Multi-Spectra Multi-Species team

Tropospheric HDO/H_2O from AIRS: an update

Processing Status

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AIRS HDO

Outline

1. Terminology
2. Scientific Motivation
3. HDO Retrieval within MUSES Framework
4. Processing Status

1. Terminology

Stable isotope terminology

Isotopologues: molecules differing in isotopic composition, e.g., H_2O versus HDO. Isotopologues have slightly different physical properties, including molecular weight, freezing point, vapor pressure.

Water has several stable isotopologues, in order of decreasing abundance H_2O, $H_2{}^{18}O$, HDO, and others.

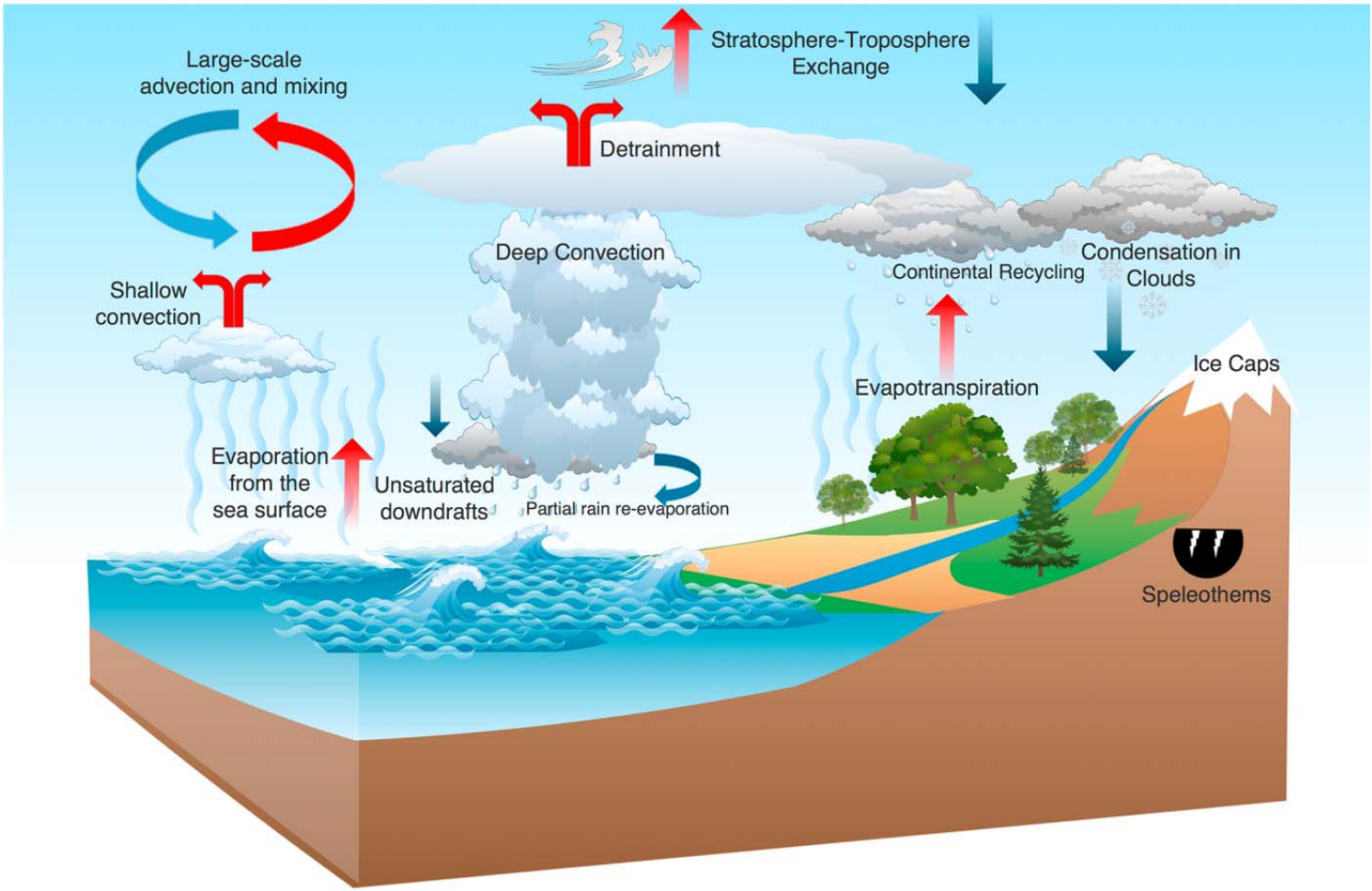
In a closed system, HDO/H_2O is conserved. In an open system, hydrologic processes such as evaporation, precipitation or mixing change the ratio.

As reference, Standard Mean Ocean Water (SMOW) has the isotopic ratio $(HDO/H_2O)_{SMOW} = 3.115 \times 10^{-4}$.

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.

