A new laser hygrometer for detection of water vapor by infrared absorption: Validation and laboratory intercomparisons

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Scientific Motivation

Water vapor in the UT/LS plays a critical role in the Earth's climate system, as a greenhouse gas contributing to increasing surface temperatures and by catalyzing stratospheric ozone loss. The ability to predict future changes in stratospheric humidity is inhibited by a lack of understanding of the mechanisms that transport water from the troposphere to the stratosphere. Distinguishing among these transport mechanisms will require water vapor measurements of significantly greater accuracy than is currently available – aircraft-borne, balloon-borne, and satellite-born water vapor instruments consistently disagree by ~1.5 ppmv, which corresponds to ~30% uncertainty at the water vapor concentrations of the tropical tropopause. To address these problems we have designed a new high precision laser hygrometer which detects water vapor by infrared absorption. The instrument will be flown in the spearpod of NASA's WB-57 aircraft in series with Harvard's well tested and flight proven Lyman-α hygrometer to provide a precise, accurate, and robust water vapor measurement.

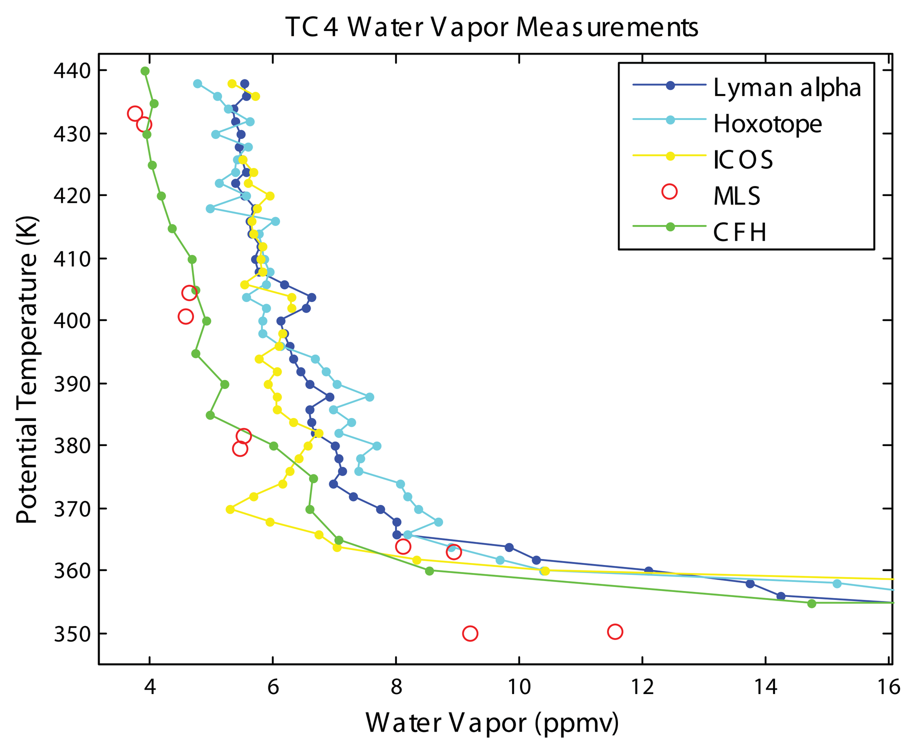

Figure 1. Water vapor measurements during the TC4 campaign from 8/5/07 - 8/8/07. Note the significant differences between the MLS satellite, CFH balloon-borne frostpoint hygrometer, and the in situ aircraft instruments Lyman-α, Hoxotope, and ICOS.

