NOAA frost point hygrometer (FPH) comparisons, measurement uncertainties, and recent instrument improvements

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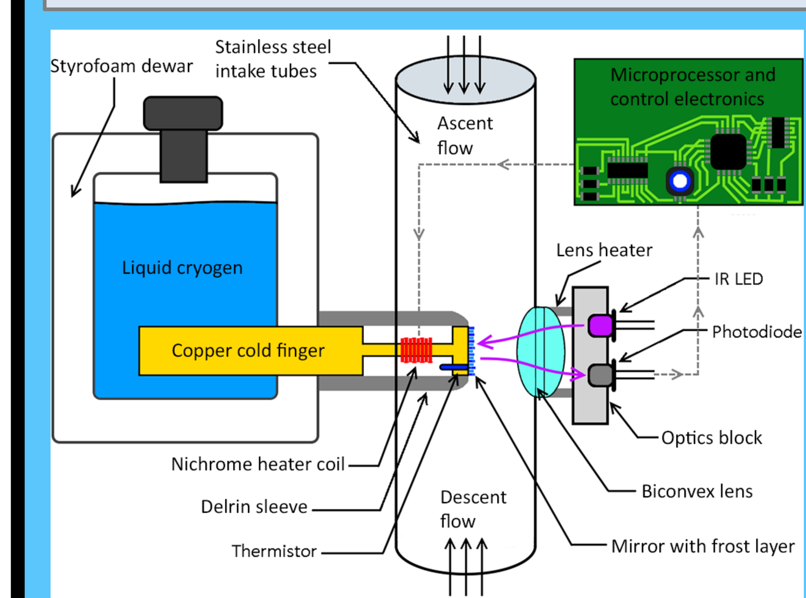
Introduction

Water vapor is an important greenhouse gas in the atmosphere and contributes to many processes and feedback mechanisms. Accurate measurements of UTLS water vapor are crucial for understanding changes in the stratospheric water vapor budget and their impact on the radiative forcing of our climate. The NOAA FPH is a balloon-borne instrument flown monthly at three sites measuring water vapor up to ~ 28 km. The ongoing 36 year Boulder stratospheric water vapor record shows a net increase of ~ 1 ppmv (27 %) since 1980.



The NOAA FPH relies on maintaining a thin, stable layer of condensate on a mirror through rapid feedback control. A calibrated thermistor embedded in the mirror accurately measures the frost point temperature. The Goff-Gratch formulation of the Clausius-Clapeyron equation is used to calculate the water vapor partial pressure.

While discrepancies in the UTLS observations between aircraft, balloon-borne, and satellite instrumentation have decreased in recent years, some significant differences still remain. During MACPEX in 2011, the differences were roughly 0.8 ppmv (20 %) [*Rollins et al.*, 2014].

