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Comparison of Optimal Estimation HDO/H_2O Retrievals from AIRS with ORACLES measurements

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Abstract

In this paper we evaluate new retrievals of the deuterium content of water vapor from the Aqua Atmospheric InfraRed Sounder (AIRS) with aircraft measurements of HDO and H_2O from the ObseRvations of Aerosols above Clouds and their intEractionS (ORACLES) field mission. Single footprint AIRS radiances are processed with an optimal estimation algorithm that provides a vertical profile of the HDO/H_2O ratio, characterized uncertainties, and instrument operators (or averaging kernel matrix). These retrievals are compared to vertical profiles of the HDO/H_2O from the Oregon State University Water Isotope Spectrometer for Precipitation and Entrainment Research (WISPER) on the ORACLES NASA P-3B Orion aircraft. Measurements were taken over the Southeast Atlantic Ocean from 31 August to 25 September 2016. HDO/H_2O is commonly reported in δD notation, which is the fractional deviation of the HDO/H_2O ratio from the standard reference ratio. For collocated measurements, the satellite instrument operator (averaging kernels and a priori constraint) is applied to the aircraft profile measurements. We find that AIRS δD bias relative to the aircraft is well within the estimated measurement uncertainty. In the lower troposphere, 1000 to 800 hPa, AIRS δD bias is -6.6‰ and the Root Mean Square (RMS) deviation is 20.9‰, consistent with the calculated uncertainty of 19.1‰. In the mid-troposphere, 800 to 500 hPa, AIRS δD bias is -6.8‰ and RMS 44.9‰, comparable to the calculated uncertainty of 25.8‰.

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1. Introduction

The deuterium content of tropospheric water vapor is sensitive to the different types of atmospheric moisture sources such as evaporation from the ocean or land and the processing that occurs during transport such as mixing or condensation (e.g., Craig, 1961; Dansgaard, 1964; Galewsky et al., 2016). Condensation and precipitation preferentially remove the heavier HDO isotopologue from the gas phase relative to the parent isotopologue H_2O, whereas evaporation of precipitation at lower altitudes in the atmosphere can enrich HDO relative to H_2O vapor. These unique, isotopic properties allow HDO/H_2O to be a tracer for the origin, condensation and evaporation history of an air parcel, thus useful for evaluating changes to the water cycle (e.g., Worden et al., 2007; Noone, 2012; Galewsky et al., 2016).

In the last decade, satellite retrievals of the isotopic composition of tropospheric water vapor (HDO and H_2O) have been developed, including Envisat/SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography) (Frankenberg et al., 2009), IASI (Infrared Atmospheric Sounding Interferometer) aboard the MetOp satellites (Herbin et al., 2009; Schneider and Hase, 2011; Lacour et al., 2012), and TES (the Tropospheric Emission Spectrometer) on the Aura spacecraft (Worden et al., 2006; Worden et al., 2007). More recently, Worden et al. have developed HDO retrievals from the Aqua Atmospheric InfraRed Sounder (AIRS) single footprint Level 1b radiance data (Worden et al., 2019). These AIRS retrievals are the subject of the present comparison with aircraft data.

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Satellite HDO measurements have been utilized to study tropical carbon/water feedbacks (Wright et al., 2017), moist processes in deep convection (e.g. Worden et al., 2007), and the global partitioning of transpiration to evapotranspiration (Good et al., 2015). A decadal record of HDO has promise in characterizing global shifts in moisture sources and atmospheric water balance in response to warming, climactic variability, and land-use. For example, Bailey et al. (2017) shows that a record of free-tropospheric HDO/H_2O would provide an observational constraint on changes in the tropical water balance (evaporation minus precipitation) in response to shifts in ocean temperature. Wright et al. (2017) also shows that free-tropospheric deuterium measurements provide a fundamental new constraint in carbon / water dynamics in the Amazon. They use the TES isotope measurements to show that dry-season evapotranspiration is critical towards initiating the southern Amazon rainfall, which in turn is critical towards sustaining the Amazon rainforest (Fu et al., 2013). For these reasons a record of the deuterium content of water vapor from the long (17 years and continuing) record from AIRS holds significant potential to evaluate changes in the global water cycle.

This paper presents detailed comparisons between new AIRS measurements of the deuterium content of water vapor (or HDO/H_2O ratio) and accurate *in situ* HDO/H_2O measurements from an aircraft sensor during the NASA ObseRvations of Aerosols above Clouds and their intEractionS (ORACLES) field mission. In this paper, we denote the volume mixing ratios q_D for HDO, and q_H for H_2O. By standard convention, we report the isotopic abundance as δD (per mil or ‰) = $[(q_D/q_H)_{obs}/(q_D/q_H)_{std} - 1] * 1000$, where $(q_D/q_H)_{std}$= 3.11x10^{-4} based on the D/H standard ratio for Vienna Standard Mean Ocean Water (SMOW).