Isotopic composition from different sources:
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 within the MUSES Framework

HDO Retrievals from AIRS

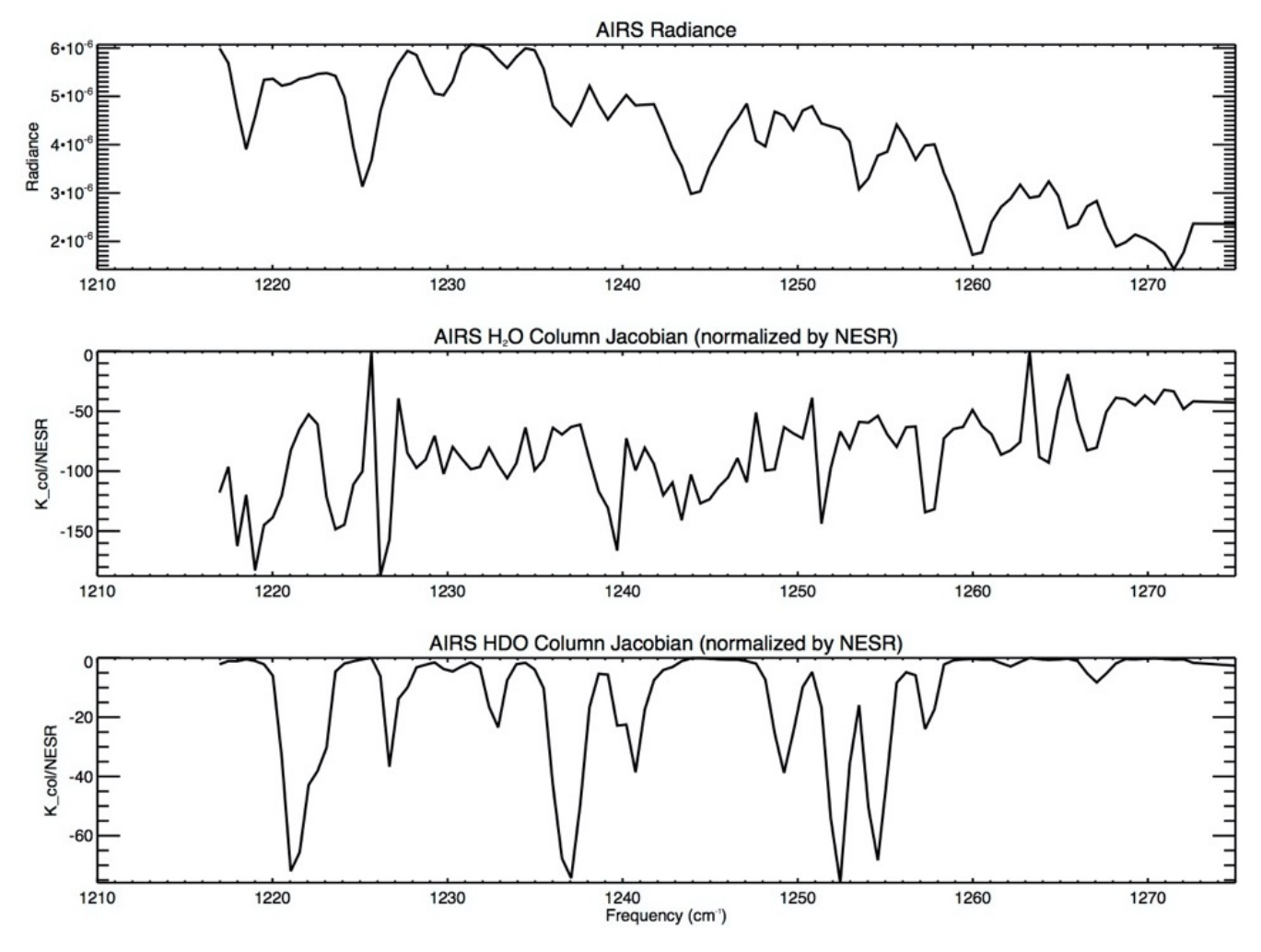
- Single footprint retrievals from the AIRS L1B radiances.
- MUSES Retrieval Framework uses Optimal Estimation. Output includes AK and obs. error covariance matrices.
- AIRS HDO retrieval algorithm has Aura-TES heritage (Worden et al., 2019)*.
- Validated using aircraft profiles from ORACLES EVS-2 (Herman et al., 2020)#.
- AIRS HDO/H_2O results have been demonstrated to be broadly consistent with TES.

* 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, 2020, https://doi.org/10.5194/amt-12-2331-2019.

Herman, R. L., Worden, J. R., Noone, D., Henze, D., Bowman, K., Cady-Pereira, K., Payne, V. H., Kulawik, S. S., and Fu, D., Atmos. Meas. Tech., 13, 1825–1834, 2020, https://doi.org/10.5194/amt-13-1825-2020.

