with ~1.5 DOFS.
- AIRS bias relative to the aircraft is -8.0‰ in the lower troposphere and -4.6‰ in the middle troposphere.
- AIRS RMS (in Delta D notation) is about 25 – 30 per mil.
- This is consistent with aircraft RMS.

*Herman et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2019-195, in review, 2019.

# 5. HDO/$H_2O$ Comparisons, AIRS vs model

# ICAM

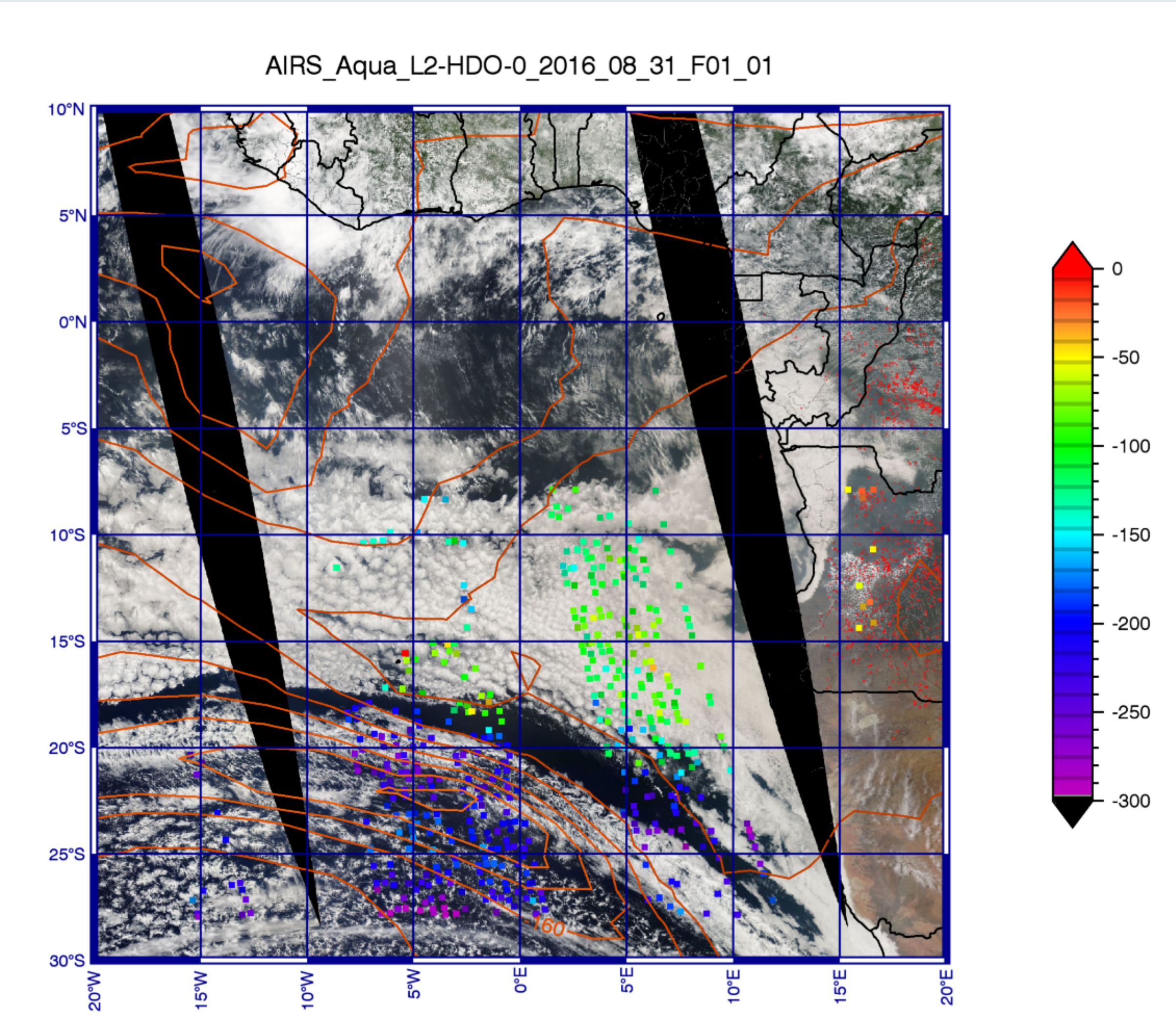
## Isotope Community Atmosphere Model

- Water isotope version of CAM developed by David Noone group (Nusbaumer et al., 2017).
- 30 levels (3.6 hPa to surface), including ~ 20 levels in the troposphere.
- Objective is to use the ORACLES observations to benchmark the model, and to compare variability between AIRS, ORACLES and model.

Nusbaumer, J., T. E. Wong, C. Bardeen, and D. Noone (2017), Evaluating hydrological processes in the Community Atmosphere Model Version 5 (CAM5) using stable isotope ratios of water, J. Adv. Model. Earth Syst., 9, 949–977, doi:10.1002/2016MS000839.

