SPARC Water Vapor Assessment: Comparison of in situ and Aura MLS stratospheric water vapor measurements from 2004 through 2011

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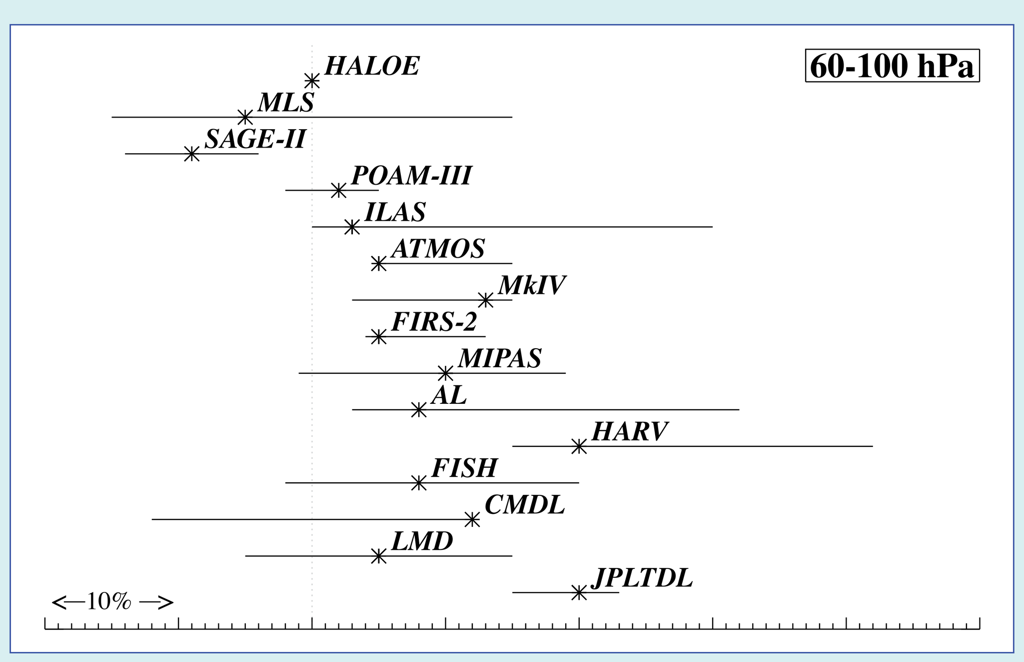
Introduction

Water vapor in the UTLS plays a role in both radiative and microphysical processes. For radiative processes, consistency of measurements through time is key; however for microphysical processes, absolute accuracy is needed.

UTLS water has been been measured by a variety of techniques; the first stratospheric measurements were done using a manually operated airborne frost point hygrometer by A.W. Brewer during World War II. The first balloon borne frostpoint measurements were done by H.J. Mastenbrook during the 1960s. Lyman-alpha balloon measurements were initially developed by D. Kley in the late 1970s. The first stratospheric satellite measurements were from the LIMS instrument launched in 1978. There have been subsequent remote sounding measuements using varying techniques, additional development of in situ measurements for aircraft, and continuation of longer term records of balloon measurements.

Intercomparisons during the early 1980s (BIC) showed significant differences between stratospheric water vapor instruments (both remote sensing and in situ techniques). A detailed comparison undertaken by SPARC (published in 2000) also showed significant spread between various stratospheric water vapor measurements (see figure below).

Large discrepancies between different instruments have continued to plague measurements of water vapor under very dry stratospheric conditions. For example, during the high altitude flights out of Costa Rica (the CRAVE campaign), when extremely cold, dry conditions were encountered, measurement descrepancies (with offsets of ~1.5 ppmv) were as much as a factor of 2. These differences are significant, because the measurements on the higher end of the range indicate the existence of very large ice supersaturations occurring near the cold tropical tropopause both in clear sky conditions and within clouds with implications for our understanding of ice nucleation and the dehydration of air entering the stratosphere. During the recent MACPEX experiment (based in Houston), the discrepancies between the water vapor instruments that had also flown during CRAVE decreased considerably, with differences less than 0.5 ppmv. However, it is not clear what the implications are for the historical water vapor measurements.



