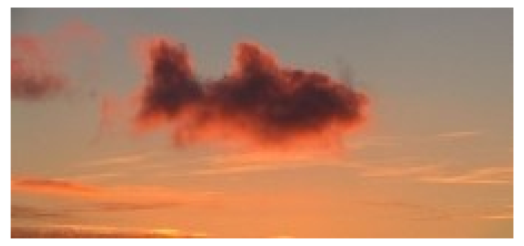
Two decades of water vapor measurements with FISH: A review with special emphasis on TTL water vapor



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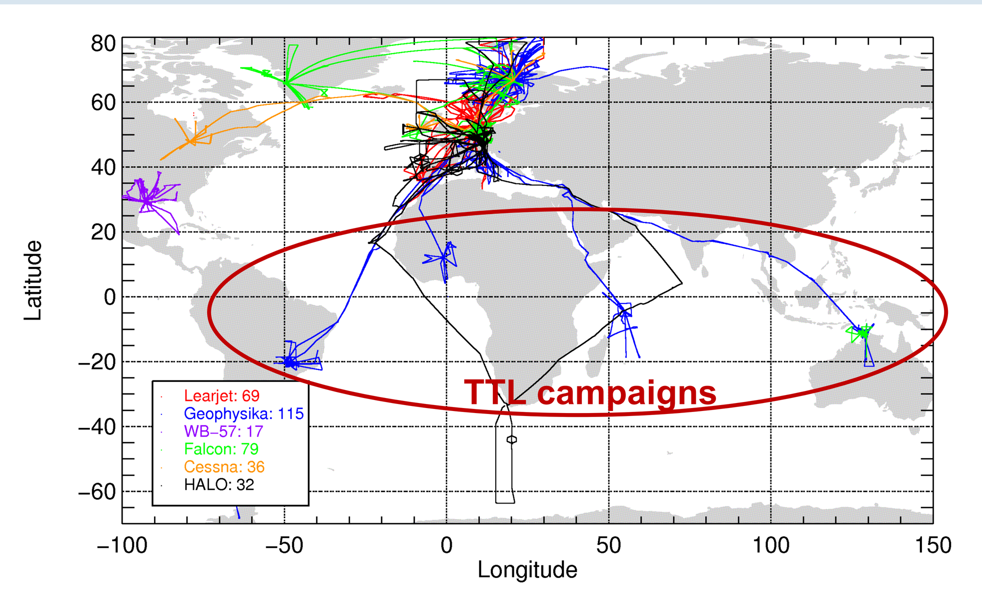
JÜLICH FORSCHUNGSZENTRUM

(1) Motivation

- Water vapor in the upper troposphere and lower stratosphere (UT/LS) 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 in the UT/LS are required to understand the underlying processes
- Difficulties in measuring water vapor in the UT/LS 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 meas.
  - a comprehensive review of the measurement principle, calibration procedure and data evaluation is performed
  - Overview of TTL total water meas. with FISH

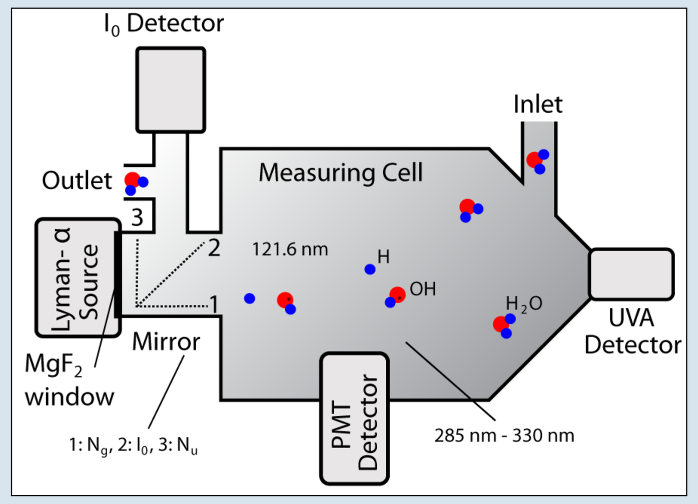
(2) FISH instrument & operation

- **F**ast **In**-situ **S**tratospheric **H**ygrometer (FISH) airborne Hygrometer for accurate and precise measurement of total water mixing ratios (WMR) (gas phase + evaporated ice) in the UT/LS
- 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 UT/LS 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
  I0: lamp intensity