AIRS HDO/H_2O retrievals

Radiance and Jacobians near 1240 cm^{-1}



4. Processing Status

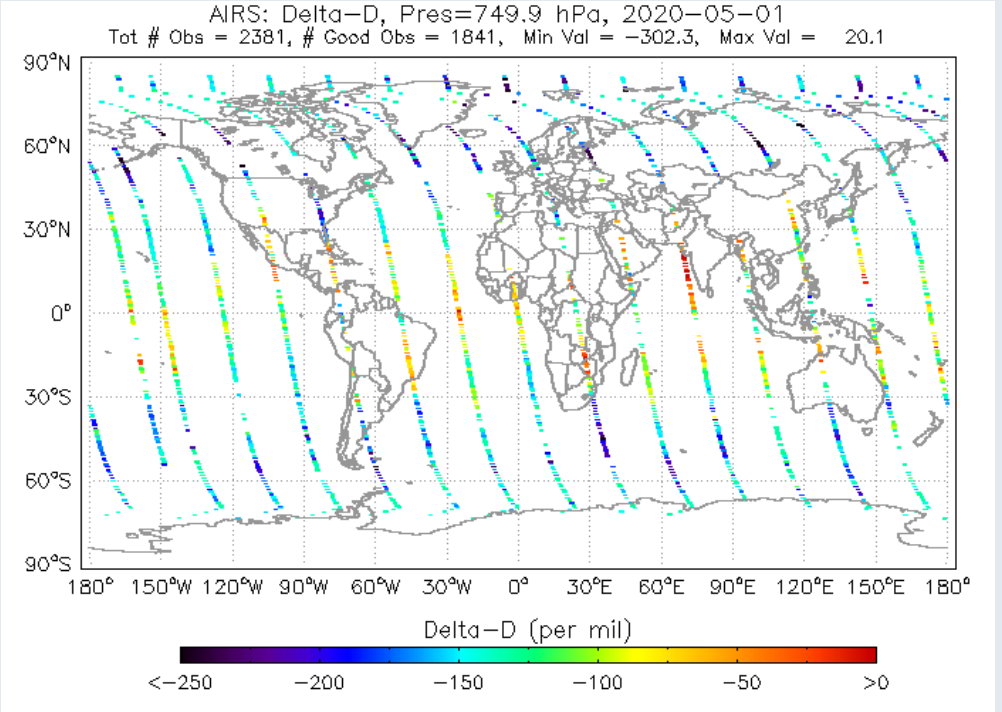
AIRS HDO/H_2O Subset

2002-2020 processed with widely-spaced observations.

AIRS HDO available now:

- TES-like Global Survey (GS)
- ~ 3,000 observations / day
- Aug 2002-Mar 2020 processed
- Available at AVDC in prelim data format (see below)
- Work in progress: HDO file format and documentation for GES DISC

Example



AIRS HDO Data Sources:

The data are publicly available at the AVDC.
https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/TES/.AIRS/

For use of the HDO data, please contact John.R.Worden@jpl.nasa.gov

AIRS HDO/H_2O Processing in conjunction with TROPESS *

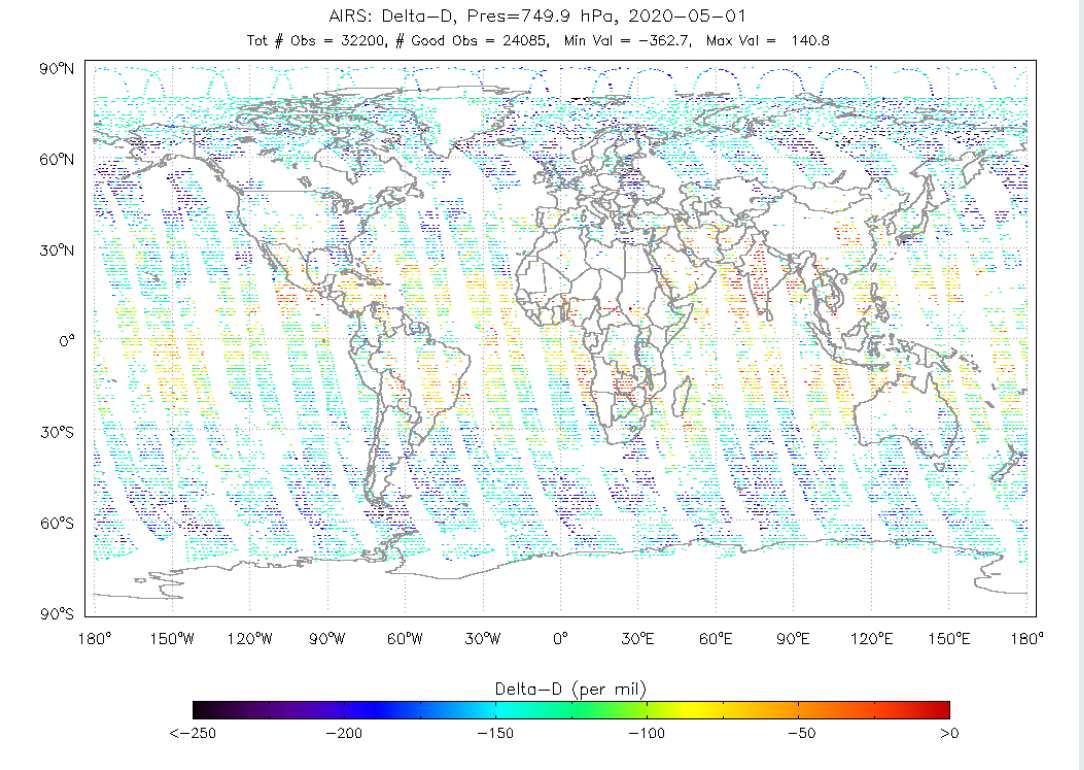
* TRopospheric Ozone and its Precursors from Earth System Sounding

Sub-sampling strategy:
~ 30,000 observations / day

Processing chain:

- AIRS+OMI radiances for daytime O_3
- Additional retrieval steps (day+night): AIRS-Only radiances for gases including O_3, CO, CH_4, NH_3 and HDO/H_2O.

The TROPESS team is coordinating with John Moses for talks with ESDIS and GES DISC teams to finalize file format and documentation.