In this analysis, we address the issue of consistency in a manner similar to that done in SPARC(2000). We compare both balloon and aircraft stratospheric water vapor measurements to what is believed to be a consistent longer-term record.

Main instruments used in this study

Microwave Limb Sounder (MLS) on the NASA Aura satellite.
Launched July 15, 2004, near polar orbit, ~13 orbits per day; continues to operate, provides global coverage
Observes thermal microwave emission from the earth's limb
Used as a reference measurements due to its extensive global coverage and stability.

NOAA Frost Point Hygrometers (FPH&CFH): Balloon borne chilled mirror instruments. Launched regularly from Boulder CO (since1980) and Lauder NZ (since 2004) and for IOPS worldwide. Longest term in situ stratospheric water vapor record available.

Fast In situ Stratospheric Hygrometer (FISH): uses Lyman-alpha photofragment fluorescence technique, balloon and aircraft borne instrument from Forschungszentrum Jülich in Germany; has flown on multiple aircraft platforms since the early 1990s.

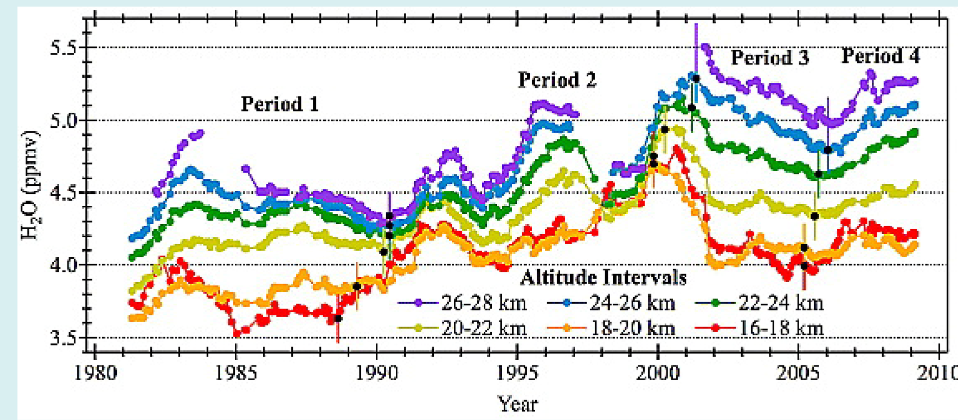
Harvard water: uses Lyman-alpha photofragment fluorescence technique aircraft borne instrument flying since the early 1990s.

JPL water: open-path tuneable diode laser spectrometer; aircraft borne, flying in the late 1990s on multiple aircraft.

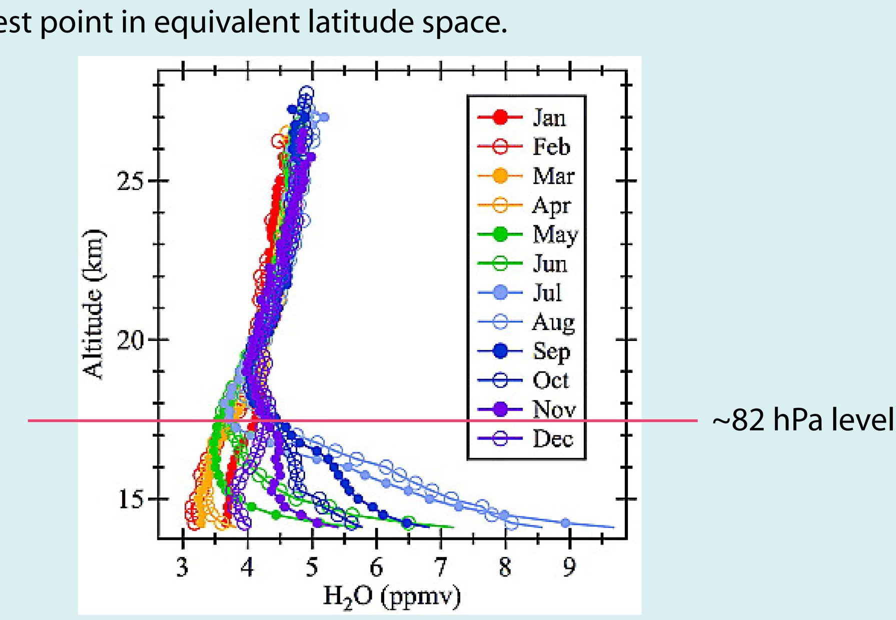
Note: There are other stratospheric water instruments that can be compared with MLS, however with shorter histories. Here we do include plots using the NOAA CIMS instrument which has only flown once and the long-term balloon record is also compared with Halogen Occultation Experiment (HALOE), a solar occultation satellite instrument that operated from 1991-2005.