- Lyman-α source: flow lamp with RF field (Ar + 1% H2)
- FISH formula to derive WVMR with calibration factors (ck, fu)

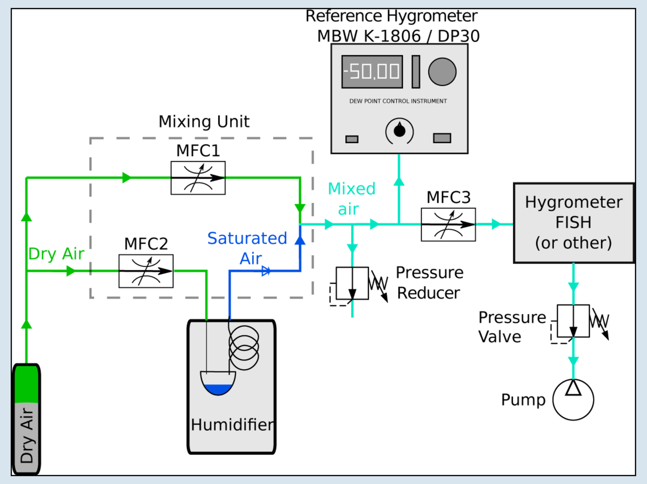
$$\mu = c_k \cdot \frac{N_g - f_u \cdot N_u}{I_0 \cdot K_f}$$

- Extended formula for especially low mixing ratios at high pressures (AIDA laboratory cond., water vapor partial pressure difference (wall – air sample) large , P_{eq} - P)

$$\mu = c_k \cdot \frac{N_g - f_u \cdot N_u}{I_0} - c_k \cdot X_w \cdot \frac{(P_{eq} - P) \cdot I_0}{flow}$$

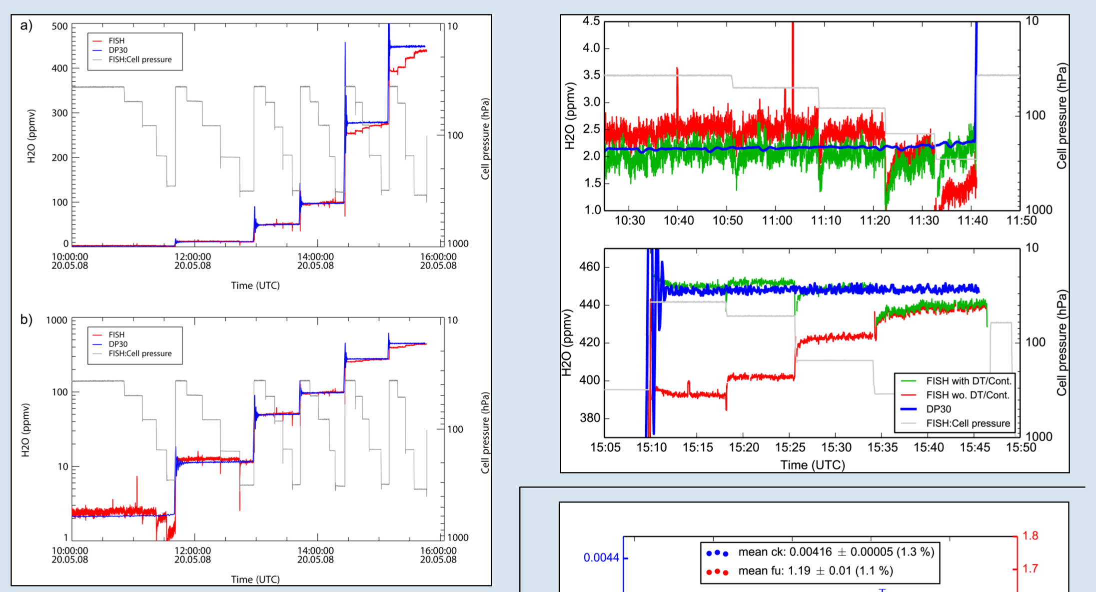
(4) Calibration setup

- Calibration performed normally before and after each research flight to ensure high data quality