# AIRS and ICAM Delta D

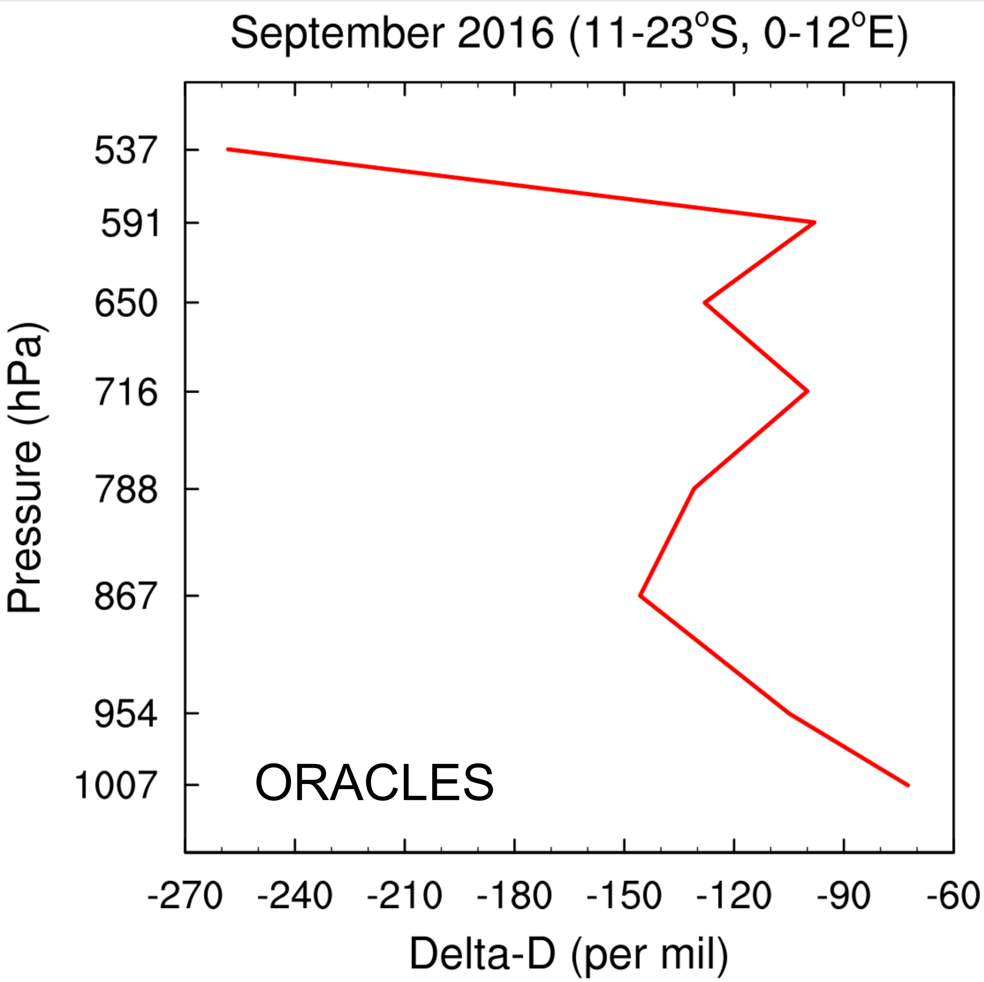
## Southeast Atlantic, 31 Aug 2016

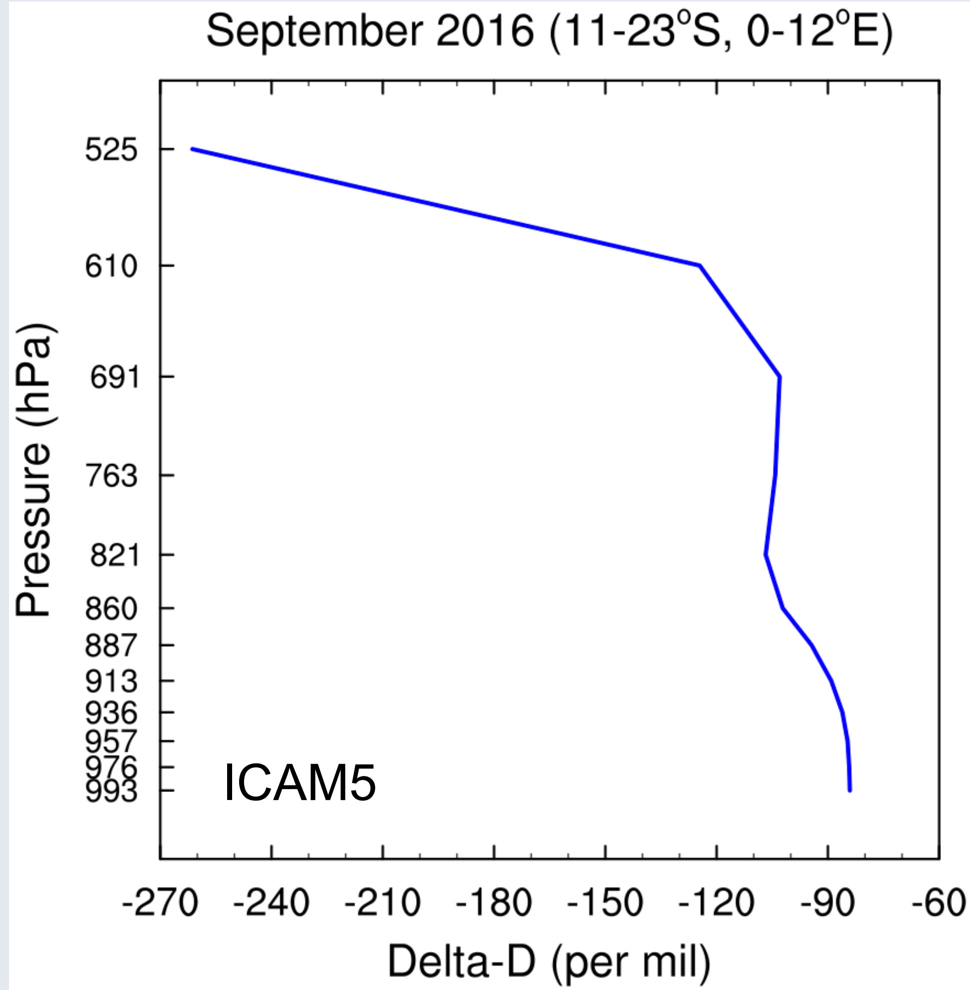



**Color scale:** mid-tropospheric AIRS delta-D.
**Clouds:** MODIS.

# September Monthly Mean Delta D

## WISPER In-situ (left) and ICAM Model (right)



# 