Microwave Limb Sounder (MLS)
Specific humidity Data Description

1. Intent of This Document

1a) This document is intended for users who wish to compare satellite derived observations with climate model output in the context of the CMIP5/IPCC historical experiments. Users are not expected to be experts in satellite derived Earth system observational data. This document summarizes essential information needed for comparing this dataset to climate model output. References to additional information for expert users are provided at the end of this document.

This NASA dataset is provided as part of an experimental activity to increase the usability of NASA satellite observational data for the model and model analysis communities. This is not a standard NASA satellite instrument product. It may have been reprocessed, reformatted, or created solely for comparisons with the CMIP5 model. Community feedback to improve and validate the dataset for modeling usage is appreciated. Email comments to HQ-CLIMATE-OBS@mail.nasa.gov .

Dataset File Name (as it appears on the ESG):

hus_Amon_MLS-Aura-v03.3_historical_r0i0p0_200408-201012.nc

1b) Technical point of contact for this dataset:

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2. Data Field

CF variable name, units:	hus, unity.
Spatial resolution	The vertical resolution is determined by the CMIP5 mandatory levels. Additionally, we provide 6 optional levels (7hPa, 5 hPa, 3 hPa, 2 hPa, 1 hPa, and 0.4 hPa). The horizontal resolution is 2 degrees of latitude by 5 degrees of longitude.
Temporal resolution and extent:	The product is formed with monthly averages covering the period from August 2004 to December 2010.
Coverage:	Global.

Note: While we provide data in the entire pressure range specified by CMIP5, the data at pressures larger than 300 hPa are not provided for scientific use as they represent purely *a priori* information. It is recommended to use AIRS specific humidity data for those pressures (larger than 300 hPa).

3. Data Origin

These data are derived from the standard MLS retrieved data (version v3.3 that can be obtained from the Goddard Earth Science (GES) Data and Information Services Center (DISC) data access [1].

The water data described in this document are retrieved from measurements of the 183 GHz H_2O rotational line spectrum [2]. The measurements were first transformed into calibrated radiances for all footprints and all channels ('Level 1' data). Then, vertical profiles of geophysical quantities such as the specific humidity were derived ('retrieved') from these geolocated radiance products on fixed (non-IPCC) pressure levels, ('Level 2' data). One month of these data was read in and screened according to the MLS data quality document. It was then binned into the latitude-longitude grid. For each grid point, the data was linearly interpolated to the IPCC pressure surfaces using the logarithm of the pressure.

4. Validation

Table 1 summarizes measurement precision and systematic biases of the retrieved specific humidity value at each pressure level [3].

The validation of this data was made by comparisons with correlative data sets from ground-based, airborne and satellite platforms operating in the UV/visible, infrared and microwave regions of the spectrum are performed [4]. Comparisons with the Goddard global modeling and assimilation office Earth Observing System analyses (GEOS-5) were also made [2].

MLS overestimates H_2O for mixing ratios greater than 500 ppmv which is consistent with a scaling error in either the calibrated or calculated MLS radiances. The precision of the individual v3.3 H_2O from 121 to 83 hPa is 10–20%. Note that the precision of the gridded products described herein is significantly improved upon this precision thanks to the monthly averaging. The vertical resolution is 1.5–3.5 km depending on height. The horizontal resolution is 210 x 7 km^2 along and perpendicular to the Aura orbit track, respectively [2]. The single-profile precision is 0.2–0.3 ppmv (4–9%), and the vertical resolution is 3–4 km in the stratosphere. The precision and vertical resolutions become worse with increasing height above the stratopause. Over the pressure range 0.1–0.01 hPa the precision degrades from 0.4 to 1.1 ppmv (6–34%), and the vertical resolution degrades to 12–16 km. The accuracy is estimated to be 0.2–0.5 ppmv (4–11%) for the pressure range 68–0.01 hPa. The scientifically useful range of the H_2O data is from 316 to 0.002 hPa. The single-profile precision is 13–25 ppbv (7–38%), the vertical resolution is 4–6 km and the accuracy is estimated to be 3–70 ppbv (9–25%) for the pressure range 100–4.6 hPa [4].

