Mass spectrometry for water vapor measurements in the UT/LS

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1. Water vapor observations in the UT/LS

Water vapor is the most important and most abundant atmospheric greenhouse gas. It influences the radiation budget of the Earth's atmosphere mainly by absorption and reemission of solar and terrestrial radiation and by cloud formation.

In addition atmospheric water vapor represents an important feedback parameter for the climate system sensitivity to radiative forcing.

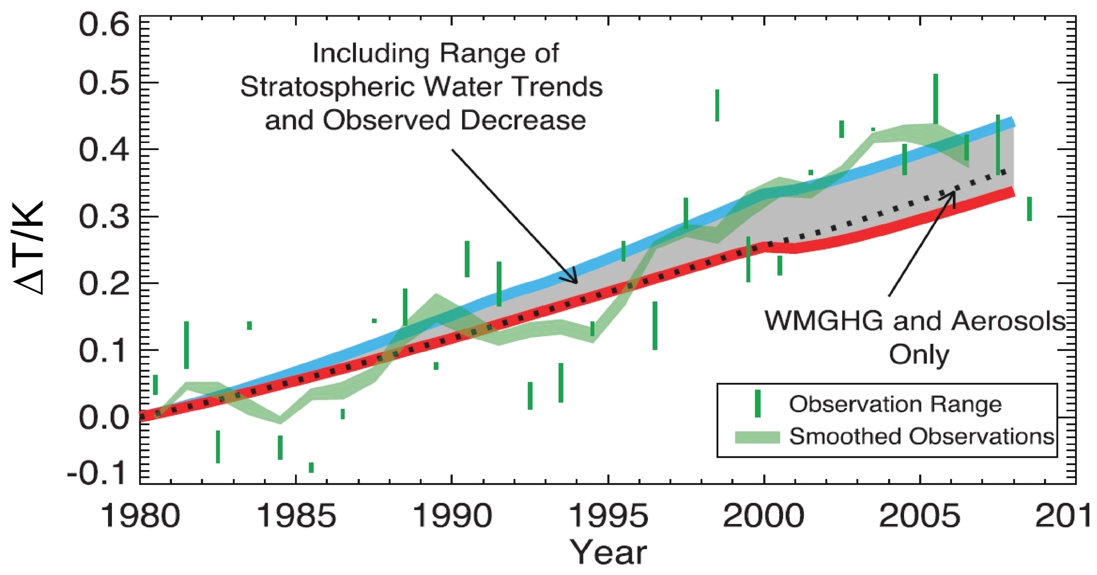

Fig. 1: Change in surface temperature with (blue) and without (red) a 0.5 ppmv/decade increase in stratospheric water vapor. In both cases a singular decrease in stratospheric water vapor of 0.4 ppmv is included in the year 2000. (Solomon et al. Science, 2010)

