Tropospheric HDO/H$_2$O from AIRS and CrIS:
Comparisons with Aircraft and Model HDO/H$_2$O

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. JPL / Caltech 2. Oregon State University. 3. BAERI,
4. Atmos. and Environ. Research, Inc., *Now at Univ. of Auckland, NZ

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AIRS HDO

Outline

1. Scientific Motivation
2. HDO Retrieval
3. HDO/H$_2$O Comparisons, AIRS vs aircraft
4. HDO/H$_2$O Comparisons, AIRS vs iCAM model
5. New HDO/H$_2$O from CrIS
1. 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

1) Characterizing Evaporation and Precipitation (John Worden and Mingjie Shi, this meeting)
2) Partitioning transpiration and river run-off (Good et al., Science 2015)
3) Amazon transpiration initiates rainy season (Wright et al., PNAS 2017)
2. HDO/H$_2$O Retrieval
The Retrieval Framework is an Optimal Estimation retrieval algorithm (TES heritage) using AER OSS forward model.

These retrievals use the AIRS single footprint IR geolocated and calibrated radiance data (Aumann et al., 2003).

AIRS and TES show a small bias for the HDO/H$_2$O ratio, AIRS biased low by -2.6 per mil. with latitudinal variation.

AIRS HDO are publicly available from the following link:

https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/TES/.AIRS/

3. HDO/H$_2$O Comparisons, AIRS vs aircraft
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.
- Water Isotopologue measurements from the WISPER instrument on the NASA P-3B Orion aircraft (Noone’s OSU group).
Multi-Spectra Multi-Species team

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$_2$O retrievals
Southeast Atlantic Ocean, 31 Aug 2016

AIRS tropical HDO/H$_2$O 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)
Estimated Error of AIRS HDO

Empirical Error from obs (black) and AIRS estimated error (red)
AIRS versus aircraft Summary:
Herman et al. (2020)*

- AIRS HDO/H₂O retrievals are very well characterized with ~1.5 DOFS.
- AIRS bias relative to the aircraft is -6.6‰ in the lower troposphere and -6.8‰ in the middle troposphere.
- AIRS RMS (in Delta D notation) is about 25 – 30 per mil.
- This is consistent with aircraft RMS.

4. HDO/H$_2$O 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.
- Grid cells 1.9 deg Latitude by 2.5 deg Longitude.
- Objective is to use the ORACLES observations to benchmark the model, and to compare variability between AIRS, ORACLES and model.

AIRS and ICAM Delta D
Southeast Atlantic, 31 Aug 2016

Color scale: mid-tropospheric AIRS delta-D.
Clouds: MODIS.
September Monthly Mean Delta D
AIRS (left), WISPER In-situ (middle) and ICAM Model (right)
September Monthly Mean Delta D
WISPER In-situ (left) and ICAM Model (right)
September 2, 2016, Comparison
AIRS averaging kernel applied to ICAM model

September 2nd 2016 (20°S, 3°E)

Pressure (hPa)

Delta-D (per mil)

AIRS
ICAM
ICAM AK
5. CrIS HDO
Multi-Spectra Multi-Species team

Global Comparisons
AIRS only (left) and CrIS 1.7.0 (right) Delta D for April 2020

AIRS: Delta-D, Pres=681.3 hPa, 2020-04-01 to 2020-04-19
Tot # Obs = 45505, # Good Obs = 39341, Min Val = -365.6, Max Val = 103.5

CRIS: Delta-D, Pres=681.3 hPa, 2020-04-01 to 2020-04-12
Tot # Obs = 43423, # Good Obs = 26308, Min Val = -778.2, Max Val = 183.7
Summary: AIRS and CrIS Delta D

AIRS HDO/H$_2$O retrievals are very well characterized $\sim$1.5 DOFS.

The small bias and consistent RMS suggests that the AIRS HDO/H$_2$O retrieval provides well characterized measurements. This level of uncertainty is good enough to address science questions.

Preliminary CrIS HDO/H$_2$O retrievals are encouraging.
AIRS
backup slides
1. Terminology
**Isotopologues**: molecules differing in isotopic composition, e.g., H$_2$O 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$_2$O, HDO, H$_2^{18}$O.

Standard Mean Ocean Water (SMOW) has the isotopic ratio (HDO/H$_2$O)$_{SMOW} = 3.115 \times 10^{-4}$.

**Delta notation**: $\delta D_{\text{sample}} = \left[\frac{(\text{HDO}/\text{H}_2\text{O})_{\text{sample}}}{(\text{HDO}/\text{H}_2\text{O})_{\text{SMOW}}} - 1\right] \times 10^3$

(per mil or ‰).
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).
AIRS HDO/H$_2$O retrievals
Radiance and Jacobians near 1240 cm$^{-1}$