Example of trends:

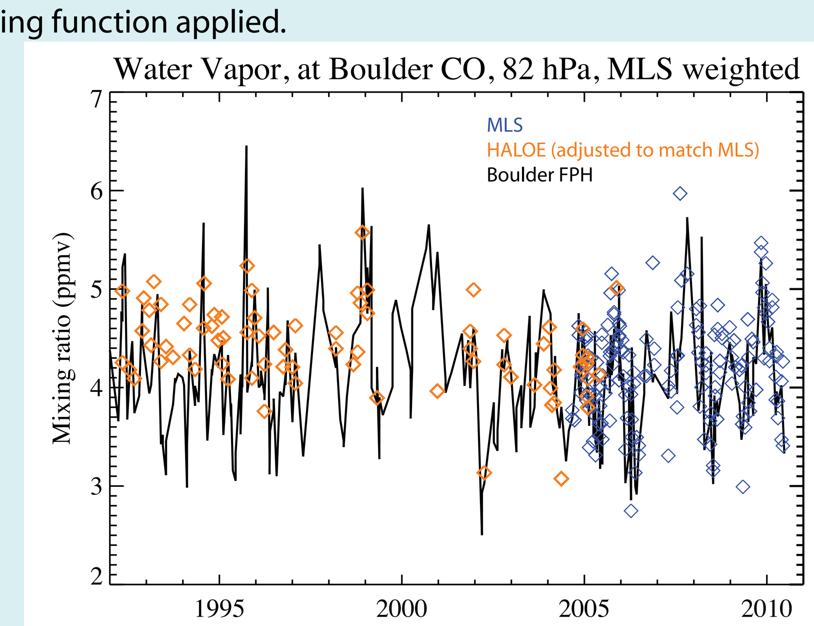
from Hurst et al, 2011 (JGR):, plot is from Boulder, CO data. Stratospheric water increased by ~1.0 ± 0.2 ppmv (27 ± 6%) during 1980-2010: however the trend was not a simple linear increase. Note that this puts on constraint on the consistency of measurements needed to deduce long term trends.