2. Instrumentation

2.1 AIRS Instrument Description

The Atmospheric InfraRed Sounder (AIRS) on the NASA Aqua satellite is a nadir-viewing, scanning thermal infrared grating spectrometer that covers the 3.7 to 15.4 µm spectral range with 2378 spectral channels (Pagano et al., 2003, and Aumann et al., 2003). Launched on May 4, 2002, Aqua is in a sun-synchronous orbit at 705 km with an approximately 1:30 pm equator crossing-time as part of the A-Train satellite constellation. AIRS continues to make daily measurements of most of the globe with its wide cross-scanning swath of coverage. The AIRS instrument makes collocated measurements with the Advanced Microwave Sounding Unit (AMSU) on the Aqua satellite. There are nine AIRS single footprint observations (nadir horizontal resolution of ~13.5 km) arranged in a 3 by 3 grid within a single AMSU footprint of ~45 km (Aumann et al., 2003). For HDO retrievals, the single footprint AIRS Level 1b (L1b) radiances are utilized. Absolute radiometric accuracy between 220 K and 320 K at all observation angles is better than 0.2 K (Pagano et al., 2003, 2008). The algorithm applied to AIRS radiances to yield HDO is described below in Sect. 3.1.

2.2 WISPER system for aircraft measurements

Aircraft measurements were made on the NASA P-3B Orion aircraft during the NASA ORACLES field mission. ORACLES is a five-year Earth Venture Suborbital (EVS-2)

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investigation with three Intensive Observation Periods (IOP) designed to study key processes that determine the climate impacts of African biomass burning aerosols in 2016, 2017, and 2018. The ORACLES experiment provided multi-year airborne observations from the NASA P-3B Orion and ER-2 aircraft over the complete vertical column of the key parameters that drive aerosol-cloud interactions in the southeast Atlantic Ocean region. The focus of the ORACLES field measurements was a biomass burning plume that advected west from the African continent to the lower troposphere (at 2 to 5 km above sea level, ASL) above the Atlantic Ocean. Here we use data from the ORACLES 2016 IOP (ORACLES Science Team, 2017), and report on aircraft versus satellite comparisons from eight flights (Fig. 1 and Table 1).

Water vapor isotopic abundances (HDO/H_2O and $H_2{}^{18}O/H_2{}^{16}O$) were measured in situ on the aircraft with the Oregon State Water WISPER system (Water Isotope Spectrometer for Precipitation and Entrainment Research, Henze et al., in prep.), which uses a modified commercial Picarro L2120-i δD/ $\delta^{18}O$ Ultra High-Precision Isotopic Water Analyzer. The measurement technique is cavity ring-down (CRD) spectroscopy (O'Keefe and Deacon, 1988; Berden et al., 2000; Gupta et al., 2009). The majority of measurements analyzed in this paper are located within the biomass burning plume, characterized by elevated H_2O (approximately 6000 ppmv) and elevated δD (-100 to -70‰). At these abundances of HDO/H_2O, the 1-Hz precision (1σ) of the measurements of δD is ±3‰, and the accuracy is ±6.5‰.

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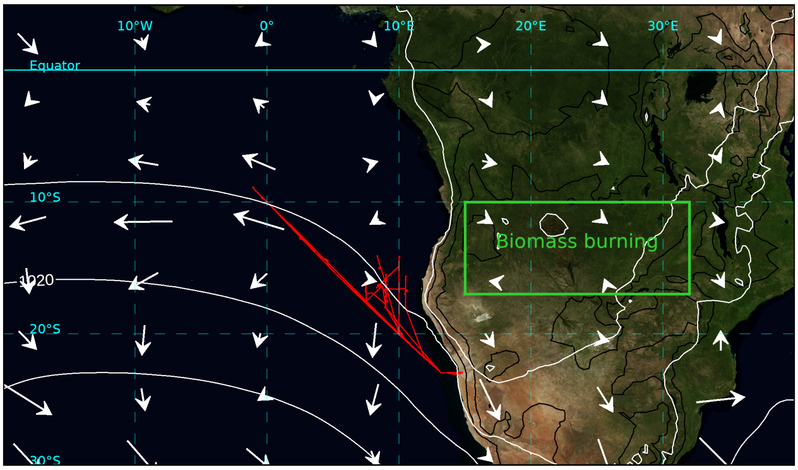

Figure 1. Selected flight tracks (red lines) of the NASA P-3B Orion aircraft during the ORACLES 2016 IOP used in this study, with corresponding flight dates listed in Table 1. Also shown is the biomass burning region (green rectangle), 700 hPa winds (white vectors), and surface pressure (white isobars).

Table 1. Summary of matches AIRS and WISPER δD measurements during NASA ORACLES*.

Flight Date	Daily Number of Matched Profiles, loose lat/lon constraint.	Daily Number of Matched Profiles, tighter lat/lon constraint.
31-Aug-2016	138	26
2 Sep 2016	15	15

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4 Sep 2016	102	26
10 Sep 2016	48	7
12 Sep 2016	18	4
14 Sep 2016	12	5
20 Sep 2016	11	4
25 Sep 2016	102	23
Total	**446**	**110**

*NASA ORACLES is the "ObseRvations of Aerosols above Clouds and their intEractionS" Earth Venture Suborbital Mission.

