File Revision Date:
September 19, 2025

Data Set Description:

PI: Elizabeth Asher (prior to April 2022, PI Dale Hurst)
Instrument: NOAA frost point hygrometer
Sites: Boulder, CO U.S.A. 39.949°N, 105.197°W, 1743 masl
Hilo, HI U.S.A. 19.717°N, 155.049°W, 10 masl
Lauder, NZ 45.038°S, 169.683°E, 370 masl

Measurement Quantities: Pressure, Temperature, Relative humidity, Geopotential height, Frost point temperature, Water vapor mixing ratio, GPS Altitude, Latitude and Longitude of payload, Horizontal wind speed and direction

NOTE: Most FPH soundings are archived under the instrument name WVSONDE and have filename extensions ".w[HH]" where [HH] is the hour of balloon launch (UTC). For some Boulder soundings two FPHs were flown on the same balloon. To differentiate between the two instruments the second FPH sounding is archived under the instrument name WVSONDE2 with the filename extension ".h[HH]".

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Reference Articles:

Mastenbrook, H. J. and Dinger, J. E.: Distribution of Water Vapor in the Stratosphere, J. Geophys. Res., 66, 1437–1444, 1961.

Mastenbrook, H. J. and Oltmans, S. J.: Stratospheric water vapor variability for Washington, DC/Boulder, CO: 1964–82, J. Atmos. Sci.,40,2157–2165, 1983. Oltmans, S. J.: Measurements of water vapor in the stratosphere with a frost-point hygrometer, Moisture and Humidity-1985-Measurement and Control in Science and Industry, 251–258, 1985.

Oltmans, S. J. and Hofmann, D. J.: Increase in lower-stratospheric water vapour at a mid-latitude northern hemisphere site from 1981 to 1994, Nature, 374, 146–149, doi:10.1038/374146a0, 1995.

Oltmans, S. J., Vömel, H., Hofmann, D. J., Rosenlof, K. H., and Kley, D.: The increase in stratospheric water vapor from balloonborne, frostpoint hygrometer measurements at Washington, D.C., and Boulder, Colorado, Geophys. Res. Lett., 27, 3453–3456, doi:10.1029/2000GL012133, 2000.

Scherer, M., Vömel, H., Fueglistaler, S., Oltmans, S. J., and Staehelin, J.: Trends and variability of midlatitude stratospheric water vapour deduced from the reevaluated Boulder balloon series and HALOE, Atmos. Chem. Phys., 8, 1391–1402, doi:10.5194/acp-8-1391-2008, 2008.

Hurst, D. F., Oltmans, S. J., Vömel, H., Rosenlof,K. H., Davis, S. M., Ray, E. A., Hall, E. G., and Jordan, A. F.: Stratospheric water vapor trends over Boulder, Colorado: Analysis of the 30 year Boulder record, J. Geophys. Res., 116, D02306, doi:10.1029/2010JD015065, 2011.

Hall, E. G., Jordan, A. F., Hurst, D. F., Oltmans, S. J., Vömel, H., Kühnreich, B. and Ebert, V.: Advancements, measurement uncertainties and recent comparisons of the NOAA frost point hygrometer, Atmos. Meas. Tech., 9, 4295–4310, doi:10.5194/amt-9-4295-2016, 2016.

Instrument Description: The NOAA FPH is a compact and lightweight balloon-borne chilled mirror hygrometer first developed in the 1960s at the Naval Research Laboratory, Washington, D.C., then routinely flown from Boulder starting in 1980. The instrument measures the frost point temperature of the air stream flowing through it. First, a thin layer of frost is grown on a small reflective mirror continuously in thermal contact with a cold bath. The frost layer is then stably maintained by a micro-controller, using Proportional-IntegralDerivative (P-I-D) logic, that applies pulses of heat to the mirror to counteract the persistent cooling by the cold bath. The surface frost coverage is monitored by a small infrared beam (LED) that reflects off the mirror to a photodiode detector. When changes in frost coverage are sensed the heating pulses are rapidly adjusted to re-stabilize the frost layer. When the frost layer is stable it is in equilibrium with the moisture in the air stream flowing over the mirror, and the frost point temperature is equal to the mirror temperature.

Algorithm Description:
The partial pressure of water vapor (Pw) in the flowing air stream is calculated directly from the measured frost point temperature using the well-established Goff-Gratch equation that relates the saturation vapor pressure over ice to the ice surface temperature. The water vapor mixing ratio (H2O) is calculated from Pw using H2O (ppmv) = Pw/(Pa-Pw) (x1e^6) where Pa is the measured atmospheric pressure. Mixing ratios are defined as mole fractions in dry air so it is necessary to subtract the water vapor partial pressure from the measured atmospheric pressure. Water vapor mixing ratios in units of ppmv (parts per million by volume) are similar to mole fraction units (micromoles water vapor per mole dry air). The accuracy of water vapor mixing ratios calculated in this way depends on the accuracies of the frost point temperature measurements and the radiosonde measurements of Pa but is typically < 10% in the stratosphere and <12% in the troposphere (see below for details). Two data columns were added in 2025 to the NDACC data files. The first data product is a smoothed vertical profile of the water vapor mixing ratio and the second is an associated uncertainty, available at 1 Hz. The