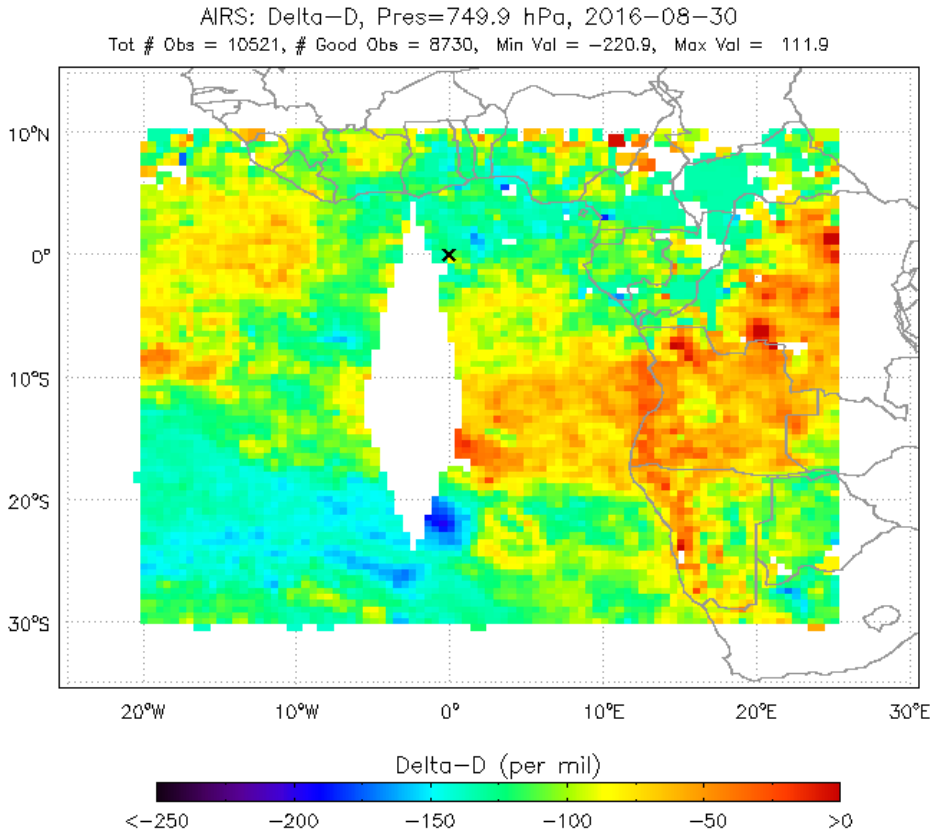


AIRS Dense Sampling in Special Observations

MUSES framework allow custom sub-sampling processing

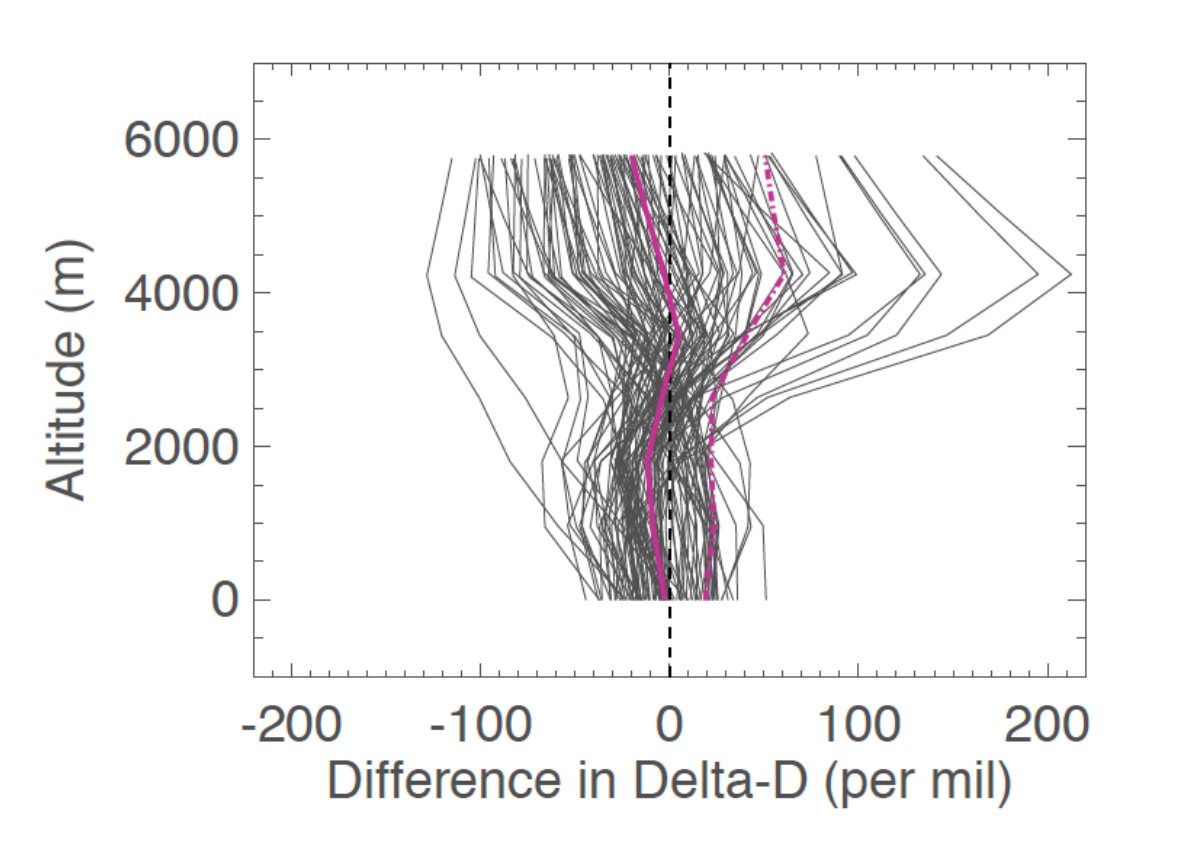
Available Now:

- Special Observations rectangle over SE Atlantic and Africa.
- All FOVs in ORACLES domain
- 10 N to 30 S, 20 W to 25 E.
- ~ 10,000 obs / day
- Dates
  - 2016: August 30 to September 30
  - 2017: August 9 to September 2



Statistics of AIRS minus WISPER Delta D

WISPER is airborne in-situ HDO instrument in ORACLES



446 pairs (black),
mean (red solid)
RMS (red dash dot)

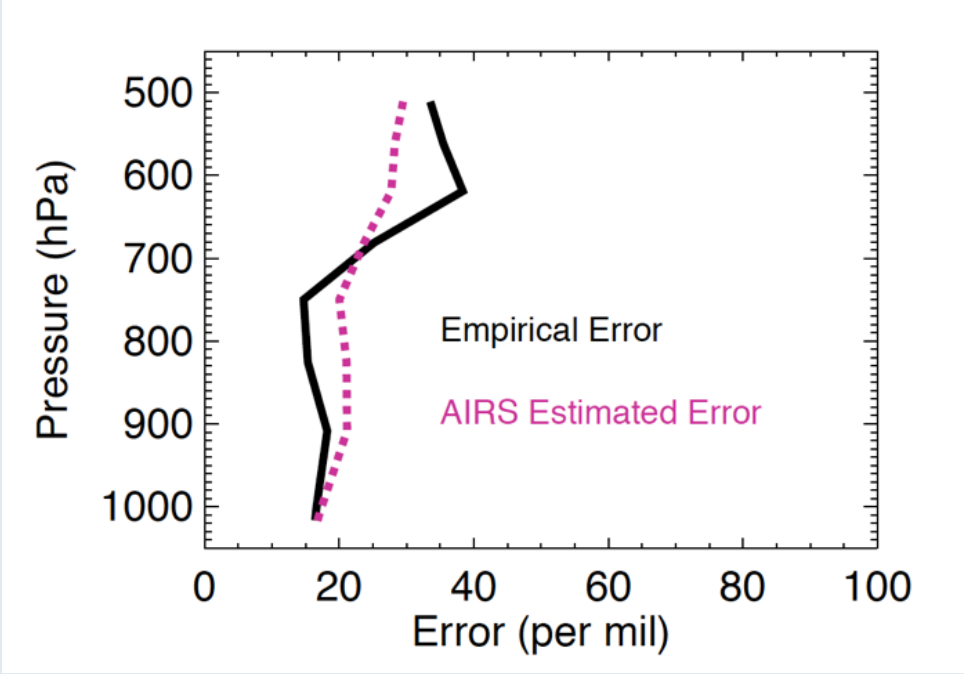
Robert L. Herman, John Worden, David Noone et al., Atmos. Meas. Tech., 13, 1825–1834, 2020, https://doi.org/10.5194/amt-13-1825-2020

Error Estimate, Delta D

Optimal Estimation

AIRS Estimated Error of HDO/H_2O is comparable to Satellite vs. Aircraft Empirical Error.

This validates not just AIRS delta-D but also the reported error estimates in the retrieval product.



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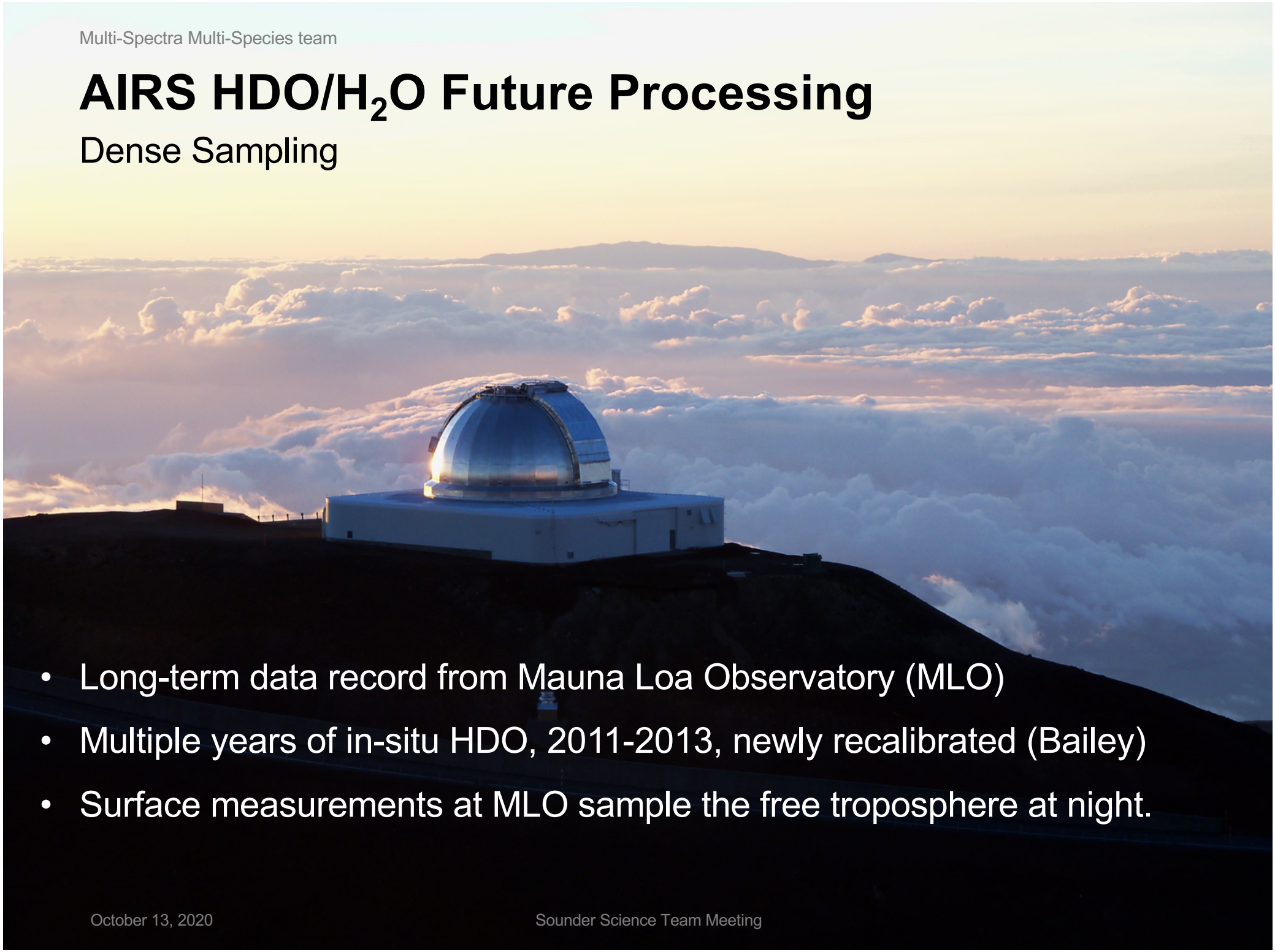
AIRS HDO/H_2O Future Processing