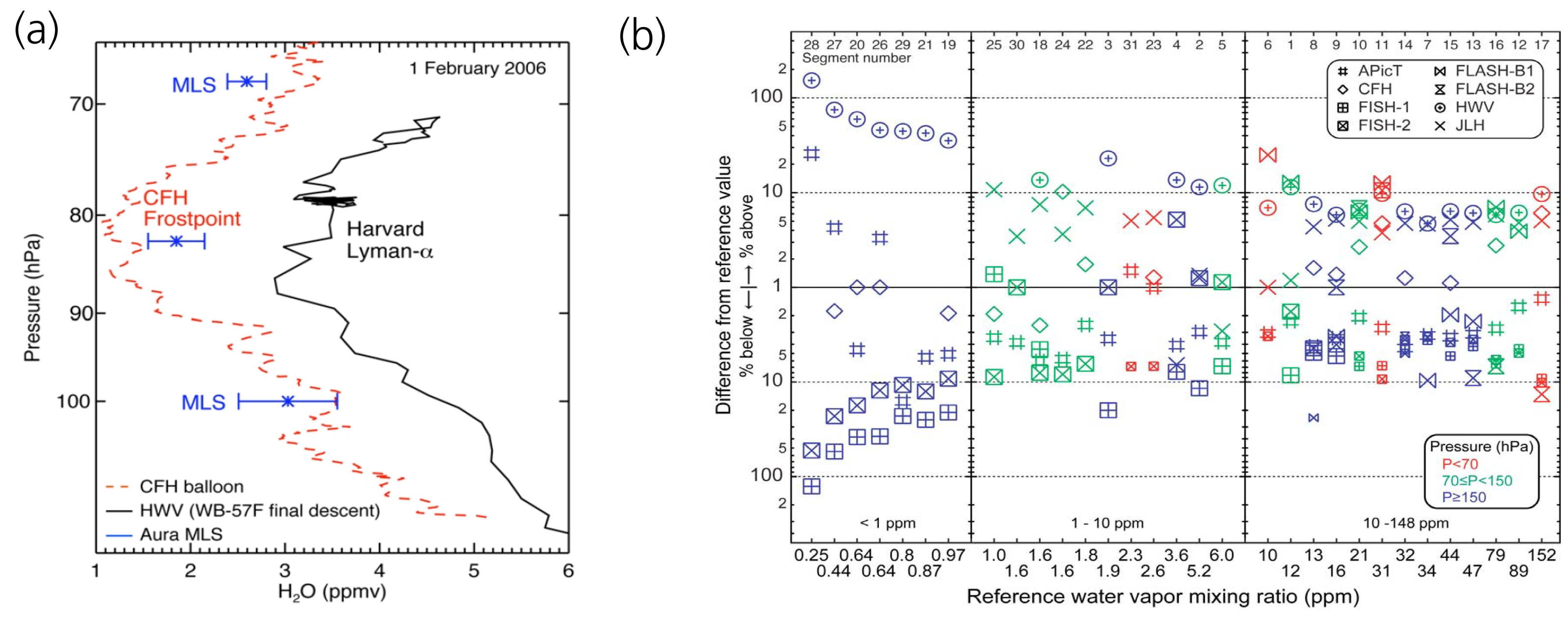

Fig. 2: (a) Stratospheric water vapor measurements from different platforms (balloon, aircraft & satellite) near San Jose in February 2006 (Figure from E. Jensen, NASA). (b) Results of the water vapor instrument intercomparison AquaVIT performed 2007 at the AIDA climate chamber in Karlsruhe (D. W Fahey, R.-S. Gao, and O. Möhler, "Summary of the AquaVIT Water Vapor Intercomparison: Static Experiments" https://aquavit.icg.kfa-juelich.de/AquaVit/).

Airborne water vapor measurements on different platforms (aircraft, balloon, satellite) can differ by up to a factor of 2 at water vapor mixing ratios below 10 ppmv typical for the lower stratosphere (Fig. 2 a). An instrument intercomparison in the laboratory (AIDA chamber) shows significantly lower deviations between the individual instruments, but still in the < 20% range (Fig. 2 b).

In sight of the high sensitivity of the atmospheric radiation budget on the water vapor concentration in the UT/LS, the measurement uncertainties currently limit our understanding of how water vapor influences the climate system.

2. The Atmosperic direct Ionization Mass Spectrometer AIMS-H2O

In cooperation with NOAA, a linear quadrupole mass spectrometer instrument has been developed as a new independent method for the detection of water vapor in the UT/LS.

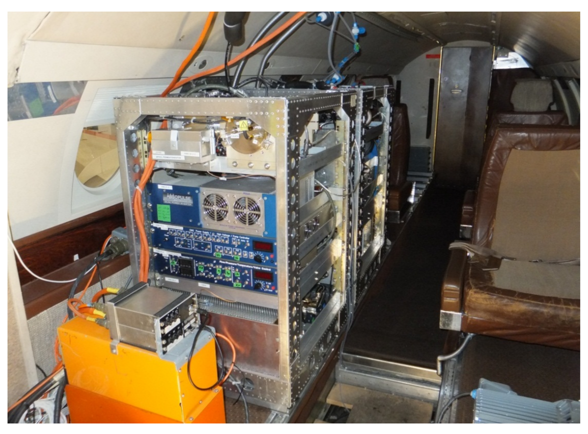

Fig. 4: AIMS-H2O integrated in the DLR-Falcon

Detection principle:

- Direct ionization of ambient air using high voltage gas discharge
- Detection of $H_3O^+(H_2O)_n$ ions (n=1 - 3) with a mass spectrometer
- In-flight calibration standard using the catalytic reaction of H_2 and O_2 on Pt surface (Rollins et al., 2011)

Characteristics:

- Time resolution: 4,2 Hz
- Horizontal resolution ~50 m
- Dynamic range:
  - 1 - 100 ppmv (uncertainty 8 - 12%)
  - 100 - 250 ppmv (uncertainty 10 - 15%)

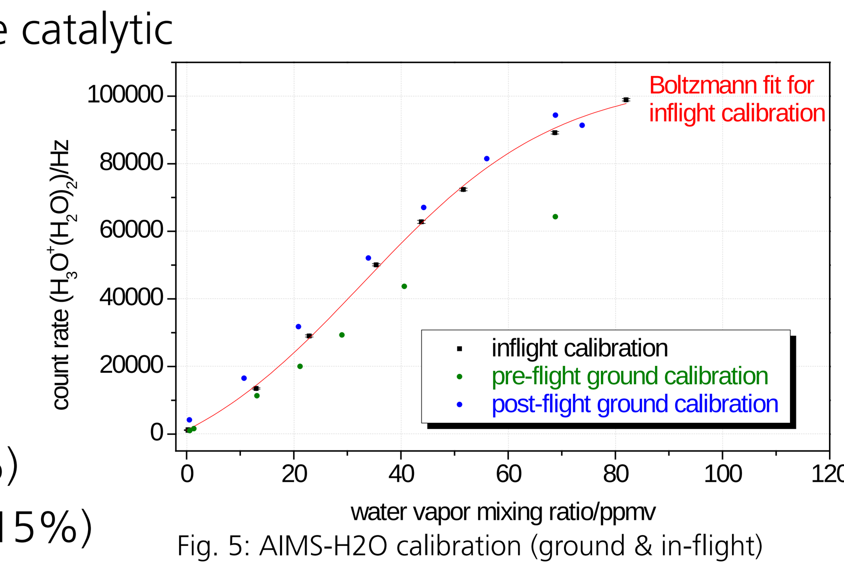

Fig. 5: AIMS-H2O calibration (ground & in-flight)