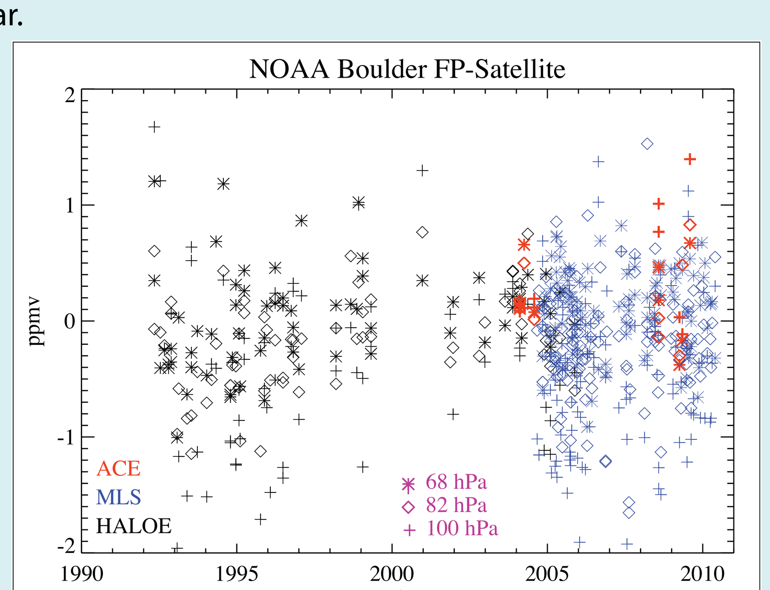
Here we mainly limit our analysis to the lower stratosphere; 82 hPa (~17.5 km) is a standard MLS and HALOE satellite level that should consistently be in the stratosphere and is low enough to overlap with aircraft measurements. There is still a significant annual cycle at this level (see figure below from Hurst et al, 2011), but spatial gradients are smaller that would be the case in the troposphere, hence matching criteria for comparisons is not overly constrictive. For MLS, matches are typically within 6 hours, 1º latitude and 10º longitude. For HALOE (with more limited sampling), we extended the temporal coincidence to 3 days and chose the closest point in equivalent latitude space.



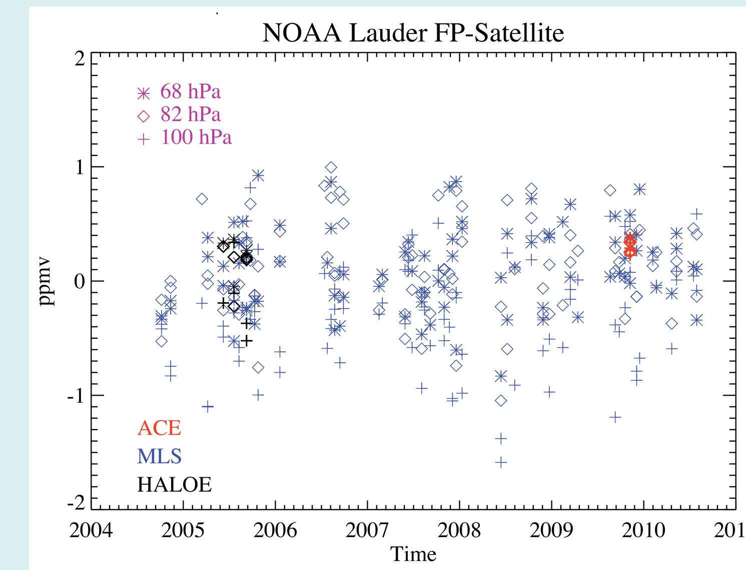
The satellite senses information on water vapor from a layer, while the *in situ* measurements are valid at a point. To better match measurements between satellite and in situ data, we apply the satellite weighting function to the aircraft and balloon profiles. In regions without large vertical gradients, this can be simulated just with a 3-4 km average centered on the satellite pressure; however for the balloon comparisons we have used the weighting algorithm provided by the MLS science team. Below we show an example at 82 hPa using the Boulder balloon water vapor with the MLS weighting function applied.