3 Satellite Retrieval

3.1 Retrieval Algorithm

The single footprint AIRS HDO profile data used in this work were produced using the retrieval algorithm, named the MUlti-SpEctra, MUlti-SpEcies, MUlti-Sensors (MUSES) algorithm (Fu et al., 2013, 2016, 2018; Worden et al., 2019). The MUSES algorithm can use radiances from multiple instruments including AIRS and other instruments (CrIS, TES, OMI, OMPS, TROPOMI, and MLS) to quantify geophysical observables that affect the corresponding radiance. The AIRS single footprint HDO profile retrievals have been described by Worden et al. (2019), and have heritage from the TES algorithm (Worden et al., 2004, 2006, 2007, 2011, 2012, 2013; Bowman et al. 2006, 2002). The Optimal Spectral Sampling (OSS) fast radiative transfer model (Moncet et al., 2008, 2015) for single footprint AIRS measurements has been integrated into the MUSES algorithm, in support of the operational data production towards the multi-decadal record of global HDO profiles. The supplement attached to this paper discusses the sensitivity of the retrievals to the choice of forward model. The retrieval uses the optimal estimation method to quantify atmospheric HDO and H_2O (Worden et al. 2006, 2012, 2019). For both AIRS and TES retrievals, height discrimination of the HDO/H_2O ratio in the troposphere is provided by spectral resolution of pressure and temperature broadened absorption features of their corresponding lines (Beer et al., 2002). The algorithms and spectral microwindows are described by Worden et al. (2019). Chemical species CH_4, CO, HDO, and H_2O are jointly retrieved along with atmospheric temperature, surface temperature, land emissivity and clouds (Worden et al. 2012). The retrieval optimizes the ratio of HDO to H_2O, as opposed to either HDO or H_2O alone (Worden et al., 2019, 2012, 2006). AIRS radiances at wavelengths from 8 to 12 μm are used here, excluding the 9.6 μm ozone band. The parent molecule H_2O is retrieved at both 8 and 12 μm, but HDO is retrieved primarily from strong absorption lines in the 8 μm region (particularly in the wavenumber range 1210 to 1270 cm^{-1}). Cloud optical depth and cloud top pressure are jointly retrieved with the chemical species, using the approach described in Kulawik et al. (2006). The cloud-clearing approach (Susskind et al., 2003), utilized in AIRS operational products up to and including AIRS v6, where retrievals are reported on the 45 km AMSU footprint, is not utilized here. As described by Worden et al. (2019), retrievals are performed on single AIRS 13.5-km footprints in order to preserve the Level 1B radiance noise characteristics (Irion et al., 2018; DeSouza et al., 2018).

For H_2O, the a priori constraint vectors come from NASA's Goddard Earth Observing System (GEOS) data assimilation system GEOS version 5.12.4 processing stream (Rienecker et al., 2008). These are produced by the Global Modeling and Assimilation Office (GMAO) at the NASA Goddard Space Flight Center (GSFC). The GMAO GEOS-5.12.4 water mixing ratios are linearly interpolated to the latitudes, longitudes, and

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log(pressure) levels of satellite retrievals to generate the a priori profiles.

For all HDO retrievals, the initial profile of the $HDO/H_2{}^{16}O$ isotopic ratio is set equal to a simulated tropical profile (Worden et al., 2006). In the AIRS HDO product files, a priori HDO is defined as the product of the local a priori H_2O profile (GMAO GEOS-5.12.4) and one tropical a priori profile of the HDO/H_2O isotopic ratio (Worden et al., 2006). The initial guess profiles for H_2O are set equal to the a priori.

3.2 Method of comparison

The AIRS HDO/H_2O retrievals are matched up in space and time with the aircraft in situ HDO/H_2O measurements. A critical aspect of validating satellite retrievals is obtaining data that span the altitudes where the satellite has sensitivity to HDO/H_2O. AIRS data are sensitive to the HDO/H_2O ratio in the atmosphere from the surface up to approximately 10,000 m altitude. The aircraft samples HDO and H_2O from the surface up to 6000 m altitude, spanning most of the altitudes where the AIRS data are sensitive and therefore allowing us to validate AIRS HDO/H_2O with in situ measurements.

For direct comparison of AIRS HDO/H_2O with in situ HDO/H_2O, the AIRS instrument operator (averaging kernel and *a priori* constraint) is applied to the in situ data (see Eq. 1 below), as described by Rodgers (2000). This has the effect of smoothing the in situ data to the same resolution as the satellite retrievals. The averaging kernel matrix A is the sensitivity of the AIRS estimate to the true concentration in the atmosphere (Rodgers, 2000). The in situ profile with applied averaging kernel $x_{insituw/AK}$ is calculated jointly for

HDO and H_2O using the AIRS operator:

$$x_{insituw/AK} = x_a + A_{xx}(x - x_a) \quad (1)$$

Joint HDO/H_2O retrievals are performed on the logarithm of the volume mixing ratios, $x_D = \ln(q_D)$ and $x_H = \ln(q_H)$ (Worden et al., 2012, 2006). The data structure for AIRS HDO files is similar to TES HDO, with details provided by Herman et al. (2014).