3. The CONCERT 2011 campaign

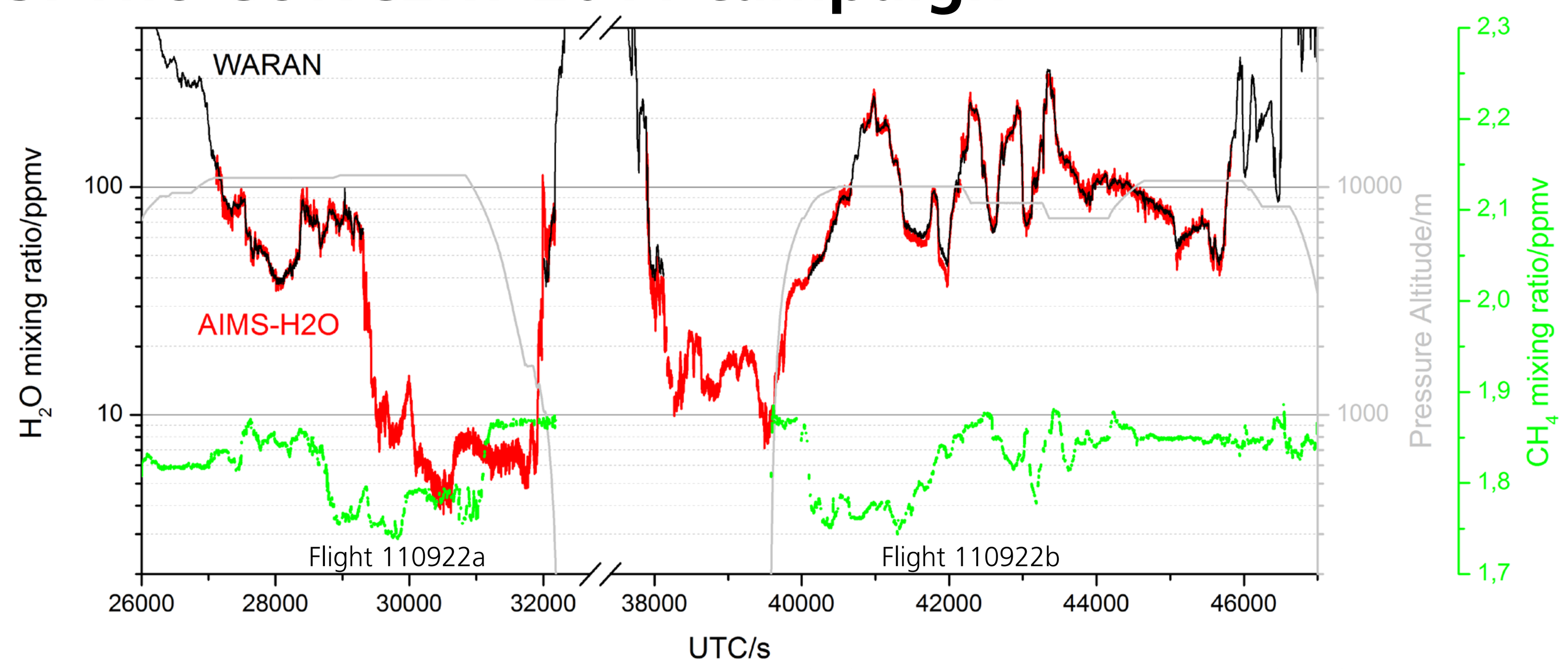

Fig. 6: Water vapor mixing ratio measured by AIMS-H2O (red) and the WARAN TDL instrument (black) during two flights on 22 Sept 2011. The CH_4 mixing ratio (green line) measured by a Piccaro cavity ringdown spectrometer and flight altitude (grey line) are included.

During the CONtrail and Cirrus ExpeRimenT (CONCERT) a stratospheric intrusion passed over northern Europe on 22 Sept 2011. On that day, we performed a return flight with the DLR research aircraft Falcon from Oberpfaffenhofen to Bergen. During the first flight we measured H_2O mixing ratios down to 4 ppmv at 11 km altitude in and above the tropopause fold. The structure and gradients at the edge of the stratospheric intrusion were probed at 3 different levels (7, 9 and 11 km) during the return.