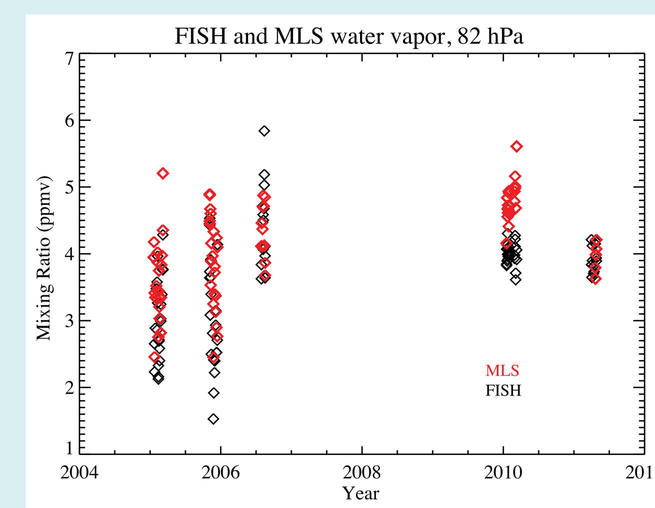
Differences between satellite and Boulder frost point hygrometer matches are shown below for 3 levels in the lower stratosphere. At 82 hPa the difference between NOAA FPH and MLS is -0.18(.91) ppmv and the trend in the difference is +0.010(.051) ppmv/year (2-sigma uncertainty). For HALOE, (after an adjustment to match HALOE and MLS measurements) the average difference is -0.19(.85) ppmv and the trend in the difference is +0.036(.023) ppmv/year.

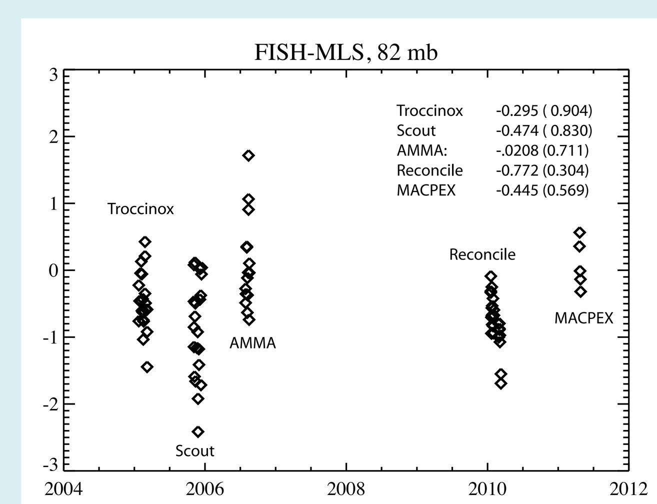


Differences between satellite and Lauder, NZ frost point hygrometer matches are shown below for 3 levels in the lower stratosphere. At 82 hPa the difference between NOAA FPH and MLS is +0.11(.79) ppmv and the trend in the difference is +0.014 (.049)) ppmv/year (2-sigma uncertainty). There is only one year of overlap between Lauder and HALOE, so no trend estimtes were computed.



Differences between FISH and MLS coincidences are shown below as well as the measurements at 82 hPa.





Troccinox: mainly SH tropical; transits between Europe and Brazil

Scout: mainly SH tropical, transits between Europe and Darwin

AMMA: (West Africa) mainy NH tropics, transits to and from Europe

Reconcile: NH high latitude (Arctic)

MACPEX: NH Texas (near 30N)