6. CrIS Delta-D

# FIREX-AQ

Fire Influence on Regional to global environments EXperiment - Air Quality

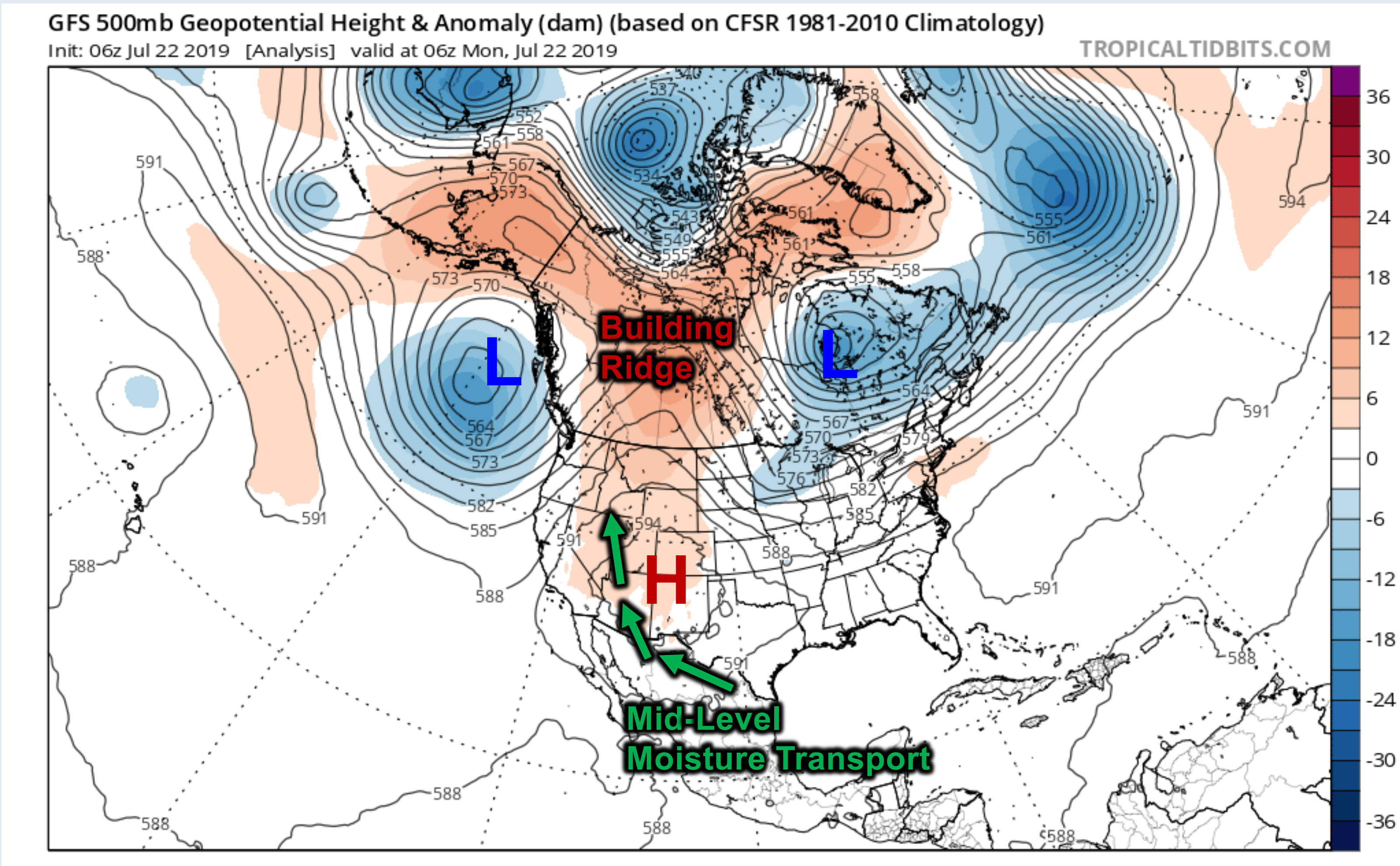
The overarching objective of FIREX-AQ is to provide measurements of trace gas and aerosol emissions for wildfires and prescribed fires in great detail to:

- relate them to fuel and fire conditions at the point of emission,
- characterize the conditions relating to plume rise,
- follow plumes downwind to understand chemical transformation and air quality impacts, and
- assess the efficacy of satellite detections for estimating the emissions from sampled fires.