Dense Sampling



- Long-term data record from Mauna Loa Observatory (MLO)
- Multiple years of in-situ HDO, 2011-2013, newly recalibrated (Bailey)
- Surface measurements at MLO sample the free troposphere at night.

Summary:

AIRS Delta D

A global subset (~3,000 obs / day) of AIRS HDO/H_2O has been processed for the time period August 2002 – March 2020.

Under TROPESS:
A larger global subset (~30,000 obs / day) of AIRS HDO/H_2O will be processed using the same sub-sampling as the AIRS+OMI O_3 product.

Future validation opportunities include all FOVs during two-year data record at MLO.

Questions posed:

- What overarching science questions would you like to address with long-term sounder composition records, given what you know about their quality and uncertainty? ***How is regional hydrology changing (Delta-D as indicator)?***

- What should be the highest priorities when developing new trace gas products for air quality / climate monitoring? *Specific answer:* ***Integration of HDO from multiple instruments, e.g., TROPOMI and CrIS. General: signatures of rapidly changing climate.***

- What are the highest priorities from the perspective of chemical data assimilation? ***I defer to other speakers.***

- Given that the LEO sounders (IASI, IASI-NG, CrIS) will continue to be in orbit till ~2040s, what, in your mind, are the key observational gaps? ***Need HDO product from geostationary sounders. Missing Geo TIR over the Americas.***

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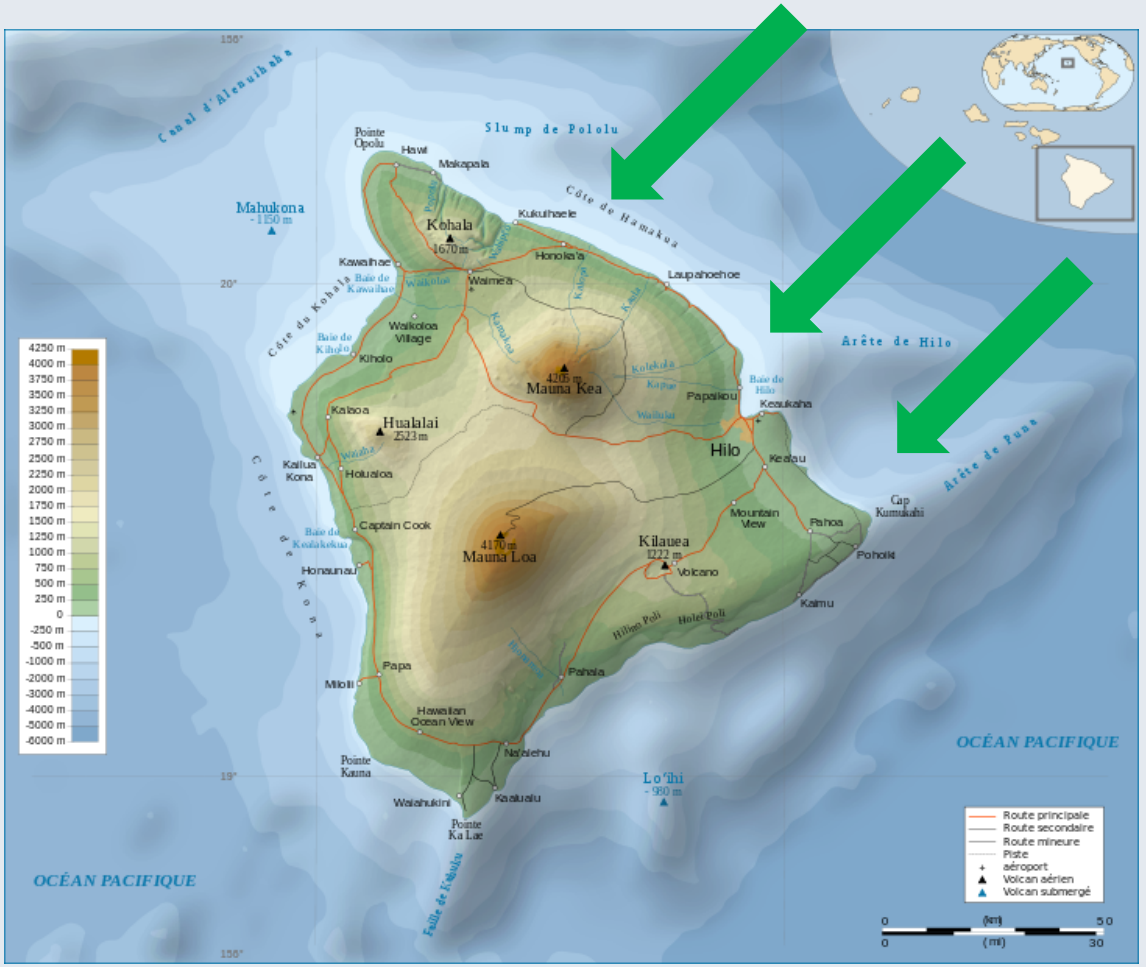
Backup Slides