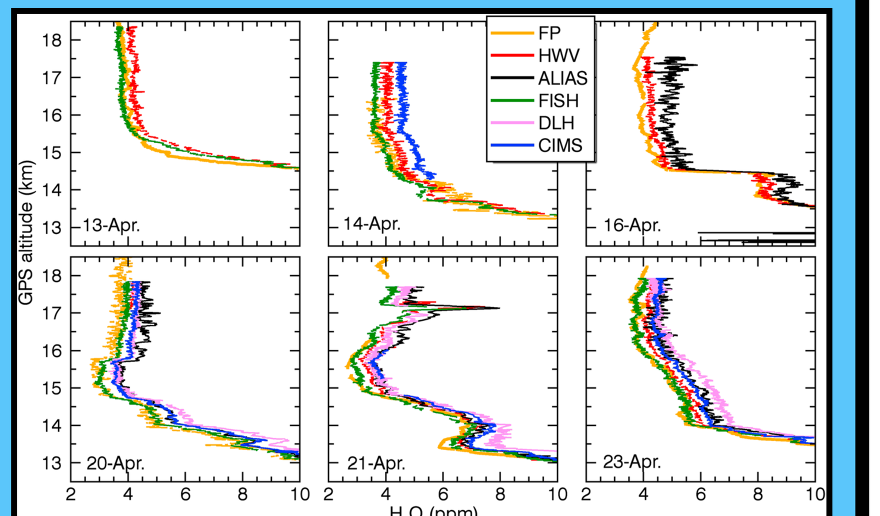
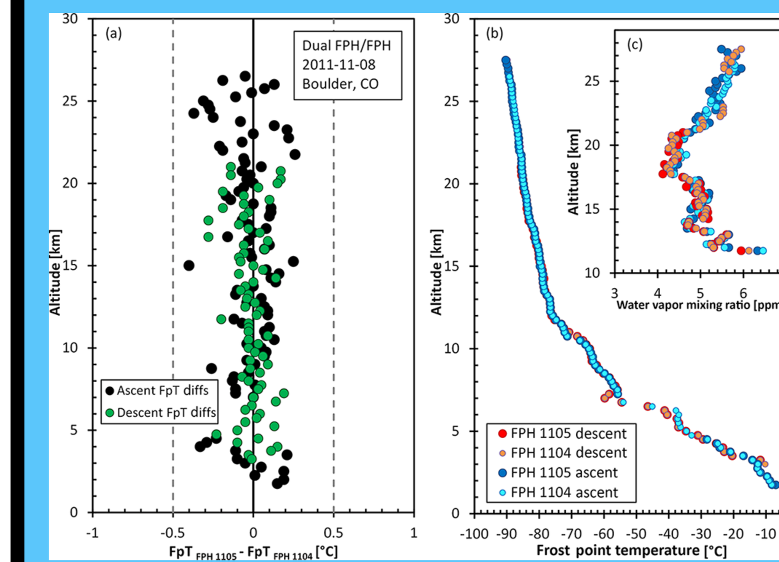
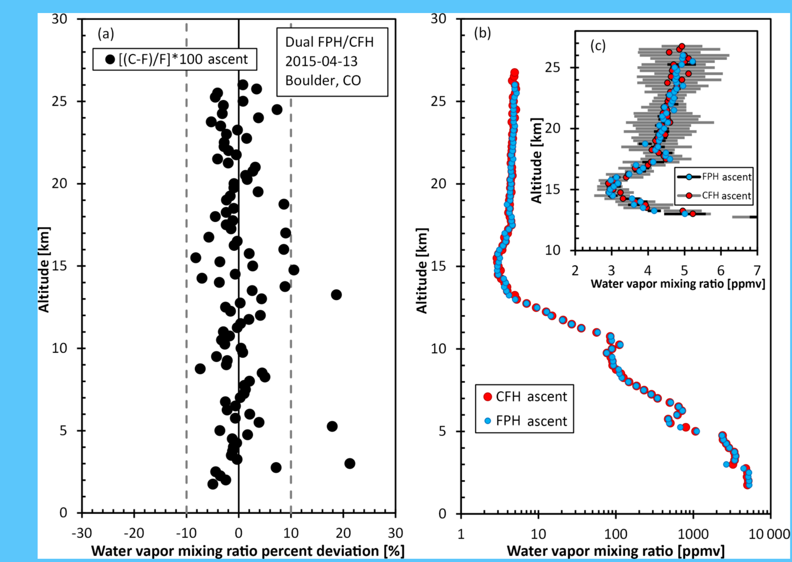