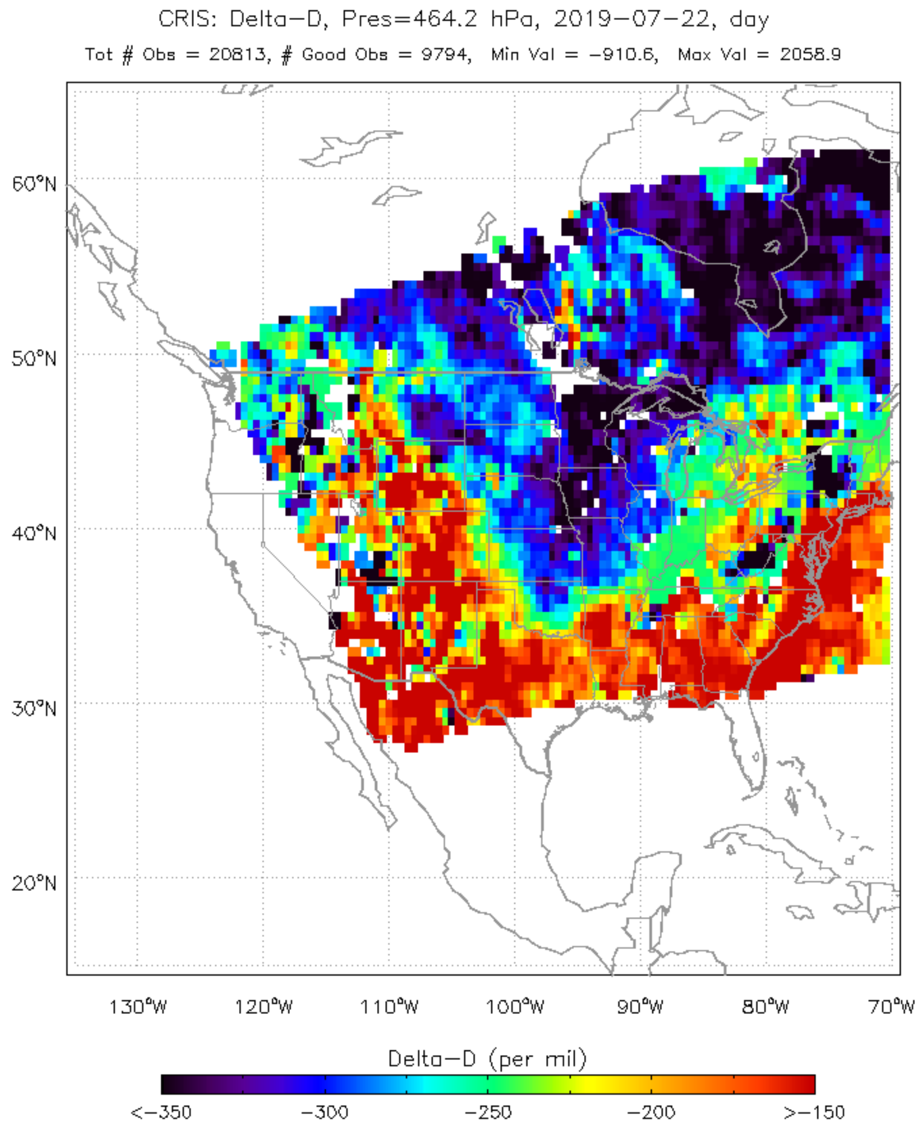
Here FIREX-AQ meteorology over the CONUS is compared with preliminary CrIS Delta D retrievals.