AIRS Validation Plan

Delta-D compared with constructed true from MLO

trade winds

AIRS single-footprint radiances will be processed for 2011-2013 to compare with in-situ MLO data.



MLO

Daytime Meteorological Conditions (Garrett, MWR, 1980)

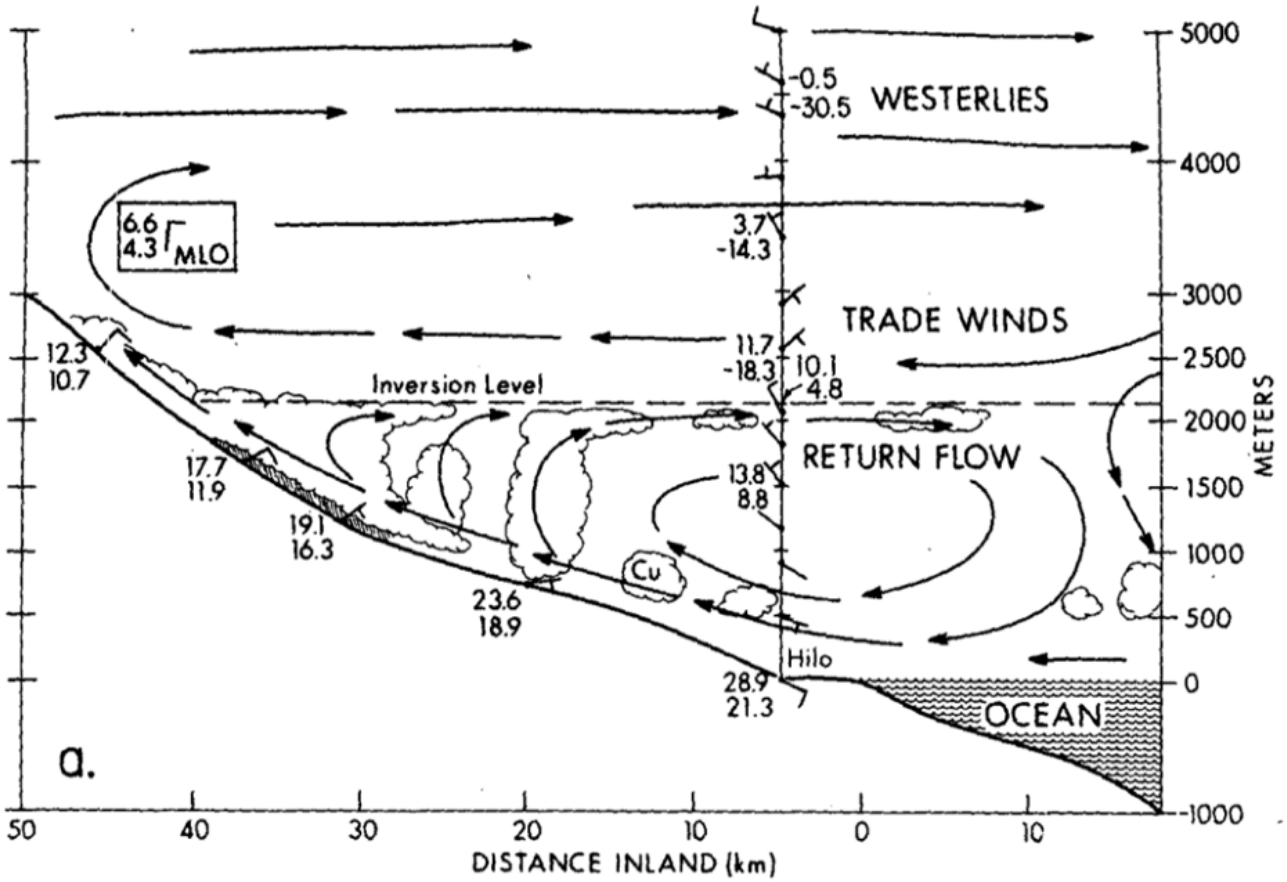


FIG. 7. East-west cross section depicting conceptual model of land and mountain-sea breeze circulations. Daytime upslope-sea breeze case (a) is from 1400 LST 3 June data. Nighttime drainage-land breeze case (b) is from 0600 LST 5 June data. Horizontal wind arrows: half feather = 2.5 m s^{-1}, full feather = 5 m s^{-1}. Dry-bulb temperatures (°C) are plotted above dewpoints and accompany wind arrows at each surface station. The same plotting convention is used for Hilo sounding. MLO is included