Table 1: Spatial resolution, retrieval precision, and systematic bias of MLS specific humidity measurements

Pressure [hPa]	Resolution Vert. [km]	Resolution Hor. [km]	Min ppmv	Precision (a) %	Accuracy ppmv
0.4	5.8	413	0.08	1.06	6
1	4.6	410	0.08	1.00	4
2	4.0	384	0.05	1.00	5
3	3.9	360	0.05	1.00	6
5	3.6	317	0.05	1.00	7
7	3.5	302	0.05	1.00	8
10	3.3	280	0.05	1.00	9
20	3.2	288	0.05	1.00	7
30	3.2	273	0.06	1.17	6
450	3.1	236	0.08	1.59	4
70	3.2	219	0.07	2.07	6
100	3.4	210	0.03	3.75	8
150	3.5	227	0.10	5.12	15
200	2.4	200	0.75	8.48	23
250	1.6	215	0.94	9.05	21
300	1.5	195	1.53	14.07	16
1000-400	USU				

(a) Precision for a single MLS profile, precisions of the monthly averages provided in these data products are substantially improved upon by the monthly averaging.

5. Consideration for Model-Observation Comparisons

If judicious model-observation comparisons are to be made, users should be aware of several aspects that distinguish these data products from model outputs.

5.1 Time Sampling Bias

Because MLS is on board the Aura satellite in a sun-synchronous polar orbit, it samples at the two fixed local solar times at each location (e.g. 1:45 AM and 1:45 PM at the equator) and does not resolve the diurnal cycle [6]. MLS observations at a given latitude on either the ascending (north-going) or descending (south-going) portions of the orbit have approximately (to

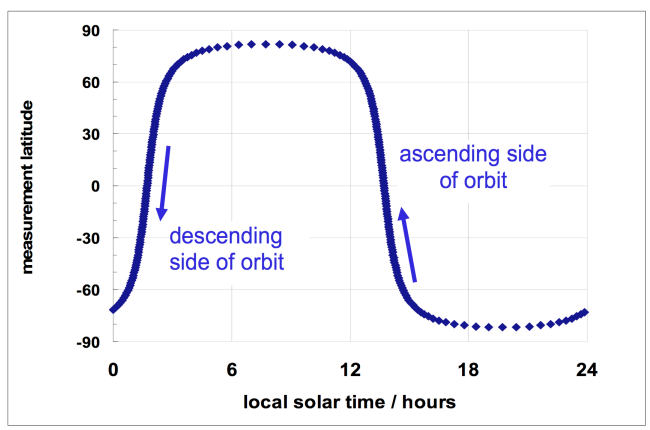

Figure 1: Local solar time when MLS observes a given latitude on the Aura sun-synchronous polar orbit.

within several minutes) the same local solar time throughout the mission, as indicated in Fig. 1 [7]. In contrast, typical model monthly averaged outputs contain the averaged values over every point in a time series of data with a fixed time interval (e.g. every 6 hours). For many constituents in the upper troposphere, this difference is not likely to be an issue. However, for regions influenced by deep convection and its modulation of the diurnal cycle (e.g. tropical land masses), this time sampling bias should be considered.

5.2 Inhomogeneous Sampling

Because the monthly averaged value in this MLS data product is an average over observational data available in a given lat-lon box, the number of samples used for averaging varies with the location of the box. Due to the geometry of the Aura sun-synchronous polar orbit, there are no observations above latitude 82° and there are more observations near the boundary (70°-82°) than the rest of the area. Figure 2 shows the distribution of the typical number of samples used for the monthly averaged product.