For comparison with AIRS, the in situ HDO and H_2O profiles are extended to cover the full range of AIRS levels. In the boundary layer, from the surface up to the lowest altitude aircraft data, we assume constant values of HDO and H_2O set equal to the first aircraft measurement. In the range of aircraft data (up to 6000-m flight ceiling), the aircraft in situ HDO and H_2O data are interpolated to the levels of the AIRS forward model, smoothing fine scale features. In the layers above the aircraft maximum altitude, the profile is extrapolated using a scaled a priori profile. In this paper, all comparisons have been completed applying Eq. 1.

4 Validation

Validating the accuracy of AIRS HDO and H_2O retrievals is important for studies of the hydrologic cycle, exchange processes in the troposphere, and climate change. Comparisons of AIRS and TES over five years (2006-2010) indicate that the retrieval characteristics of the AIRS HDO/H_2O measurements have similar vertical resolution and uncertainty in the middle troposphere but with slightly less sensitivity in the lower troposphere (Worden et al., 2019). Worden et al. (2019) reported that the calculated

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uncertainty of AIRS HDO/H_2O is ~30 per mil for a tropospheric average between 750 and 350 hPa, with mean bias between TES and AIRS (TES-AIRS) for the HDO/H_2O ratio of ~-2.6 per mil and a latitudinal variation of ~7.6 per mil.

4.1 Comparison of AIRS with Aircraft Measurements

ORACLES 8/31 to 9/25/2016 data comparison.

In this section, we describe comparisons between AIRS and ORACLES aircraft HDO measurements. First, time segments of each aircraft flight are identified where the aircraft profiled from the boundary layer up to approximately 6000 m altitude. To minimize the impact of atmospheric spatial and temporal variability, same-day AIRS measurements are selected for the same latitude/longitude rectangle as each aircraft profile (Fig. 2). These matched pairs are compared by the method described in Sect. 3.2. Within each flight are several profiles each spanning 1 to 3 degrees (or ~ 100 to 300 km), so measurement pairs are typically within 3 degrees (Fig. 2). The standard data retrieval quality flags for the retrieval are used in this analysis, which are based on the Aura TES data retrieval quality flags (Herman and Kulawik, 2018). For closer spatial coincidence, we also selected AIRS-aircraft measurement pairs within 0.3 degrees (Fig. 3). Following Worden et al. (2007) and Brown et al. (2008), we filter data for a reasonable threshold of DOFS (DOFS > 1.1), but include all cloud optical depths. Fig. 4(a) shows a representative 31 Aug 2016 comparison between aircraft water vapor δD from WISPER and the coincident AIRS retrieval. Fig. 4(b) shows the corresponding averaging kernels.