Laboratory Intercomparisons

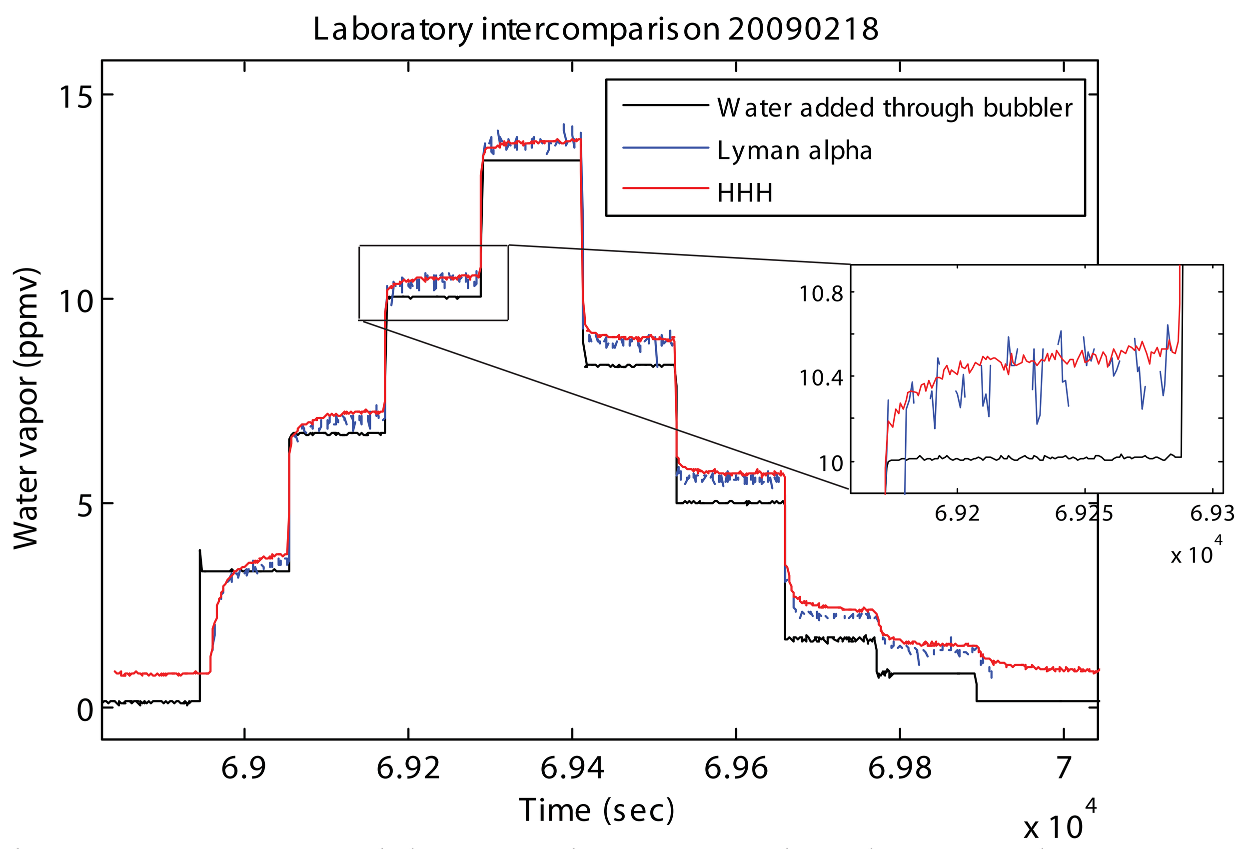

Figure 2. Low water laboratory intercomparison between the HHH and Lyman-α hygrometers sampling in parallel.

Harvard Herriott Hygrometer (HHH)

- HHH uses a fiber coupled 1.4 μm DFB laser to scan over a strong water absorption line.
- 90% of the laser beam is directed through a Herriott cell composed of two 3-inch mirrors spaced 105 mm apart to create a 98-pass cell with a total pathlength of 10 meters.
- 5% of the light is directed though a Si etalon in order to determine the tuning rate of the laser.
- 5% of the light is directed to an open path cell to determine the background spectrum.
- An additional diagnostic for detection by direct absorption will be the extension of the laser scan range to cover two water absorption lines.
- Preliminary tests show precision of < 0.05 ppmv for 1-second data.