MLO

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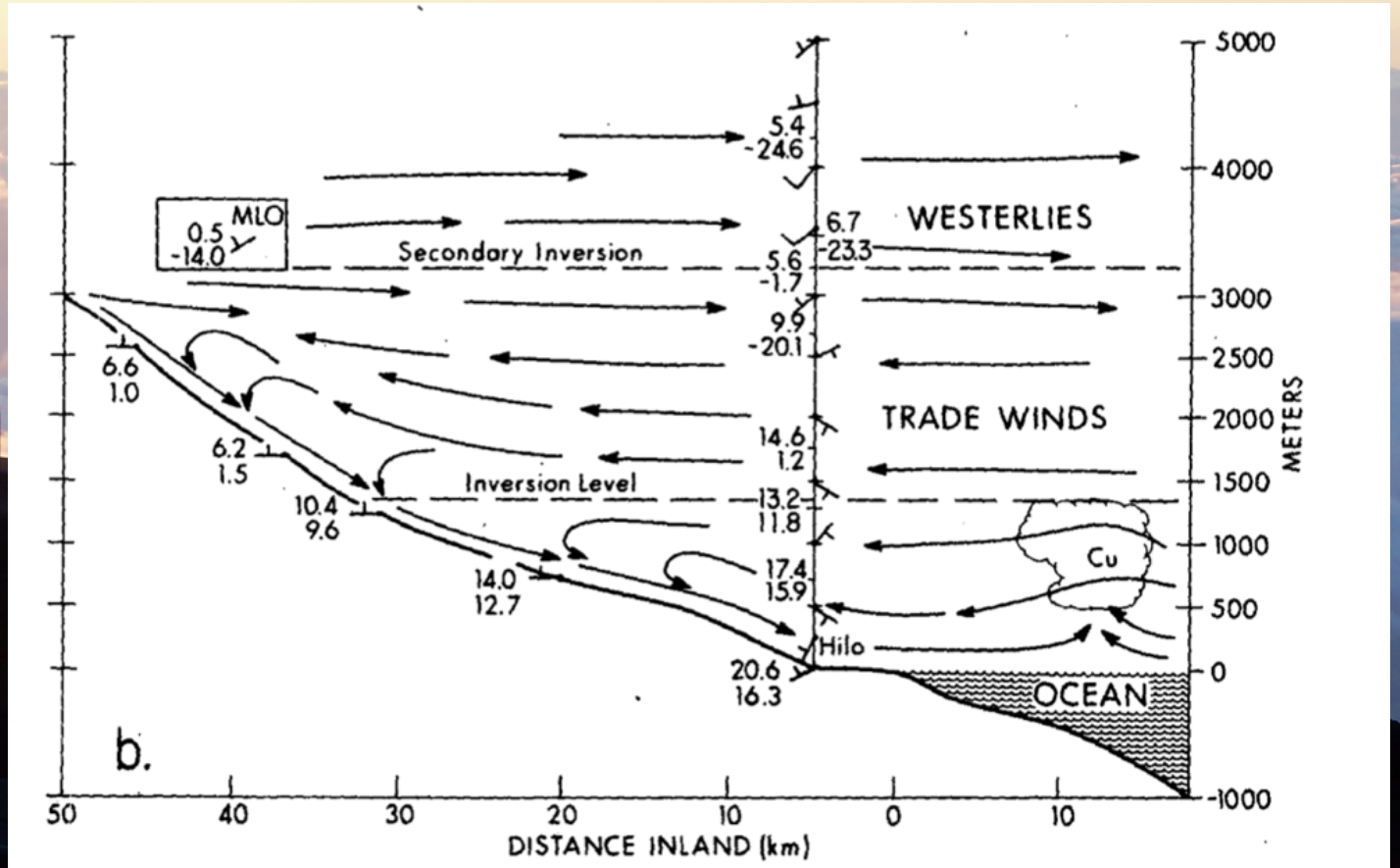

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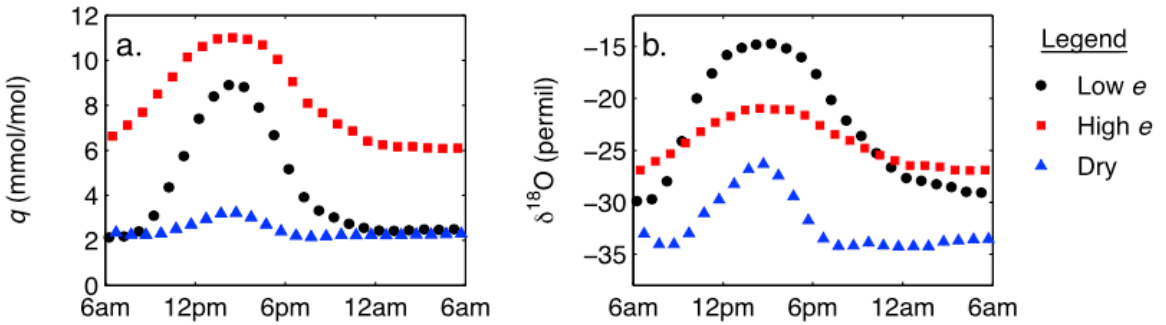
MLO

Diurnal Meteorological Conditions (from Bailey et al., JGR-A, 2015)

Journal of Geophysical Research: Atmospheres 10.1002/2015JD023403



q is H_2O volume mixing ratio
Delta-D behaves like 8*Delta^{18}O + 10
e is precipitation efficiency