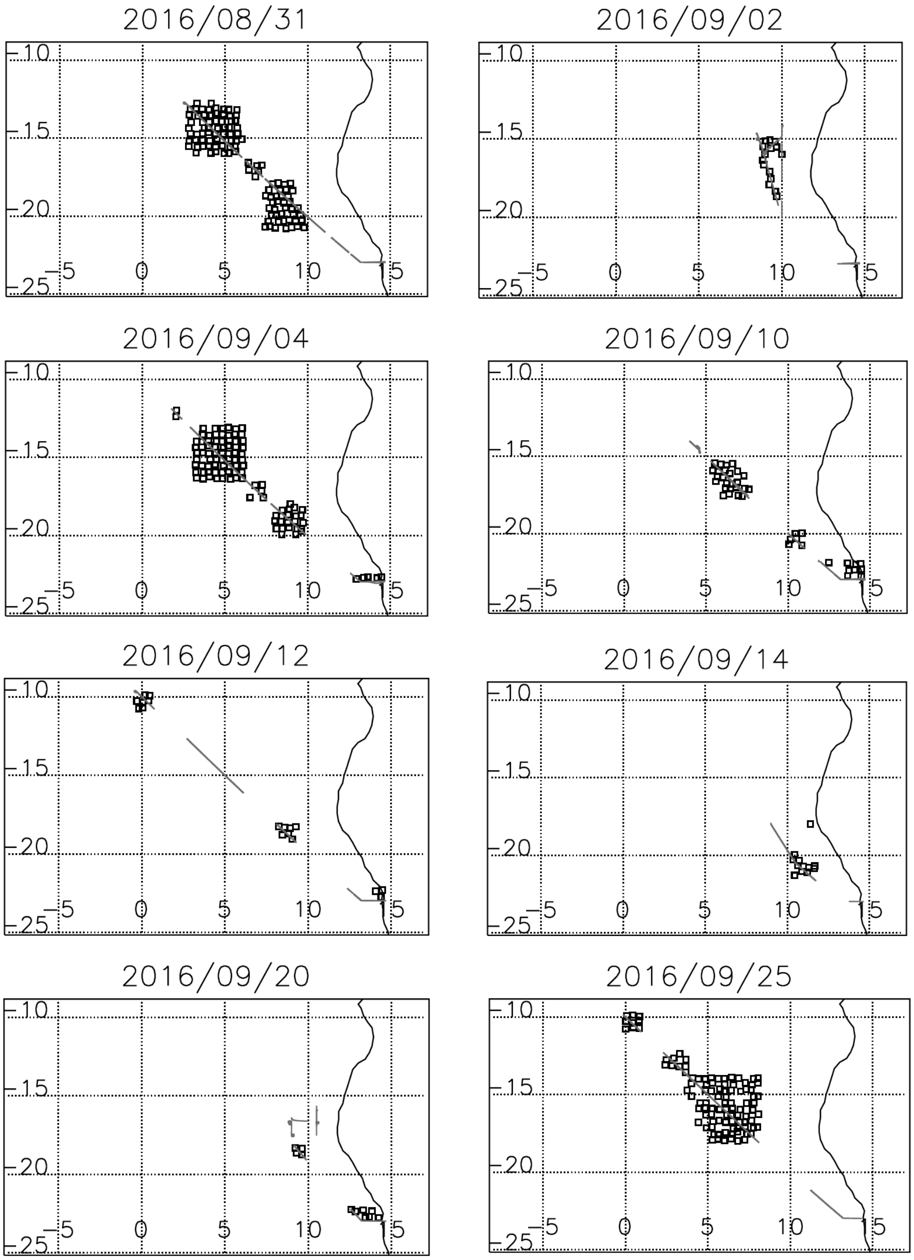

Figure 2. ORACLES aircraft profiles (thin grey line segments) over the southeast Atlantic Ocean to the west of Africa are matched to AIRS fields of view (FOVs) (square symbols) within the same latitude/longitude rectangle as the aircraft profiles for eight

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flights in 2016.

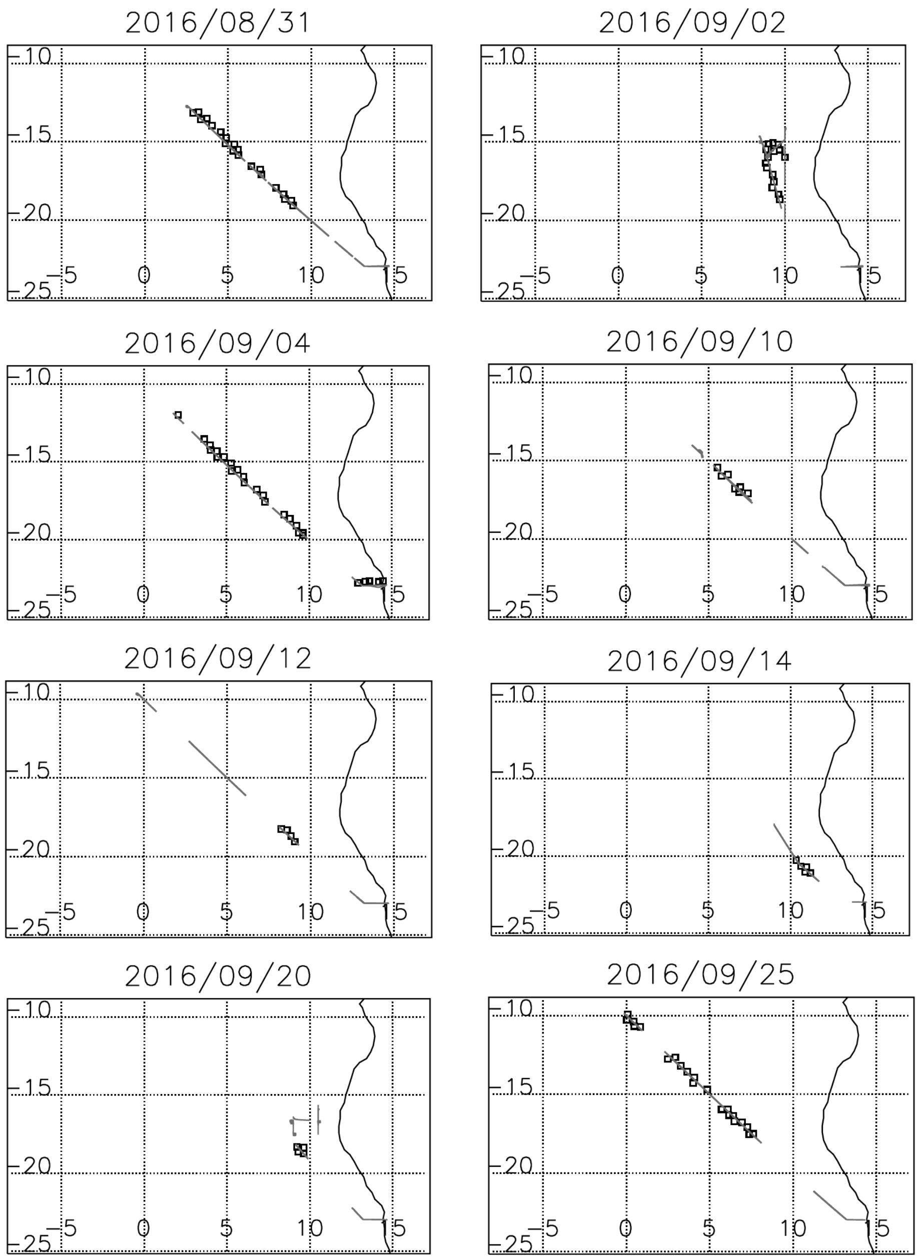
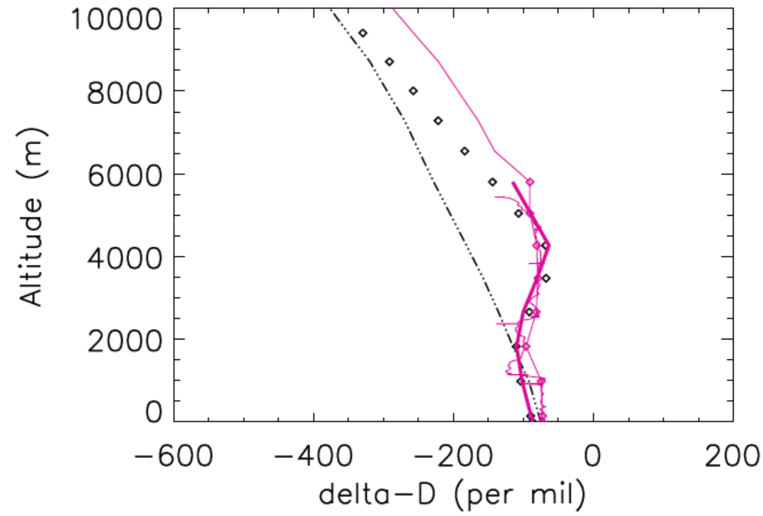