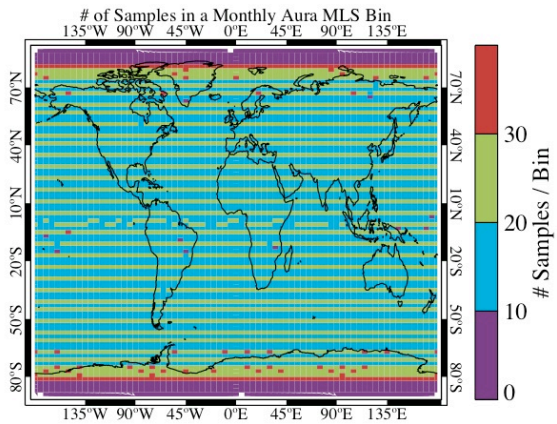

Figure 2: Distribution of the typical number of samples used for the monthly averaged MLS

5.3 Anisotropic and Inhomogeneous Resolution

While a typical model output has a fixed horizontal resolution, MLS observations have anisotropic and inhomogeneous resolutions in a horizontal direction due to its viewing geometry and radiometric response. MLS horizontal resolutions for specific humidity measurements range from 1.5 to 5.8 km across the orbit track and 195 to 413 km along the orbit track (see Table 1 for details). Therefore, MLS observations have elongated shape 'footprints'. The sample data used in the monthly averaging are the collection of observations whose footprint centers are located in a given grid box. This means that the averaged value for a given grid box can be influenced by the state of the atmosphere in neighboring grid boxes, due to the mismatch between the gridded box resolution and the MLS native observation resolution.

5.4 Cloud influence

MLS observations are affected by thick clouds associated with deep convection. The MLS level 2 data processing algorithms discard or deemphasize radiances by increasing the precision of those identified as being affected by clouds [4].

6. Instrument Overview

The Earth Observing System (EOS) Microwave Limb Sounder (MLS) is a satellite instrument that provides observations of atmospheric composition, temperature, moisture, and cloud ice profiles in the upper troposphere and lower stratosphere. The MLS measurements are designed to (1) track stability of the stratospheric temperature layer, (2) help improve predictions of climate change and variability, and (3) help improve understanding of global air quality.

MLS is one of four instruments on the NASA's EOS Aura satellite, launched on July 15th 2004. Aura is in a near-polar 705 km altitude sun-synchronous orbit. As Earth rotates underneath it, the Aura orbit stays fixed relative to the sun and gives daily global coverage at a fixed local times for

each latitude on the ascending and descending side of the orbit, with observations in the tropics and mid-latitudes made around 1:30am (descending) and 1:30pm (ascending), and ~13 orbits per day. Aura is part of NASA's A-train group of Earth observing satellites. These satellites fly in formation with the different satellites making measurements within a short time of each other as shown in Fig. 3.

MLS obtains remote measurements of atmospheric parameter profiles by measuring millimeter

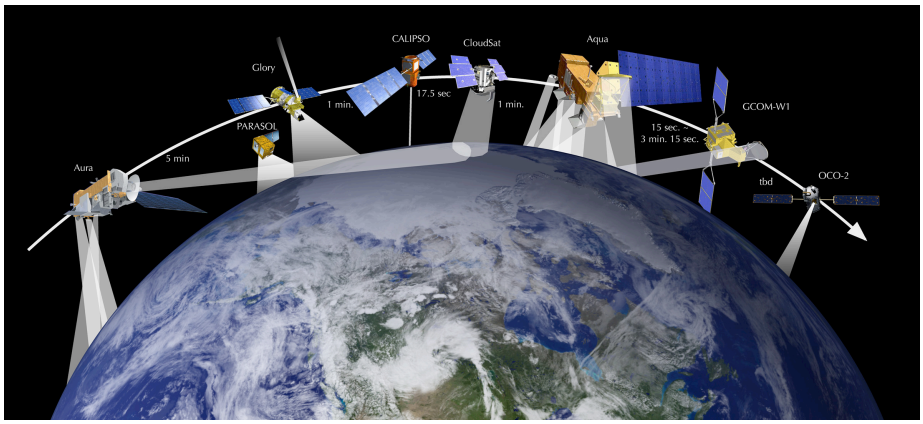

Figure 3: NASA's A-train group of Earth observing satellites.