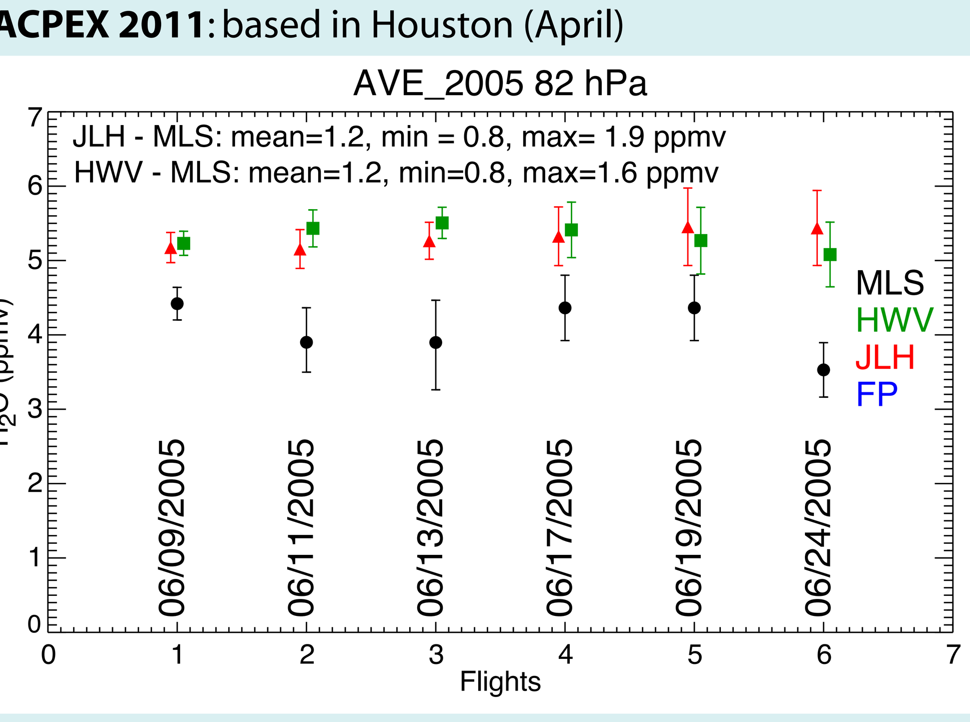
Reconcile is the only mission that gives results statistically different from MLS.

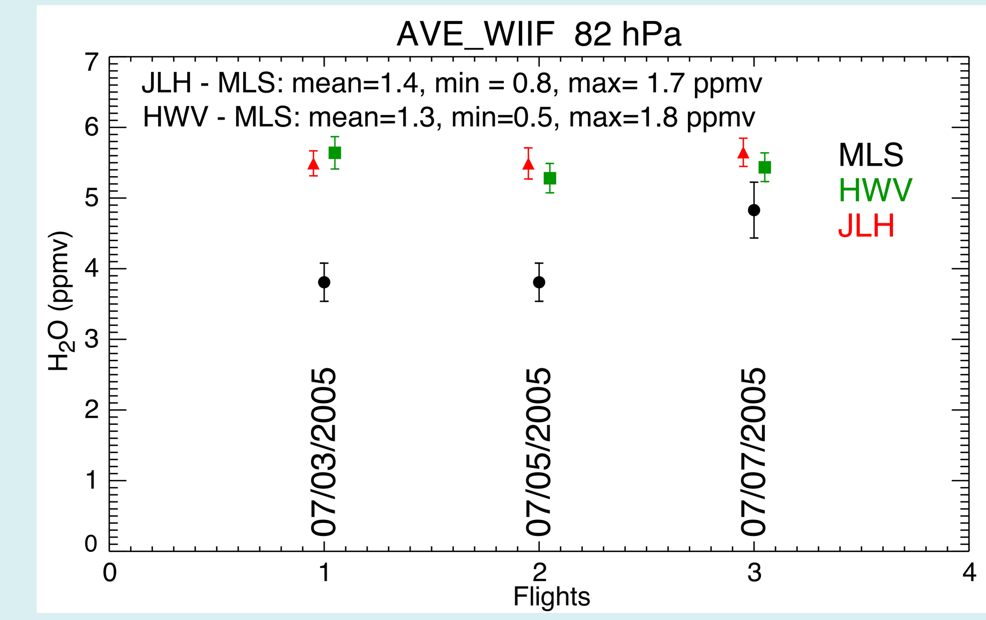
Results at 100 hPa are similar.