Figure 3. In close spatial coincidence, ORACLES aircraft profiles (thin grey line segments) are matched within 0.3 degrees to AIRS FOVs (square symbols).



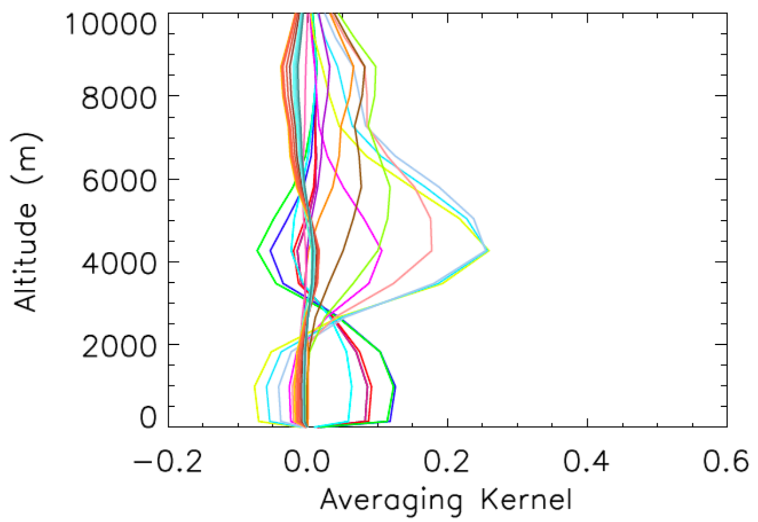


Figure 4. **(a)** Sample comparison of the δD profiles by aircraft and satellite over the southeast Atlantic Ocean during ORACLES on 31 August 2016: shown are AIRS δD (black diamond symbols), the prior δD (black dash-dot-dot line), nearest WISPER δD (thin red line), WISPER δD interpolated to satellite levels (red diamonds), and the WISPER δD with the AIRS averaging kernel applied (thick red line).

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(b) Averaging Kernel corresponding to same AIRS profile on 31 August 2016, color-coded by pressure level. Averaging kernels with the largest positive sensitivity below 2000 m are from the lowest altitudes.

4.2 AIRS Bias correction

TES HDO/H_2O ratios are biased compared to model and in situ measurements (Worden et al., 2006, 2007, 2011). We assess whether AIRS HDO has a bias relative to in situ measurements. As described above, AIRS and TES show a small bias for the HDO/H_2O ratio of ~-2.3 per mil (Worden et al., 2019) after a bias correction is applied, so it is reasonable to see how well in situ and AIRS data agree if the TES bias correction is applied to the AIRS HDO. Herman et al. (2014) estimated the TES bias δ_{bias} by minimizing the difference between bias-corrected TES and in situ δD with TES operator applied:

$$\delta_{bias} = 0.00019 \times Pressure - 0.067 \quad (2)$$

We apply the TES δ_{bias} to the AIRS data to evaluate against ORACLES aircraft data. There are 446 matched profiles of AIRS and ORACLES within the same latitude/longitude boxes (Fig. 2), and 110 closely-matched profiles within 0.3 degrees or approximately 30 km (Fig. 3). Comparisons with averaging kernel applied are shown in Fig. 5 and Table 2. Over the range of aircraft data, 0 km to 6 km altitude, AIRS δD has a mean bias of -6.7‰ relative to the aircraft profiles, well within the estimated measurement uncertainty of both AIRS and the WISPER calibration. This is consistent with TES δD (Worden et al., 2019; Herman et al., 2014). AIRS lower-tropospheric δD bias is -6.6‰ and RMS 20.9‰ (surface to 800 hPa). In the mid-troposphere, 800 to 500

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hPa, AIRS δD bias is -6.8‰ and RMS 44.9‰.