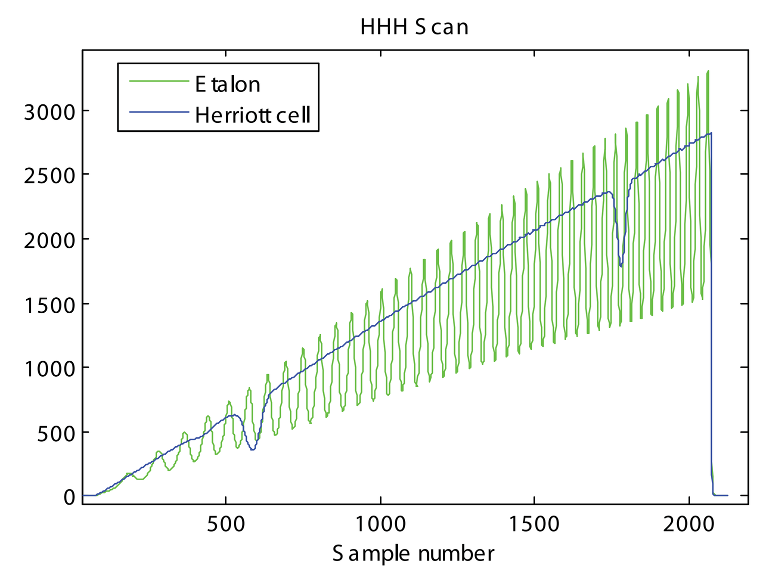

Figure 3. Sample HHH scan

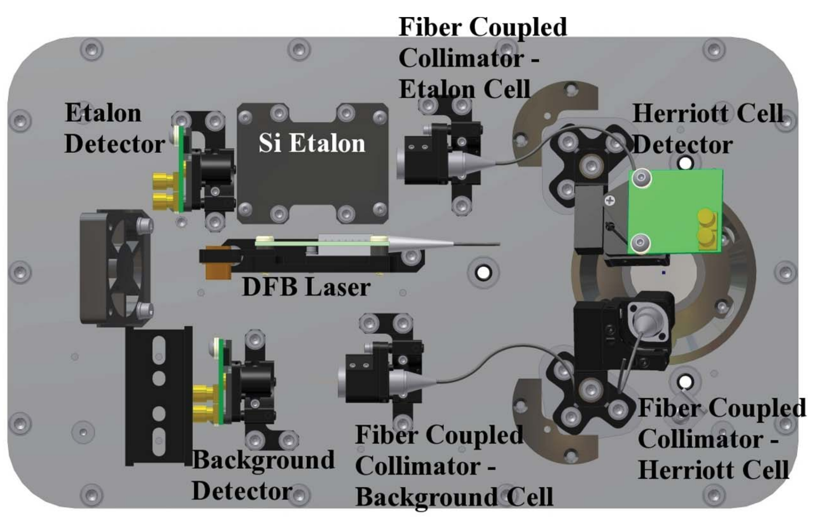

Figure 4. Schematic of HHH laser housing.

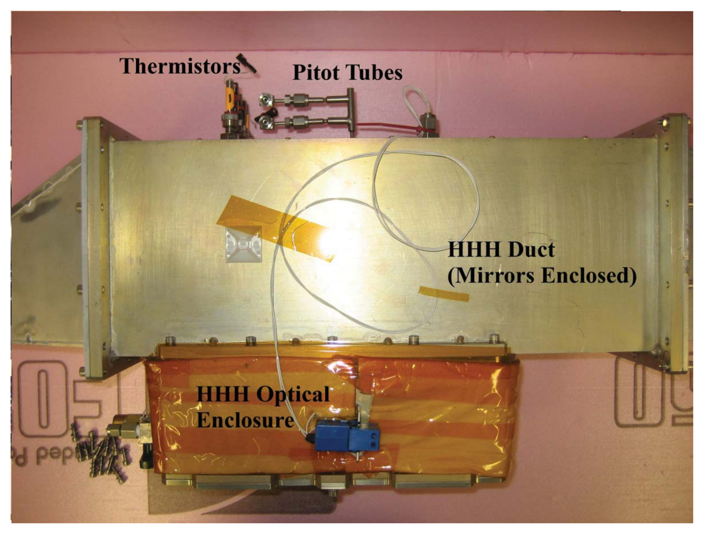

Figure 5. HHH detection axis

Lyman-α Hygrometer

$H_2O + h\nu(121.6\ nm) \rightarrow OH(A\ ^2\Sigma^+) + H$

$OH(A\ ^2\Sigma^+) \rightarrow OH(X\ ^2\Pi) + h\nu(305\text{-}325\ nm)$

The Harvard Lyman-α hygrometer has flown on NASA's WB-57 aircraft since 2001 and has proved its reliability and accuracy during the CRYSTAL-FACE, Pre-AVE, MidCiX, CRAVE, and TC4 missions.