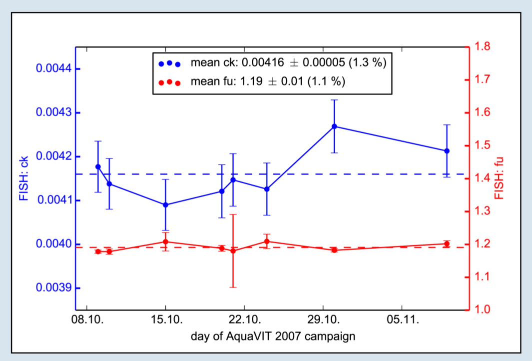


- Calibration bench consists of:
  - Dry syn. air supply
  - Humidifier
  - Pressure regulator
  - Reference Instrument (MBW DP30)

- Left: normal calibration run; Right: calibration run with extended formula → better agreement at all pressures

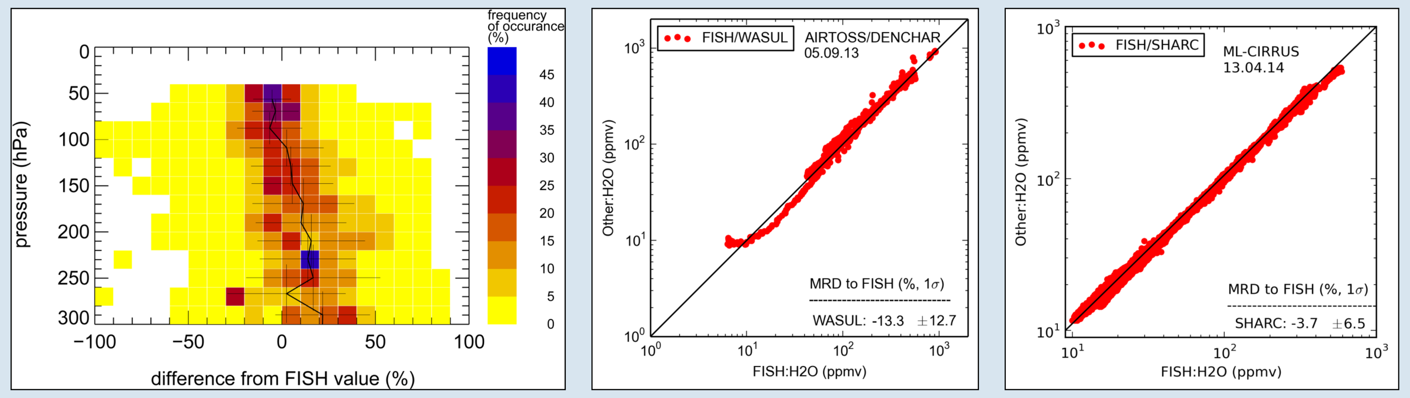


- Stability of calibration factors within one campaign (better 1.5%)



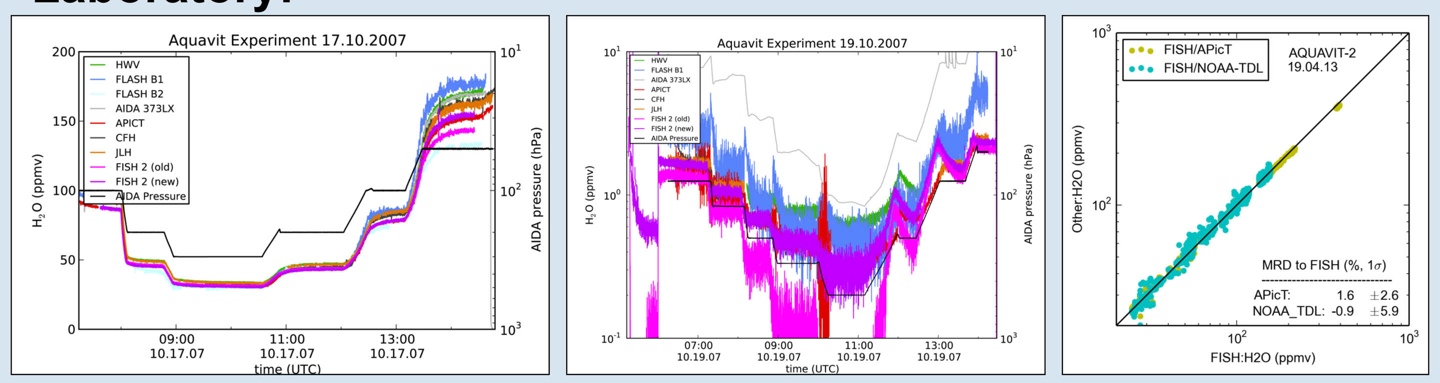
(5) FISH intercomparisons

Aircraft:



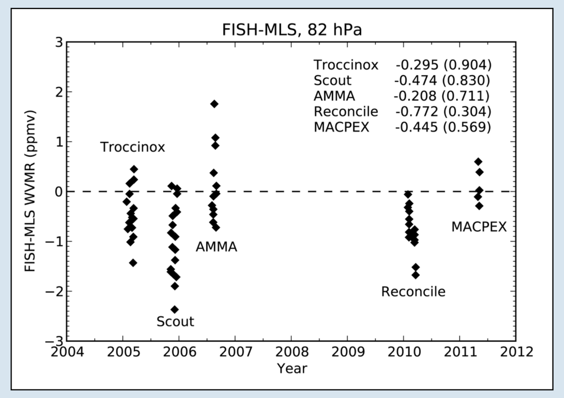
- FISH vs.: FLASH < 30% (Geophysica); WASUL 13,1%, SHARC 3,7% (HALO)

Laboratory:



- FISH <10% against others (AquaVit-1); APicT 1,6%, NOAA-TDL 0,9% (AquaVit-2)

MLS - Satellite:



Agreements:

Year	Instrument	Range (ppmv)		Agreement (%)		Campaign	Platform
		low	high	*low*	*high*		
1995	MOZAIC		100-500		*10 in RH*	-[1]	Falcon
1999-2010	FLASH	1-1000		*≦ 30*		several[2]	Geophysica
2000	HWV, JPH, NOAA-CMDL	<10		*20*		SOLVE[3]	DC-8 and ER-2
2003	MOZAIC		10-600		*5 in RH*	CIRRUS-3[4]	Learjet
2007	HWV, FLASH, APicT, CFH, JLH	<10	10-150	*20 (10*)*	*<10*	AquaVIT-1[5]	AIDA
2011	CIMS, HWV, DLH	<10	10-150	*10 – 20*	*< 7*	MACPEX[6]	WB-57
2012	HAI	1.6-4		*-14.9 – -5.9*		TACTS/ESMVal[7]	HALO
2013	WASUL		10-1000		*-13.3*	Airtoss	Learjet
2013	APicT, NOAA-TDL	7-20	20-600	*-2.4 – 0.7*	*-0.9 – 1.6*	AquaVIT-2	AIDA
2014	SHARC		10-1000		*-3.7*	ML-Cirrus	HALO

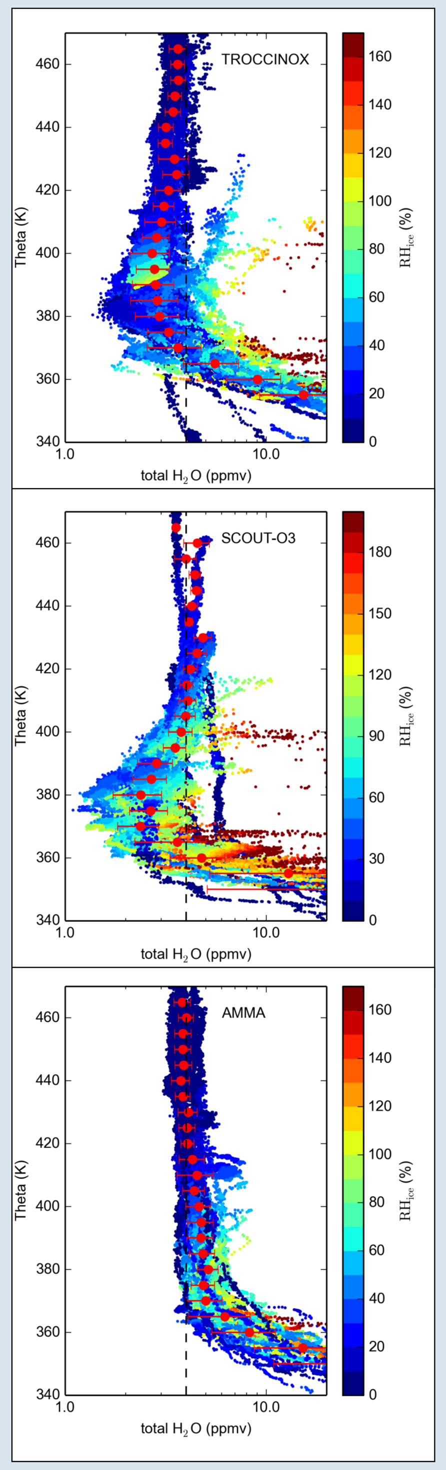
1: see Helten et al. (1998), 2: see Krämer et al. (2009),
3: see Kley et al. (2000), 4: see Neis et al. (2014),
5: see Fahey et al. (2014), 6: see Rollins et al. (2014),
7: see Rolf et al. (2014), ∗: new extended calibration evaluation