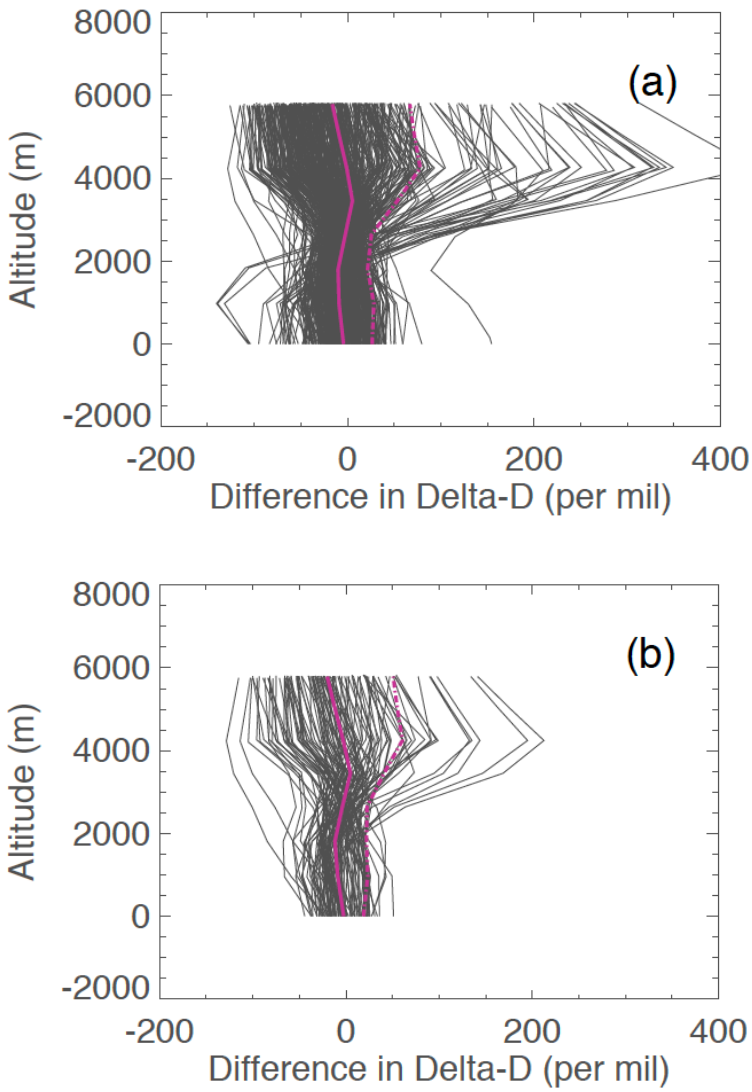

Figure 5. (a) AIRS minus ORACLES aircraft δD for the 446 matches within 3 degrees (Fig. 2). Lines are individual profiles (black lines), mean (red solid line) and RMS (red

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dash dot line).

(b) AIRS minus ORACLES aircraft δD for the 110 matches within 0.3 degrees (Fig. 3).

Table 2. Summary of satellite-aircraft comparisons for 110 matched pairs in 2016 (Fig. 3). Bias and RMS (standard deviation) of AIRS δD relative to ORACLE aircraft with averaging kernel applied ("BiasAK", "RMSak"), and for AIRS relative to mapped ORACLES aircraft, no averaging kernel ("Bias", "RMS").

Altitude (m)	Pressure (hPa)	BiasAK (‰)	RMSak (‰)	Bias (‰)	RMS (‰)
0.01	1014.63	-2.46	18.98	-14.82	22.64
136.61	1000.00	-3.35	19.38	-18.14	22.79
968.87	908.51	-8.86	23.39	-0.31	131.50
1807.71	825.40	-11.80	22.05	9.77	89.68
2641.34	749.89	-3.89	22.63	-13.24	38.07
3456.36	681.29	4.89	41.03	-3.66	35.98
4250.29	618.97	-2.96	60.63	12.52	76.03
5027.62	562.34	-11.87	55.15	-16.62	73.75
5792.12	510.90	-20.09	50.61	-40.41	81.22

5. Error estimation

In this section we characterize the error budget for AIRS and assess this error by comparison with the ORACLES aircraft measurements. Error analysis in optimal estimation has been described in detail in the literature (Worden et al., 2004, 2006; Bowman et al., 2004; Rodgers, 2000). The error $\tilde{\boldsymbol{x}}$ in the estimate of HDO/H_2O is defined as the true state $\boldsymbol{x}$ minus the linear estimate $\hat{\boldsymbol{x}}$ retrieved by AIRS (e.g., Worden et al., 2006, Eq. (15)):

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$$\boldsymbol{\tilde{x}} = \boldsymbol{x} - \boldsymbol{\hat{x}}. \tag{3}$$

Similar to Herman et al. (2014), we define the *estimated error* of the AIRS isotopic ratio HDO/H_2O, (Eq. 4) as the observation error covariance (Worden et al., 2006):

$$\boldsymbol{S} = \boldsymbol{G_R S_n G_R^T} + \boldsymbol{G_R}\left(\textstyle\sum_i \boldsymbol{K_i S_b^i K_i^T}\right)\boldsymbol{G_R^T}, \tag{4}$$

where $\boldsymbol{G_R} = (\boldsymbol{G_z^D} - \boldsymbol{G_z^H})$, $\boldsymbol{S_n}$ is the measurement error covariance, and $\boldsymbol{S_b^i}$ is the error covariance due to systematic errors and interference errors. The estimated error is given by the square roots of the diagonal elements of $\boldsymbol{S}$, the best estimate of the AIRS observation error covariance for the HDO/H_2O retrieval. In the case where AIRS is compared to in situ measurements without the averaging kernel, there is an additional smoothing error.