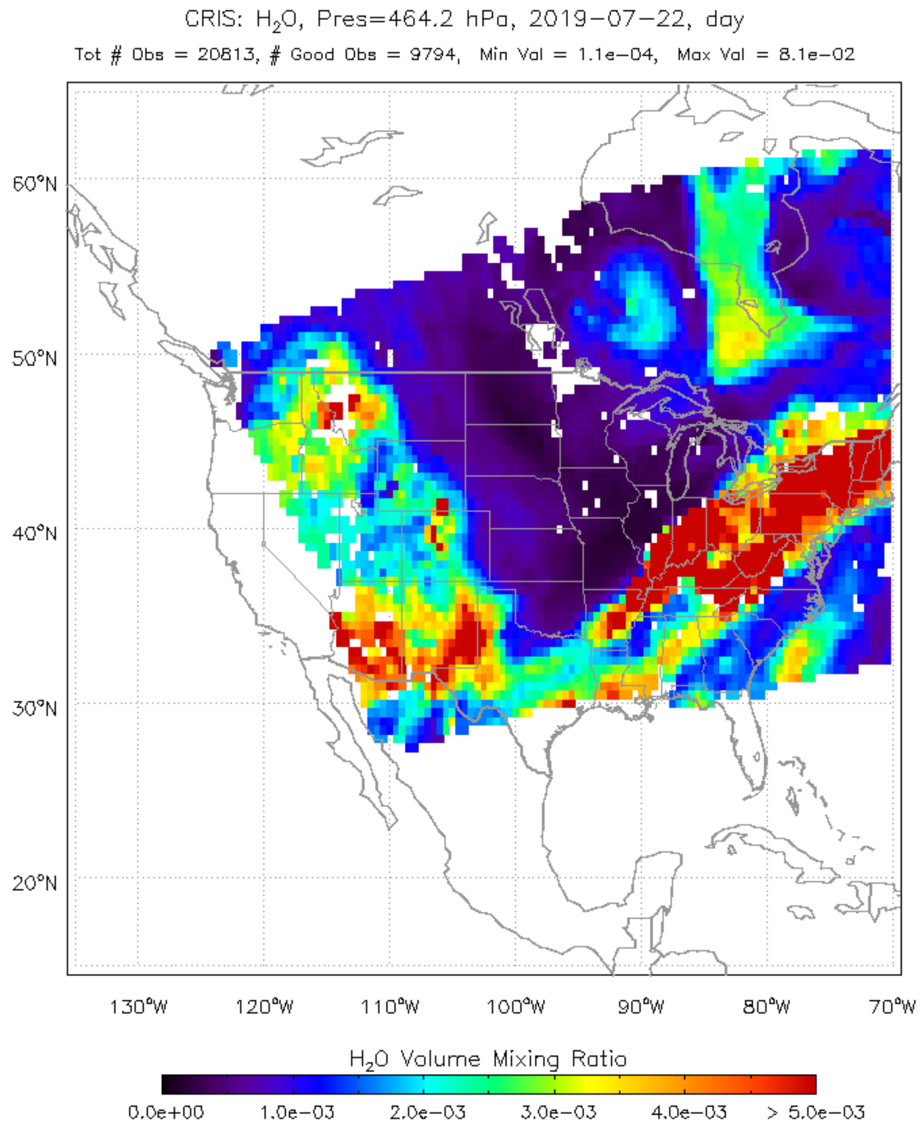
# Synoptic/Upper-Level Conditions, 7-22-2019

## Courtesy of FIREX-AQ Forecasting Team



# CrIS Delta D (left) and $H_2O$ (right), 7-22-2019



# Summary:

## AIRS and CrIS Delta D

AIRS HDO/$H_2O$ retrievals are very well characterized ~1.5 DOFS.

The small bias and consistent RMS suggests that the AIRS HDO/$H_2O$ retrieval provides well characterized measurements. This level of uncertainty is good enough to address science questions.

Preliminary CrIS HDO/$H_2O$ retrievals are encouraging.