Figure: Rollins et al., 2014

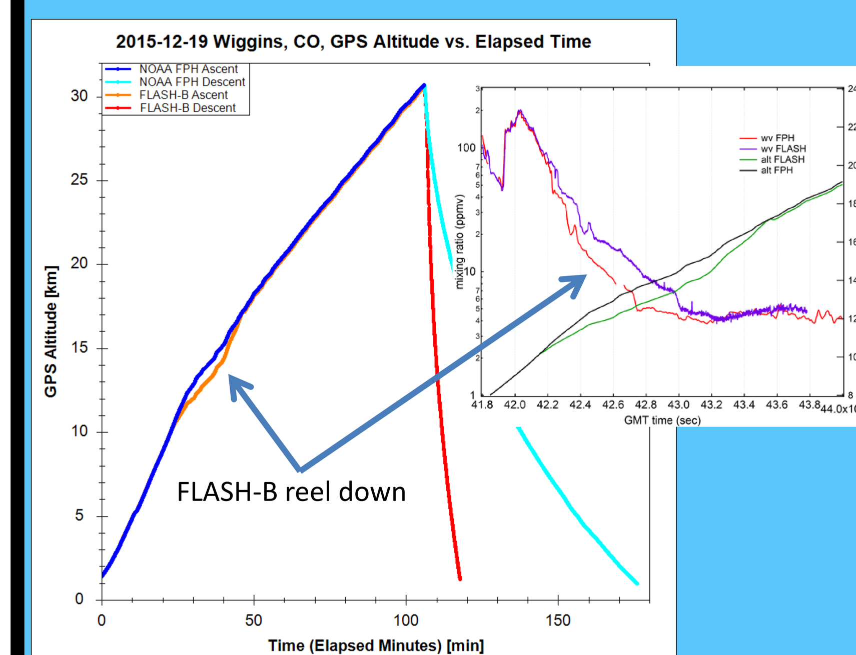
Dual Flight Comparisons



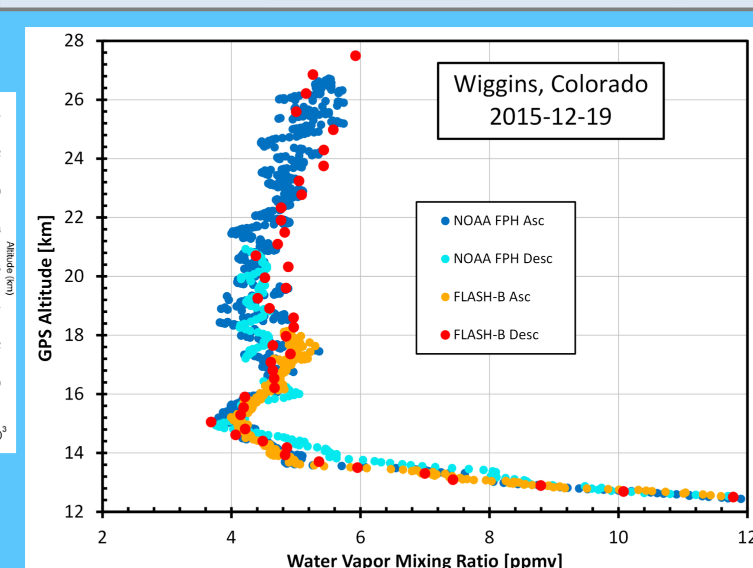
Boulder dual **FPH / FPH** balloon flight