and sub-millimeter-wavelength thermal emission with seven microwave receivers using a limb viewing geometry. MLS views forward along the Aura satellite flight direction and scanning its view from the ground to ~90 km altitude. The limb viewing geometry of MLS is shown in Fig. 4. Thanks to the limb viewing geometry, MLS provides the relatively good vertical resolution for composition observations in the upper troposphere and lower stratosphere, compared to nadir sounders. At present, the MLS record is more than 7 years long, the instrument remains in good health and we expect several years of continued operation.

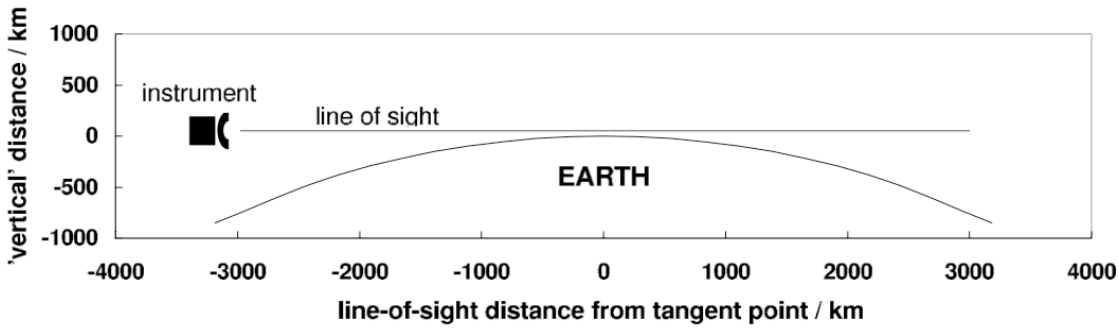

Figure 4: MLS viewing geometry. The geometry is drawn to scale with an instrument in 705 km altitude orbit of the Aura satellite and the line of sight having 50 km tangent height. The orbit plane for EOS MLS is the plane of the paper [8]

7. References

[1] http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/MLS/index.shtml

[2] W. G. Read *et al.*, "Aura Microwave Limb Sounder upper tropospheric and lower stratospheric H2O and relative humidity with respect to ice validation", JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 112, D24S35, doi:10.1029/2007JD008752, 2007.

[3] The monthly averaged data described in this document have the same accuracy as the MLS retrieval but the precision is improved by the factor of $1/\sqrt{N}$ due to the averaging over independent samples, where N is the number of the samples. As shown in Fig. 2, the number of samples N fluctuates around 16 (with a standard deviation of 5.4) between 72 degrees of latitude North and 72 degrees of latitude South. We used the data available in [2] to generate Table 1. We interpolated between two levels when a particular pressure level and its associated data were not available and we updated the precision using the number of samples involved in the monthly averaging.

[4] A. Lambert *et al.*, "Validation of the Aura Microwave Limb Sounder middle atmosphere water vapor and nitrous oxide measurements," JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 112, D24S36, doi:10.1029/2007JD008724, 2007.

[5] EOS Aura Microwave Limb Sounder Version 2.2 Level 2 data quality and description document, v2-2_data_quality_document.pdf. See Table 3.12

[6] EOS MLS Level 3 Algorithm Theoretical Basis, eos_l3_atbd.pdf, p9, p30.

[7] An Overview of the EOS MLS Experiment, eos_overview_atbd.pdf, p38.

[8] An Overview of the EOS MLS Experiment, eos_overview_atbd.pdf, p6.

8. Revision History

Rev 0 - 7/18/11 -