4. Water vapor gradients in a tropopause fold: Comparison to ECMWF

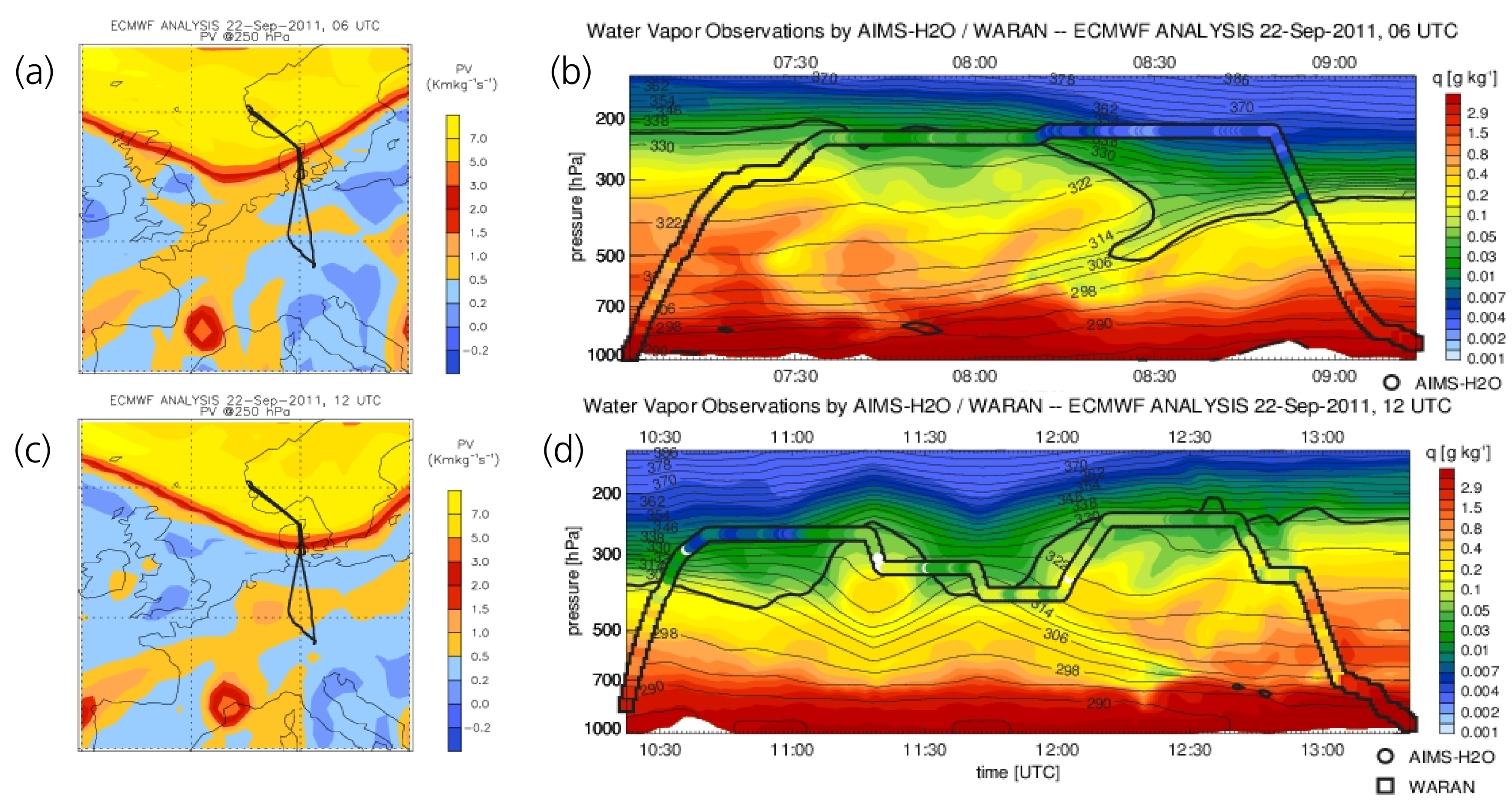

Fig. 7: (a) & (c) Potential Vorticity (PV) from analysis fields of the ECMWF Integrated Forecast System (IFS) at 6 UT and 12 UT on September 22. The black line is the flightpath of the Falcon. PV values higher than 2 $Km^2kg^{-1}s^{-1}$ indicate stratospheric air masses. (b) & (d) Profiles of water vapor mass mixing ratio along both flighttracks from September 22, again calculated from IFS data. Thin black contour lines mark levels of constant potential temperature, the thick black contour line in (b) and (d) marks the 2 PVU tropopause. In-situ measurements of water vapor by AIMS-H2O and Waran are plotted in circles and squares with the same color code as the ECMWF field in (b) and (d).

- In-situ water vapor measurements and the analysis field from ECMWF agree in the lower and mid troposphere. In the lower stratosphere, water vapor mixing ratios from ECMWF are systematically higher than the measured values.
- The dynamical tropopause (at 2 PVU = 2 $Km^2kg^{-1}s^{-1}$) in the ECMWF field coincides with a sharp gradient in the measured water vapor concentrations (Fig. 7 b).
- In-situ water vapor observations show small scale structures not resolved in the ECMWF field (horizontal resolution ~25 km). In our case the intrusion splits up in a two-fold structure at its bottom.

Summary

- AIMS-H2O with inflight calibration performed first successful flights during CONCERT 2011
- ECMWF overestimates water vapor in the lower stratosphere, the H_2O fields of ECMWF do not resolve the sharp humidity gradient found at the dynamical tropopause.
- **Outlook:** Integration of AIMS-H2O on the new research aircraft HALO for cirrus and lower stratospheric measurements at mid latitudes

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