- 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

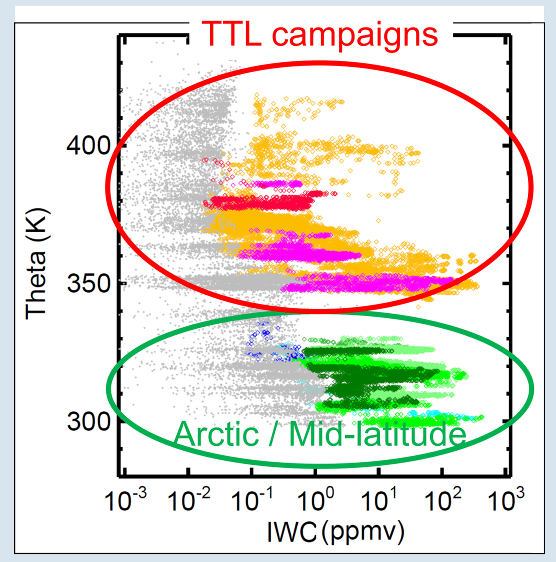
(6) WVMR in the TTL

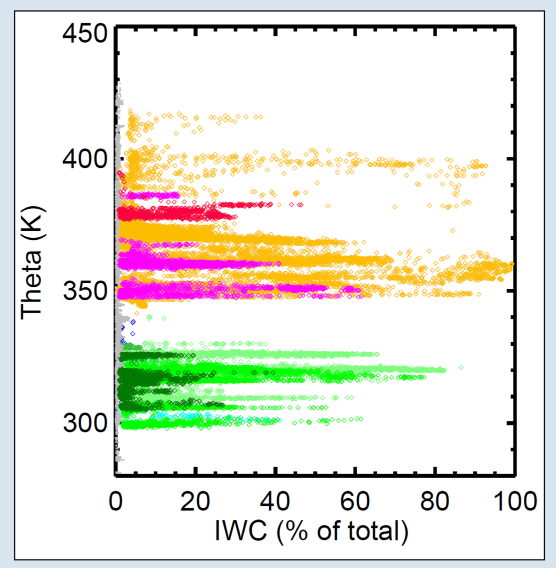
- TROCCINOX (Brazil Feb. 2005)
  SCOUT-O3 (Australia Nov-Dec 2005)
  AMMA (Burkina Faso Aug. 2006)
- Lowest WVMR 1.3 ppmv during SCOUT and 1.6 ppmv during TROCCINOX; in contrast 4-6 ppmv at cold point during AMMA
- Highest RH_{ice} and cloud occurrence during SCOUT (ongoing dehydration) cloud formation and high saturation at cold point; not frequent during AMMA and TROCCINOX
- Convective injections with RH_{ice} >100% moisten sub-saturated environment in the TTL up to 420 K
- Head of tape recorder at tropopause (380 K): minimum H_2O in NH winter, maximum during AMMA
- Hygropause at tropopause for NH winter campaigns; hygropause at 19-20 km during AMMA
- H_2O at hygropause during AMMA higher than min H_2O of other campaigns (inter-annual variability, NH/SH 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 (0.01-500 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
  - ➢ HNO_3 content 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, H_2O tape recorder
- Agreement of FISH with other hygrometers has improved over time from up to 30% or more to about 5-20% @<10ppmv and to 0-15% @>10ppmv
- 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 UT/LS

- More Information under acpd-15-7735-2015:
  Meyer, J., Rolf, C., Schiller, C., Rohs, S., Spelten, N., Afchine, A., Zöger, M., Sitnikov, N., Thornberry, T. D., Rollins, A. W., Bozóki, Z., Tátrai, D., Ebert, V., Kühnreich, B., Mackrodt, P., Möhler, O., Saathoff, H., Rosenlof, K. H., and Krämer, M.: Two decades of water vapor measurements with the FISH fluorescence hygrometer: a review, Atmos. Chem. Phys. Discuss., 15, 7735-7782, doi:10.5194/acpd-15-7735-2015, 2015