Boulder dual **FPH / CFH** balloon flight

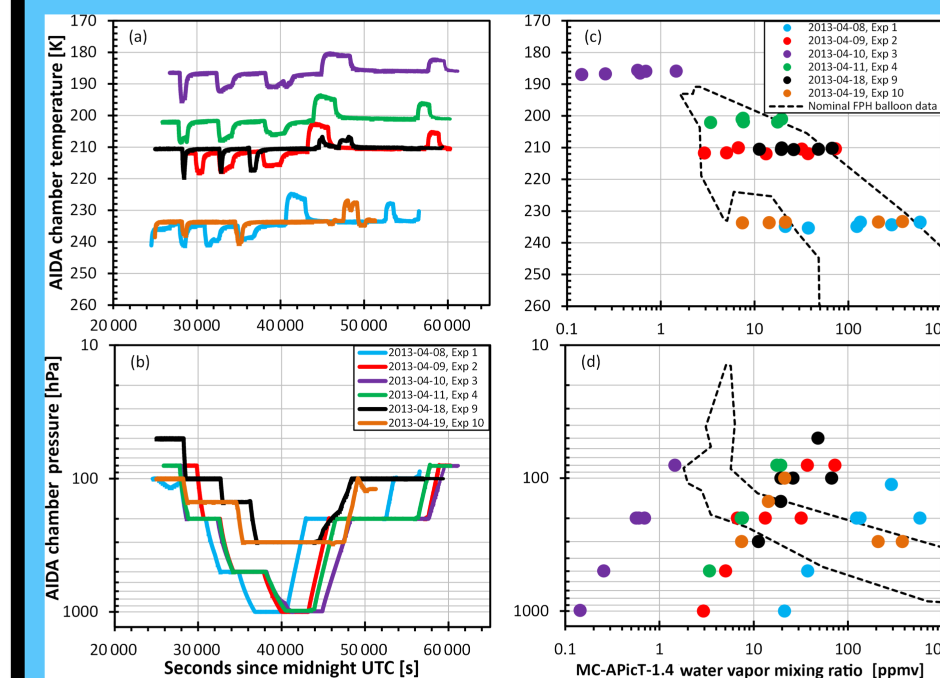


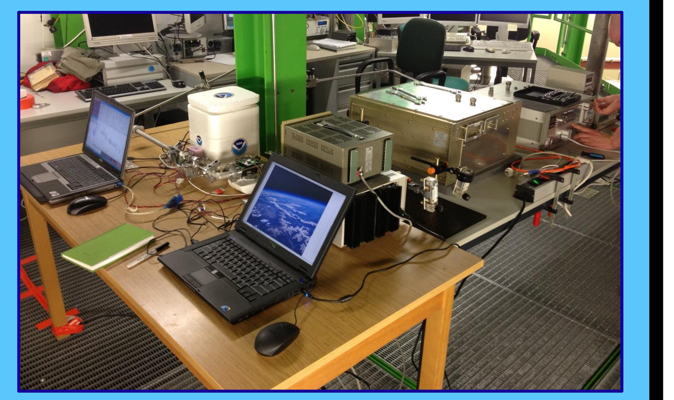
FLASH-B was reeled down 1000 m below the FPH at 10 km. It was reeled back in by 17 km but the package was stuck 130 m below the FPH due to a small reel issue.