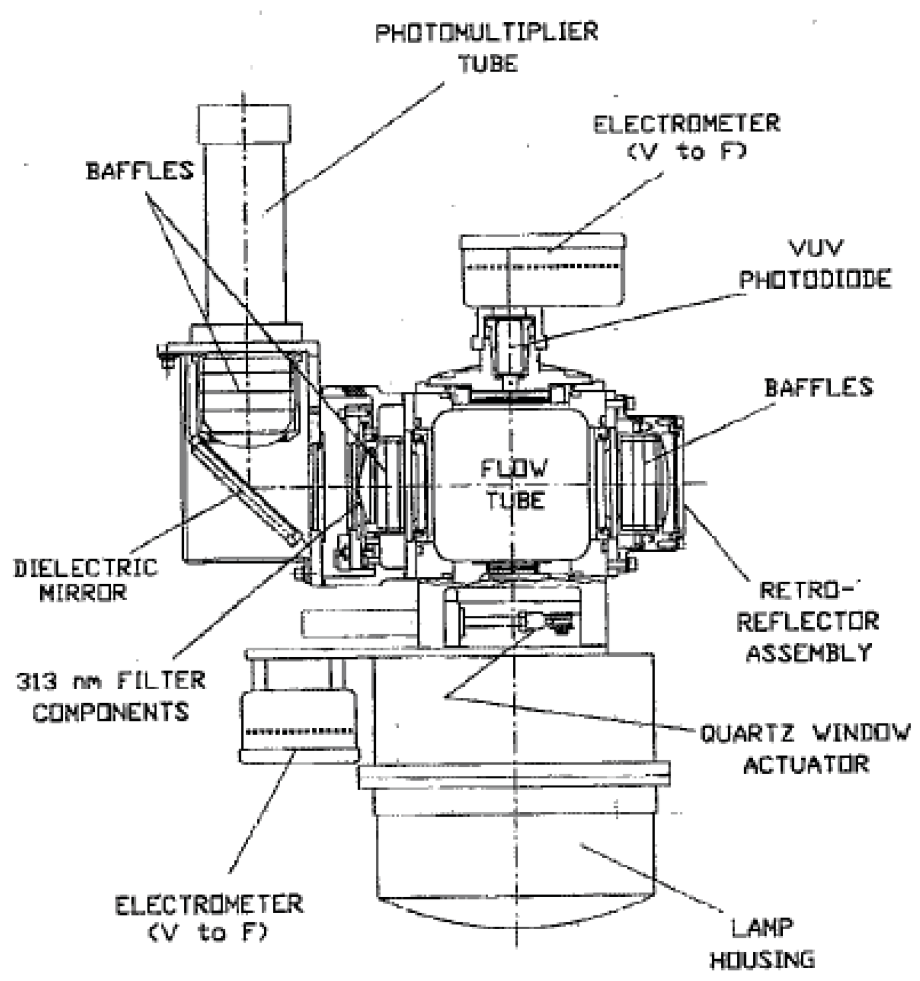

Figure 6. Lyman-α detection axis cross section.

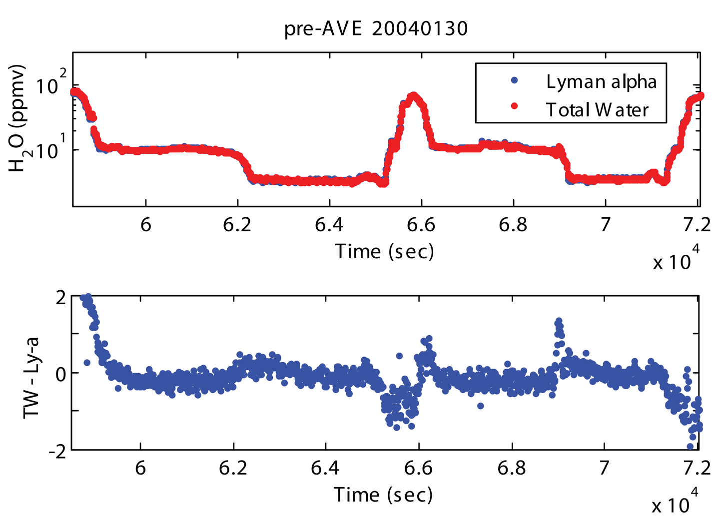

Figure 7. Lyman-α and total water comparison from pre-AVE campaign.