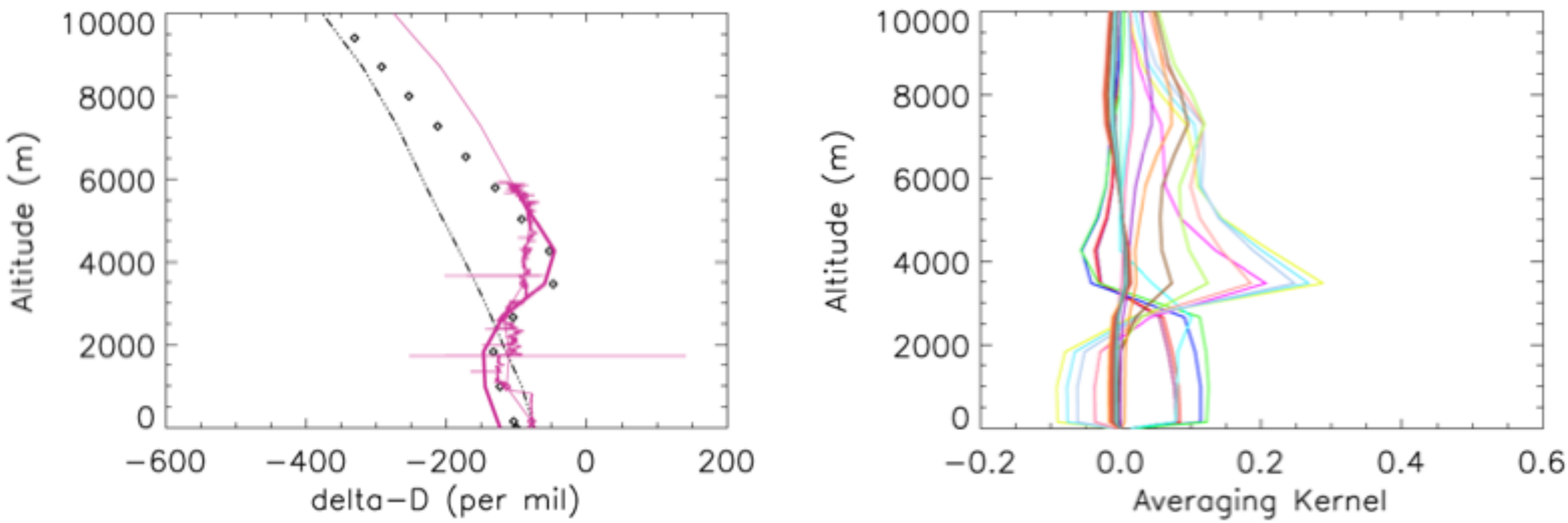
Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

# AIRS

backup slides

# **Example Comparison of AIRS delta-D** (blk diamonds) and **P-3 with AK** (thick red line)




Location is 19.46 °S, 9.65 °E for coincident retrievals on 31 Aug 2016.

# Summary: importance of water isotopologues

Water isotopes provide useful information about the hydrological cycle, including:

- The overall intensity of the hydrological cycle.
- Transport and mixing processes in the atmosphere.
- Moisture sources (e.g. local vs distant, convection vs evapotranspiration).

Spaceborne instruments that measure isotopologues of water vapor, such as TES, IASI and AIRS, provide **regional** constraints on the hydrological cycle. The isotopic abundance in tropospheric water vapor is significantly different from the isotopic abundance in precipitation, so remote sensing provides a **unique** tool.

**ORACLES** (ObseRvations of Aerosols above CLouds and their intEractionS)

- A 5-year EVS-2 investigation to study key processes that determine the climate impacts of African biomass burning aerosols.
- ORACLES provides multi-year airborne observations (2016-2018) over the complete vertical column of the key parameters that drive aerosol-cloud interactions in the SE Atlantic, an area with some of the largest inter-model differences in aerosol forcing assessments on the planet.
- Science question relevant to AIRS: How do biomass burning aerosols affect cloud droplet size distributions, precipitation and the persistence of clouds over the SE Atlantic?
- Water Isotopologue measurements from the WISPER instrument on the P-3 aircraft (Noone's OSU group).