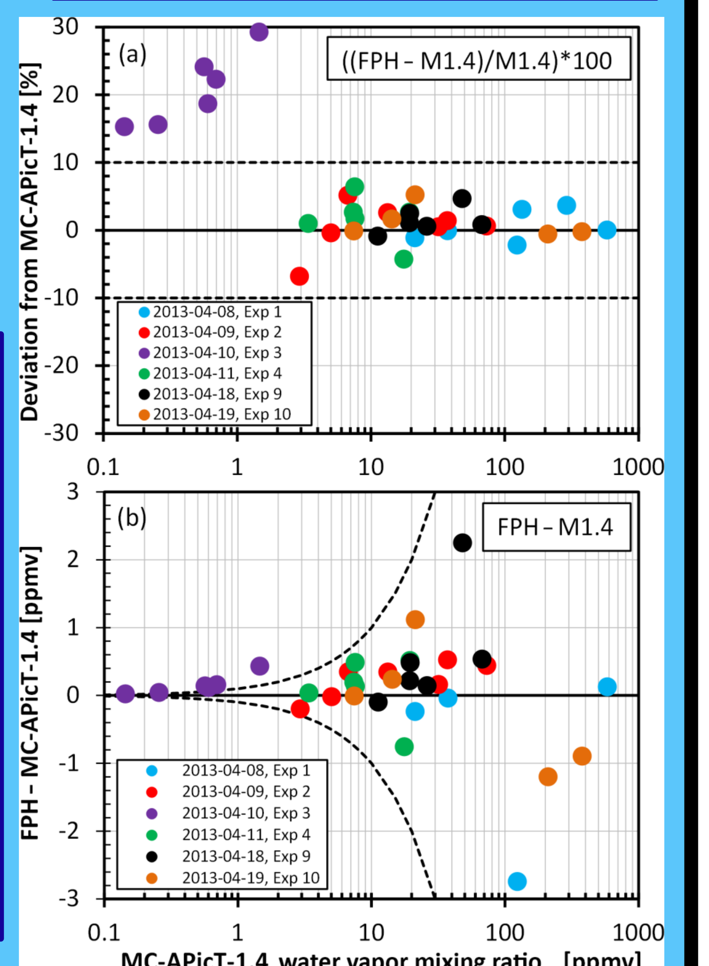


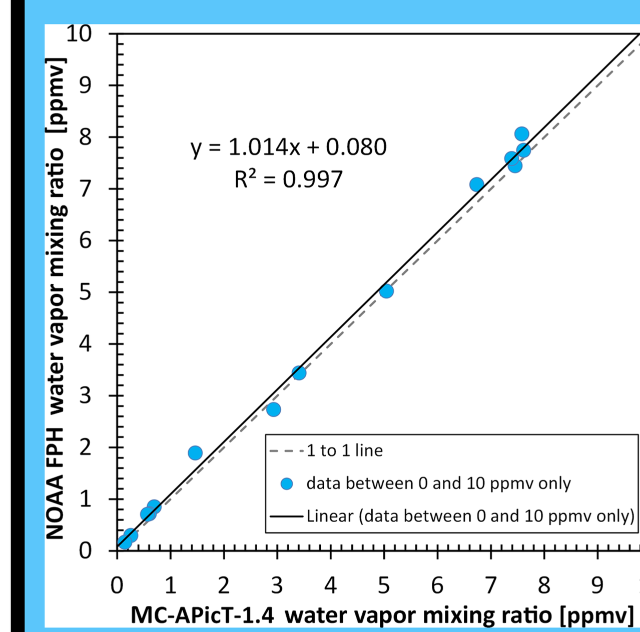
Dual **FPH / FLASH-B** night flight in Wiggins, CO near Boulder. FLASH-B separated from the FPH package at burst resulting in a fast descent. Overall, good agreement between FLASH-B and the NOAA FPH.

AquaVIT-2 Chamber Results









AquaVIT-2

- 36 Instruments
- 17 Groups
- More than 50 Scientists
- 6 Participating Countries
- 3 blind days
- 7 non-blind days

Chamber Conditions

- 1000 – 50 hPa
- 180 – 233 K
- 0.2 – 1000 ppmv

A total of 36 stable sections were analyzed lasting roughly 30 minutes each in duration. The NOAA FPH agrees with the MC-APicT-14 instrument within 10% between 2 and 600 ppmv. Below 1.5 ppmv the agreement is better than 30%.

Frost Point History

FPH version	Period	Radiosonde frequency and model	Data acquisition method	Weight without cryogen (g)
FPH V1	1980–1991	1680 MHz VIZ "A"	Analog strip chart recorder	1550
FPH V2	1991–2004	403 MHz Vaisala RS-80	Digital Strato software	1500
FPH V3	2004–2008	403 MHz Vaisala RS-80	Digital Strato software	475
FPH V4	2008–present	403 MHz InterMet iMet-1-RSB	Digital SkySonde Client/Server	450

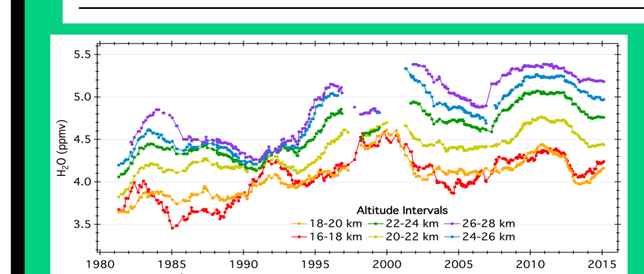


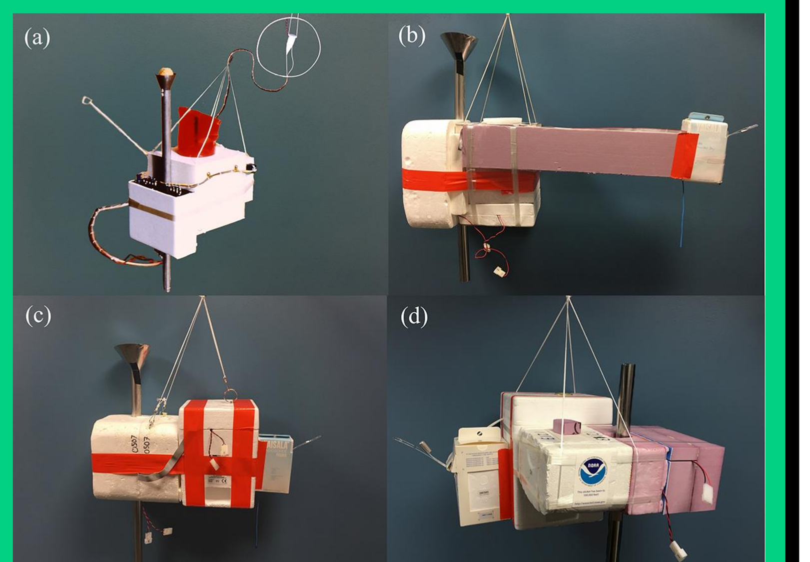
Figure courtesy Dale Hurst

Between 2005 and 2008 the digital version of the hygrometer was developed. This version incorporated a modulating sunlight filter eliminating the sun shield. A lens heater and a flexible frost point-dependent gain schedule were also incorporated.