The estimated error (Eq. 4) is compared to the empirical error calculated from the AIRS-aircraft comparisons. It is seen that the error varies from ~20 to ~40 per mil (Fig. 6). The empirical error (AIRS versus aircraft RMS) is similar in magnitude to the estimated error, but exceeds the estimated error at 500 to 600 hPa in the free troposphere. These differences are likely due to atmospheric variability as we do not have exact matchups between the AIRS data and aircraft measurements.

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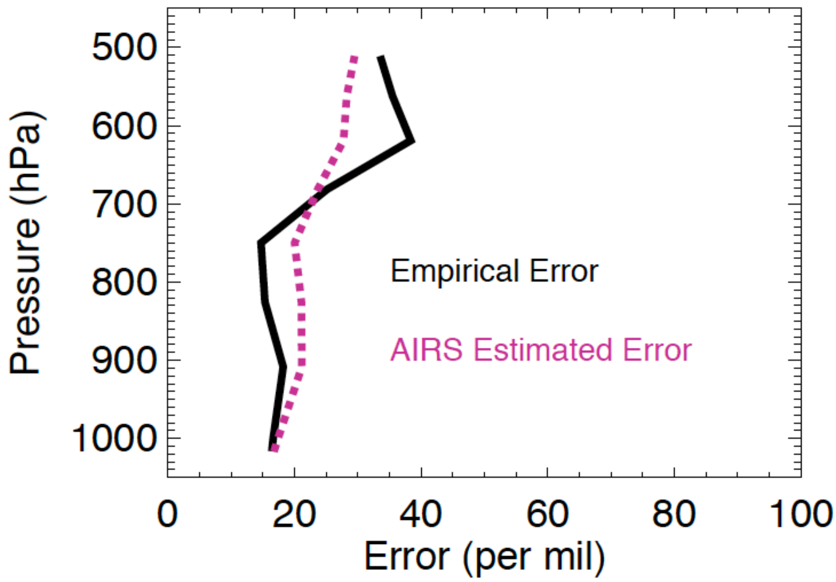

Figure 6. AIRS error analysis for coincident AIRS and ORACLES δD on 31 August 2016 shows the empirical error is comparable to the AIRS estimated error. Plotted are the AIRS δD estimated error also known as AIRS observation error (red dashed line) and the AIRS δD empirical error (black line).

6. Conclusions

HDO/H_2O estimates from AIRS single footprint radiances been compared to coincident in situ airborne measurements on the P-3B Orion aircraft by the Oregon State Water WISPER system (Water Isotope Spectrometer for Precipitation and Entrainment Research) over the Southeast Atlantic Ocean. On eight days between 31 Aug and 25 Sep 2016, there are collocated measurements between AIRS and the P-3B aircraft. We have

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shown that AIRS-only retrievals have sensitivity to HDO from the middle troposphere to the boundary layer. We demonstrate that AIRS δD has a mean bias of -6.7‰ relative to aircraft, well within the estimated measurement uncertainty. In the lower troposphere, 1000 to 800 hPa, AIRS δD bias is -6.6‰ and the RMS 20.9‰, consistent with the calculated uncertainty of 19.1‰. In the mid-troposphere, 800 to 500 hPa, AIRS δD bias is -6.8‰ and RMS 44.9‰, comparable to the calculated uncertainty of 25.8‰.

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Code/Data availability. The ORACLES aircraft data used in the data analysis can be freely downloaded from the following Digital Object Identifier: (http://dx.doi.org/10.5067/Suborbital/ORACLES/P3/2016_V1, last access: 22 April 2017). We expect the AIRS-based deuterium data to be publicly released by January 2020. Files in IDL format of the AIRS data shown and forward model output are available from coauthor John Worden upon request: john.r.worden@jpl.nasa.gov.

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Author contribution. RH carried out all steps of aircraft validation, from matching data and quality filtering to applying observation operator and statistics, while JW provided satellite-to-satellite validation. JW developed the retrieval strategies for both AIRS and TES HDO/H_2O retrievals. DF and SK built the strategies of single AIRS footprint HDO/H_2O retrievals into the MUSES algorithm. KC, RH and VP evaluated the sensitivities of retrievals to the choice of forward model. RH, VP, JW, SK, DF, DN, DH and KB contributed to the text and interpretation of the results. JW and SK helped in the estimation of HDO/H_2O measurement uncertainty, quality flagging and knowledge of the retrieval process. DN and DH provided ORACLES data, aircraft measurement uncertainty, and identified profiles in the aircraft data. All authors participated in writing the manuscript.

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