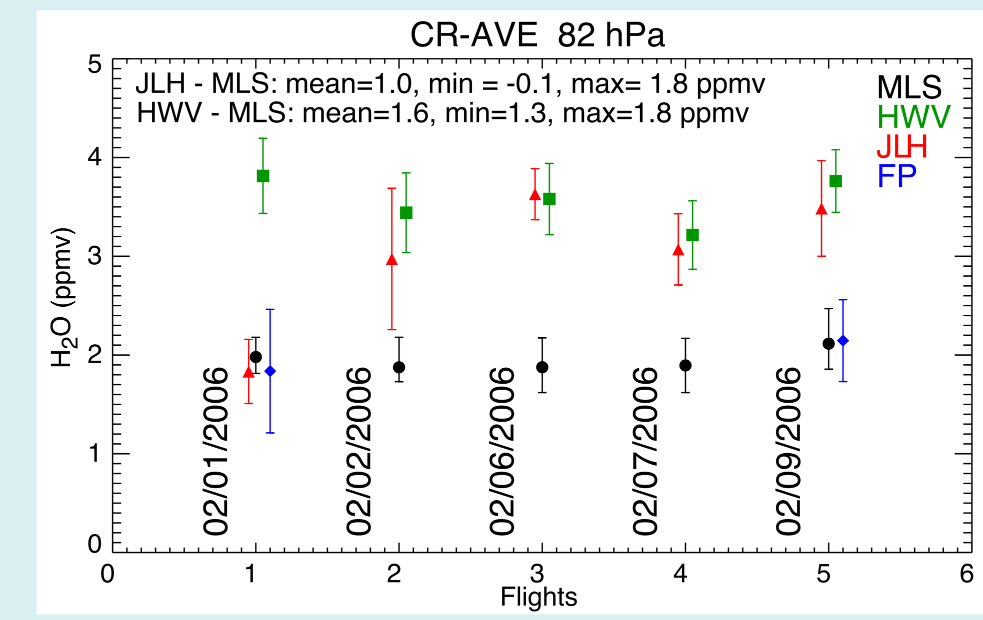
Comparisons between MLS and WB57-F *in situ* measurements

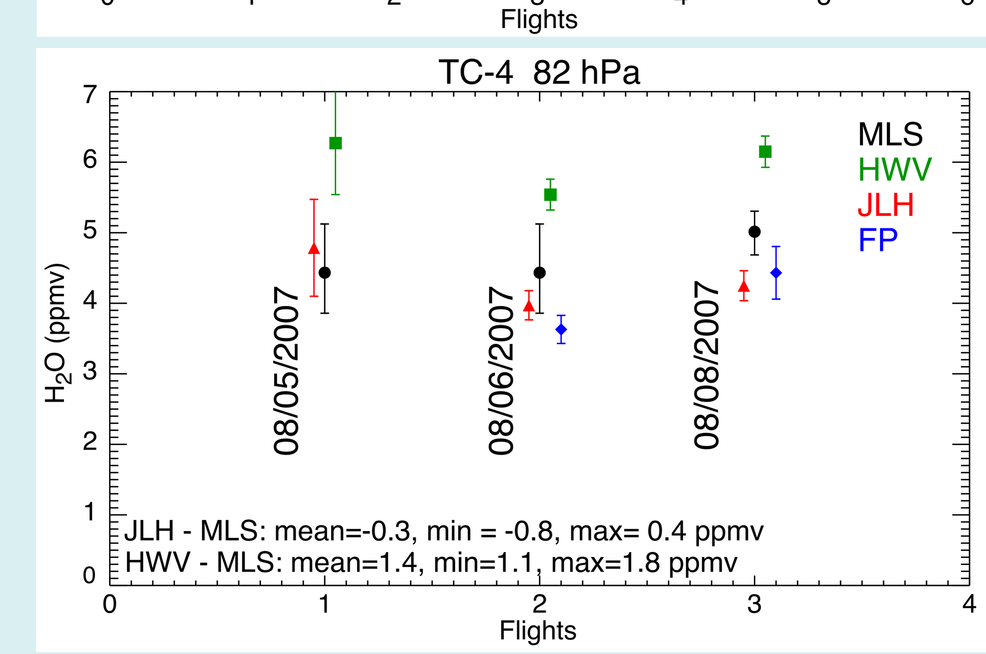
Since the launch of the Aura MLS instrument, there have been a number of aircraft campaigns including multiple water vapor instruments. Three of these campaigns had Aura validation has a prime goal, hence coincidences are quite close. Two water vapor instruments have flow during all these campaigns; the Harvard Lyman-alpha hygrometer and the JPL Tunable Diode Laser hygrometer. For some cases, there are coincident balloon profiles from the NOAA frost point instrument. We show here comparisons for the following experiments that used the NASA high altitude WB58-F aircraft:

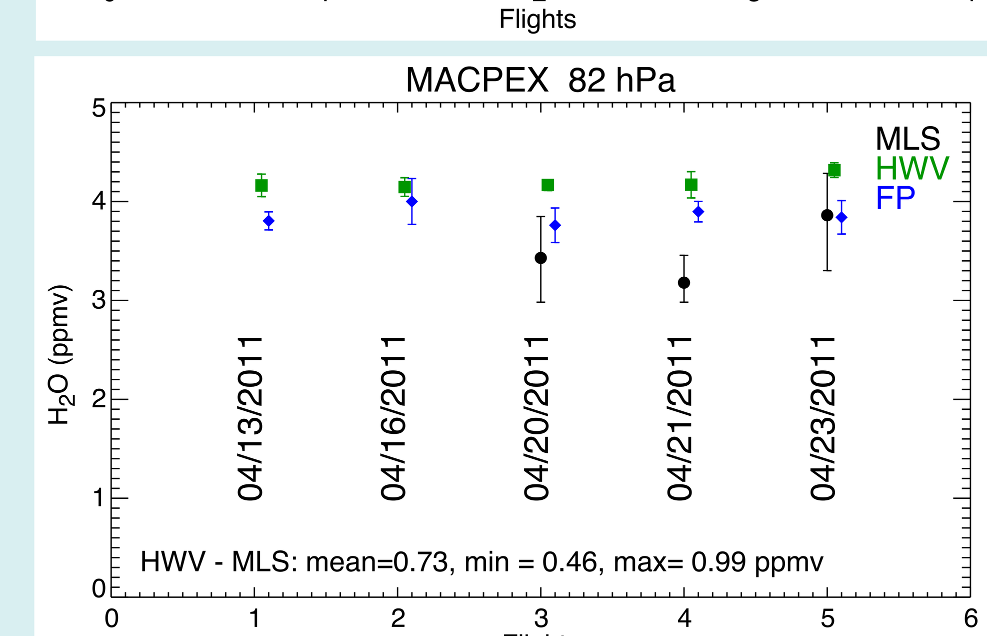
AVE 2005: based in Houston (June)
AVE WIIF 2005: based in Houston (July)
CR-AVE 2006: based in Costa Rica: (January-February)
TC-4 2007: based in Houston and Costa Rica (July-August)
MACPEX 2011: based in Houston (April)











Data is not yet final for JLH during MACPEX

Statistics

For the NOAA frost point balloon, the average difference from MLS is 0.18 ppmv at Boulder and 0.11 ppmv at Lauder with no statistically significant trend with time.

For the FISH instrument (from Juelich, Germany) average campaign differences range from 0.02 to 0.474 ppmv.

For the Harvard Lyman-alpha instrument; average campaign differences range from 0.73 to 1.6 ppmv.

For the JPL instrument, average campaign differences range from -0.3 to 1.4 ppmv.

SUMMARY

❖ FP and MLS show consistency across the MLS time period, suggesting that these measurements provide consistent (non-time varying) records.

❖FISH is consistent with MLS (except for the high-lat RECONCILE data) and shows no apparent temporal shifts.

❖JLH is higher than MLS early in the time period (~ 1 ppmv) and in reasonable agreement with MLS later in the time period.

❖ HWV exceeds MLS by ~1.5 ppmv pre-MACPEX, differences are smaller during MACPEX (~0.7 ppmv).

❖The shifts in aircraft measurements generally preclude their use for trend analysis.