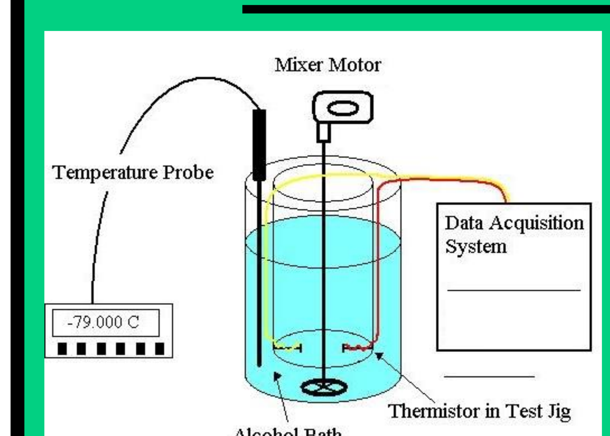
Boulder
40°N, 105.2°W
N = 463

Hilo
19.7°N, 155°W
N = 68

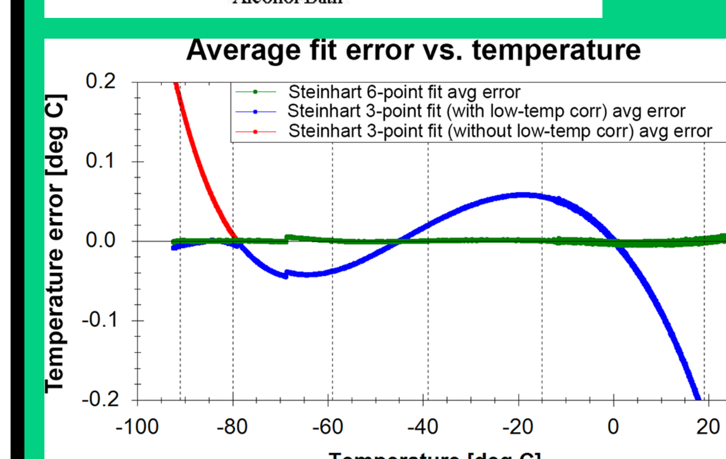
Lauder
45°S, 169.7°E
N = 144



Thermistor Calibration

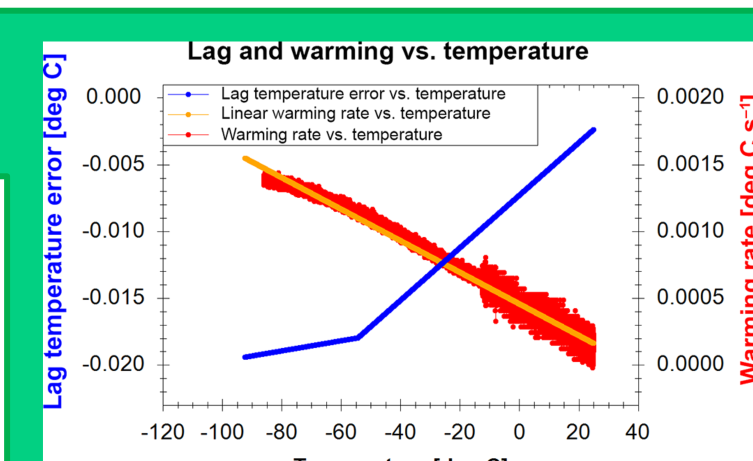


The constantly stirred alcohol bath temperature is measured by a NIST-traceable thermometer. Up to 40 thermistors can be calibrated at once using the current data acquisition system. The FPH thermistors are calibrated from -93 °C to +20 °C.

