Two decades of water vapor measurements with FISH: A review with special emphasis on TTL water vapor

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(1) Motivation
- Water vapor in the upper troposphere and lower stratosphere (UTLS) plays an important role in the climate of the Earth (affects radiation directly as a gas and indirectly in cloud formation processes)
- Accurate measurements of water vapor in the UTLS are required to understand the underlying processes
- Difficulties in measuring water vapor in the UTLS caused by the low water vapor concentration
  - larger systematic discrepancies between hygrometers have been reported (Fahey et al., 2014; Rollins et al., 2014)
- More than two decades of the FISH hygrometer:
  - >100 publications including FISH measurements
  - a comprehensive review of the measurement principle, calibration procedure and data evaluation is performed
- Overview of TTL total water meas. with FISH

(2) FISH instrument & operation
- Fast In-situ Stratospheric Hygrometer (FISH) airborne Hygrometer for accurate and precise measurement of total water mixing ratios (WVMR) (gas phase + evaporated ice) in the UTLS
- Measurement quality based on regular calibration to a water vapor reference (MBW DP30)
- From 348 FISH aircraft flights in tropics, mid-latitudes and the polar region a unique set of UTLS water vapor data is compiled
- Cirrus ice water content (e.g. Schiller et al. 2008, Krämer et al. 2009, Luebke et al. 2013)
- Water vapor transport (e.g. Kunz et al. 2008)
- Process Studies (e.g. Rolf et al., 2015)

(3) FISH principle
- Lyman-α photo-fragment fluorescence hygrometer
- Ng: fluorescence signal
- Nu: background lifetime
- lamp intensity
- Lyman-α source: flow lamp with RF field (Ar + 1% Hz)
- FISH formula to derive WVMR with calibration factors (ck, fu)

(4) Calibration setup
- Calibration performed normally before and after each research flight to ensure high data quality
- Calibration bench consists of:
  - Dry syn. air supply
  - Humidifier
  - Pressure regulator
  - Reference Instrument (MBW DP30)
- Left: normal calibration run; Right: calibration run with extended formula + better agreement at all pressures

(5) FISH intercomparisons
- Aircraft:
  - FISH vs.: FLASH <30% (Geophysics); WASUL 13.1%, SHARC 3.7% (HALO)
- Laboratory:
  - FISH <10% against others (AquaVit 1,6%, NOAA-TDL 0.9% (AquaVit 2)
- MLS - Satellite:
  - Excellent agreement between FISH and MLS: differences are between ±2 ppmv;
  - Mean differences range from -0.2 to -0.5 ppmv
  - Agreement of FISH with other hygrometers has improved over time

(6) WVMR in the TTL
- TROCCINOX (Brazil Feb. 2005)
  - SCOUT-O3 (Australia Nov-Dec 2005)
  - Lowest WVMR 1.3 ppmv during SCOUT and 1.6 ppmv during TROCCINOX; in contrast 4-6 ppmv at cold point during AMMA
- Highest RH> and cloud occurrence during SCOUT (ongoing dehydration) cloud formation and high saturation at cold point; not frequent during AMMA and TROCCINOX
- Convective injections with RH>100% most in sub-saturated environment in the TTL up to 420 K
- Head of tape recorder at tropopause (380 K): minimum H2O in NH winter; maximum during AMMA
- Hygropause at tropopause for NH winter campaign; hygropause at 19-20 km during AMMA
- H2O at hygropause during AMMA higher than NH H2O of other campaigns (inter-annual variability, NHSH difference)

(7) Cirrus clouds in the TTL
- TTL campaigns with cirrus:
  - APE-THESEO 1999
  - TROCCINOX 2005
  - SCOUT-O3 2005
- Cirrus clouds are found up to 420 K in the TTL
- Ice water content (IWC) of TTL cirrus has a wide range (0.01-550 ppmv) in contrast to Arctic / Mid-latitudes
- IWC can reach fractions of total WVMR up to 100% in the TTL
  - Indication for strong dehydration at bottom of the TTL
  - NH/SH difference in ice more relevant (Krämer et al. 2008)
  - Convective injections with IWC moisten sub-saturated environment in the TTL up to 420 K

(8) Conclusion
- Total accuracy of FISH is 6% in the range 4-1000 ppmv (as stated also in previous publications; reference Instrument DP30 2.4%)
- Precision of FISH: 0.15 - 0.4 ppmv depending on instrument performance
- Modified FISH calibration evaluation for special AIDA conditions (low WVMR at high pressures) improves agreement to better than 10%
- Four campaigns with FISH in the TTL showing dehydration, convective injection of ice crystals, H2O tape recorder
- Agreement of FISH with other hygrometers has improved over time from up to 30% more to about 5-20% at 10 ppmv and to 0-15% at 10 ppmv
- In the last two decades, the position of FISH has established as one of the core instruments for in-situ observations of water vapor in the UTLS

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TTL campaigns

- Stability of calibration factors within one campaign (better 1.5%)