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 measured by a variety of techniques; the first stratospheric water vapor measurements were made 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 measurements were from the LIMS instrument launched in 1978. There have been subsequent remote sounding measurements using varying techniques, additional development of in situ measurements for aircraft, and continuation of longer term records of balloon measurements.

Intercalibrations derived during the early 1980s (BRC) showed significant differences between stratospheric water vapor instruments (both remote sensing and in situ techniques). A detailed intercomparison 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 CRABE campaign), when extremely cold, dry conditions were encountered, measurement discrepancies (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 CRABE 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.

NOAA FPH (FP-100A): Ballonborne chilled mirror instruments. Launched regularly from Boulder CO (since 1980) 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 Juelich in Germany, has flown on multiple aircraft platforms since the early 1990s.

Harvard water uses Lyman-alpha photofragment fluorescence technique aircraft borne instrument developed in the early 1990s.

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

Example of trends:

From Haur et al. 2011 (JGR), plots from Boulder, CO data. Stratospheric water increased by ~1.0 to 0.2 ppmv (27% ± 6%) during 1980-2010; however the trend was not a simple linear increase. Note that this puts on constraint 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 Haur et al. 2011). Out spatial gradients are smaller that would be the case in the troposphere, hence matching criteria for comparisons is not overly constractive. For MLS, matches are typically within 6 hours, 1’ latitude and 10’ 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 with large vertical gradients, the RCS can be simulated just with a 2-3 km average centered on the satellite-bright pixel; however for the balloon comparison 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.

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 as a prime goal, hence coincidences are quite close. Two water vapor instruments have flown 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)

AWE WIF 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)

For the NOAA frost point balloon, the average difference from MLS is 0.18 ppmv at Boulder (not shown) with statistically significant trend with time. For the FISH instrument (from Juelich, Germany) average campaign differences range from 0.62 to 0.47 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.

Statistics

- 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.

<table>
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<th>Year</th>
<th>MAVenan</th>
<th>MLO</th>
<th>MCDR</th>
<th>SC</th>
<th>MLO</th>
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Summary

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