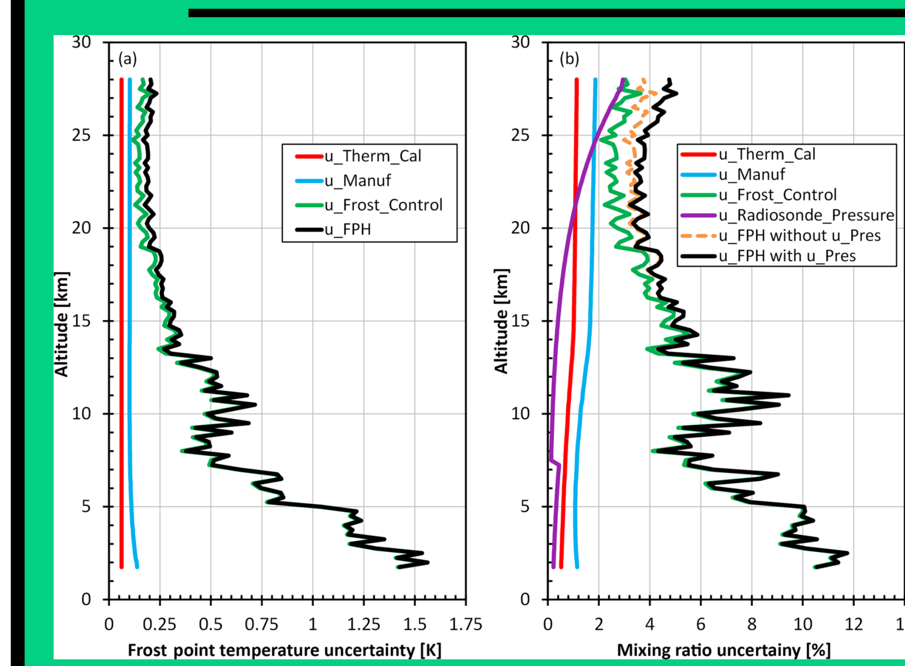


A lag correction was empirically determined with values ~ 0.02 °C at -90 °C reducing to 0.005 °C at temperatures around 10 °C. The lag correction is only necessary with the new slow warming six-point fit used since 2014.

From 1980 to 2013 a three-point fit was used on all calibrated FPH thermistors. A new six-point fit was utilized from 2014 to lower the uncertainty in the calibration fit from 0.06 °C to 0.01 °C.



NOAA FPH Uncertainties



The FPH uncertainties shown are the mean values from 24 flights in Boulder, CO. The largest FPH measurement uncertainty is the frost control instability. The mixing ratio uncertainties include manufacturer-quoted radiosonde pressure sensor uncertainties. Overall, the total stratospheric uncertainties are < 6 % (2-σ).

Uncertainty parameter	Value	R/S[1]
Frost control stability, u_Frost_Control	0.1–1.5 K	R
Temperature uniformity of the mirror, u_Mirror_ Uniform	< 0.1 K	S
FPH electronics board thermistor measurement, u_FPH_ ADC	< 0.02 K (stratosphere), < 0.17 K (troposphere)	S[2]
Manufacturing uncertainty total, u_Manuf	$= (u\_Mirror\_Uniform^2 + u\_FPH\_ADC^2)^{1/2}$	S[2]
Thermistor calibration fit, u_Cal_Fit	0.06 K (three-point fit), 0.01 K(six-point fit)	S
Thermistor calibration repeatability, u_Cal_Repeat	0.043 K (three-point fit), 0.028 K (six-point fit)	S
Reference thermometer, u_Ref_Therm	0.01 K after 1998, 0.075 K before 1998	S
Thermistor calibration total, u_Therm_Cal	$= (u\_Cal\_Fit^2 + u\_Cal\_Repeat^2 + u\_Ref\_Therm^2)^{1/2}$, 0.1 K < 1990, 0.07 K > 1990 (three-point fit), 0.03 K (six-point fit)	S[3]
NOAA FPH uncertainty total, u_FPH	$= (u\_Frost\_Control^2 + u\_Manuf^2 + u\_Therm\_Cal^2)^{1/2}$	

[1] Random or systematic; [2] dependent on frost point temperature; [3] constant in profile.

References: Rollins, A. W., et al. (2014), Evaluation of UT/LS hygrometer accuracy by intercomparison during the NASA MACPEX mission, J. Geophys. Res. Atmos., 119, doi:10.1002/2013JD020817.