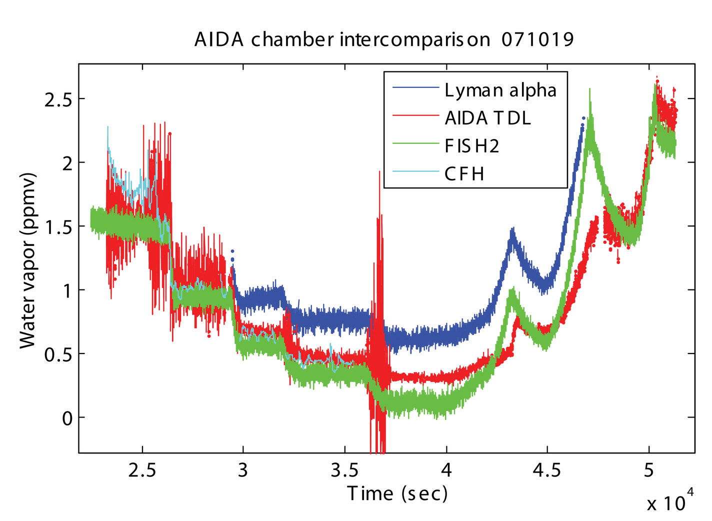

Figure 8. Multi-instrument comparison from AIDA chamber.

Proposed Flight Setup

- HHH and Lyman-α are to be flown together in the spearpod of NASA's WB-57 aircraft.
- Plan to fly in support of the Mid-latitude Airborne Cirrus Properties Experiment (MACPEX) during summer 2010.
- The use of two different measurement techniques will allow for systematic errors to be diagnosed and/or constrained both in the laboratory and in flight.

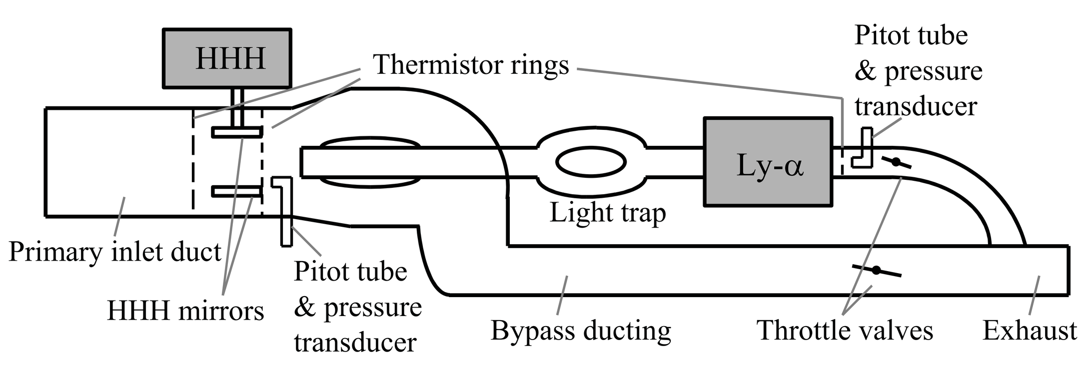

Figure 9. Inlet and ducting design for combined HHH-Lyman-α instrument to be flown in the spearpod of the WB-57. HHH inlet will have a round cross-section to minimize wall effects, while Lyman-α will use its previously flown square inlet.

Figure 10. Left: The WB-57 spearpod in which the instrument will be flown; shown as set up for Lyman-α only. Right: NASA's WB-57 aircraft, with the spearpod indicated in orange.

Conclusions

- HHH is a TDL instrument recently developed by our lab; precision of < 0.05 ppmv will constrain the magnitude of any non-white noise sources that can often lead to systematic errors when fitting direct absorption data at low water.
- The Lyman-α instrument has a long flight history and has been extensively validated through laboratory and in-flight tests.
- The Lyman-α and HHH hygrometers will be combined in the WB-57 spearpod in order to provide a precise water vapor measurement tied to the long past record of Lyman-α.
- The combined Harvard water instrument will be able to address past discrepancies in water vapor measurements.