smoothed data product is calculated using a gaussian filter and uncertainty in post-processing (see Fig.1) because the telemetered (raw) data is only available at 1 Hz. Uncertainties in the frost point temperature are added in quadrature (Hall et al., 2016) and the uncertainty in vapor pressure over liquid water (E_w) or vapor pressure over ice (E_i) is calculated according to as:

$$Unceratinty\ (E_i) = \left[\frac{dF}{dT}\right]^2 uncertainty\ (T)$$

where,

$$mean(E_i) = F(mean\ T)$$

based on a formula from National Bureau of Standards Washington, D.C. (1966). Finally, the uncertainty in water vapor mixing ratio is calculated by adding the uncertainty in the radiosonde pressure in quadrature with the uncertainty in either E_i or E_w.

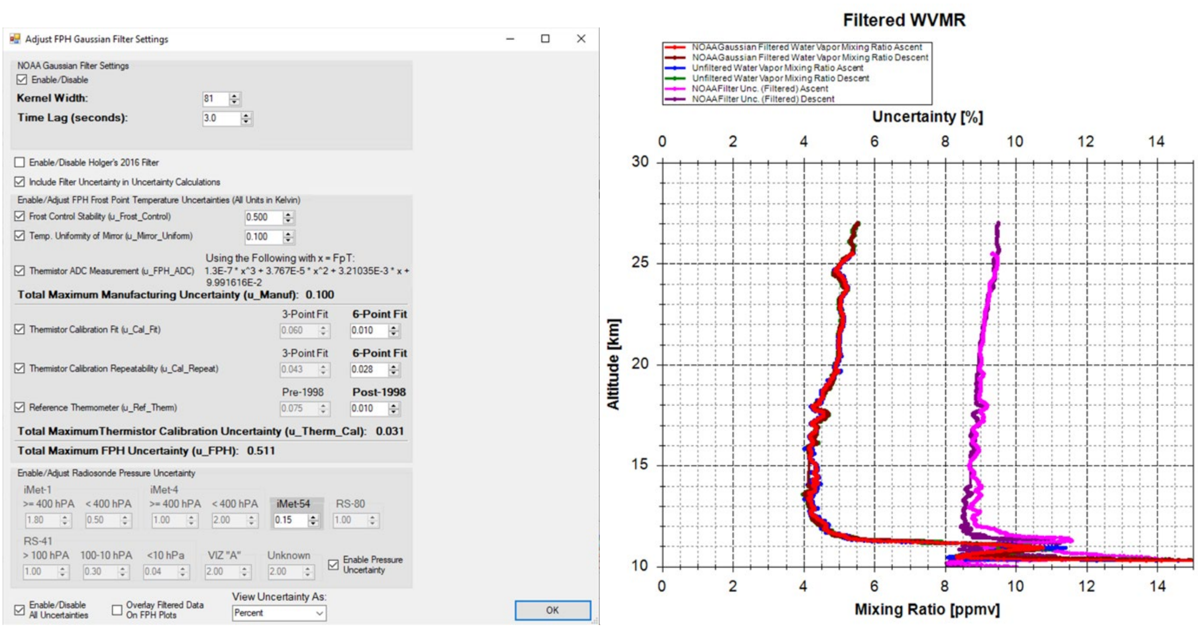

Figure 1. Default settings of the gaussian filter and sources of uncertainty in the frost point temperature measurement of the NOAA FPH, and example stratospheric profile over Lauder, New Zealand on 12 August, 2025.

Frost point temperatures can also be converted to relative humidity values by dividing the water vapor partial pressure by the saturation water vapor pressure (Pws) at the measured atmospheric temperature. RH = Pw/Pws (x100%) The accuracy of RH values calculated in this way depends on the accuracies of the frost point temperature measurements and the radiosonde measurements of temperature that determine Pws.

Expected Precision/Accuracy of Instrument:
Vaisala RS80 Radiosonde Measurements of Pressure, Temperature and Relative Humidity

Pressure:

Resolution 0.1 hPa
Accuracy +/- 0.5 hPa

Temperature:
Resolution 0.1 K
Accuracy +/- 0.2 K

Relative Humidity:
Resolution 1% RH
Accuracy +/- 2% RH
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InterMet iMet-1-RSB Measurements of Pressure, Temperature and Relative Humidity (PTU)

Pressure:
Resolution 0.01 hPa
Accuracy +/- 0.5 hPa

Temperature:
Resolution 0.01 K
Accuracy +/- 0.2 K
Relative Humidity:
Resolution 0.1% RH
Accuracy +/- 5 % RH

Geopotential Height: Calculated using radiosonde PTU measurements. Errors due to uncertainty in the PTU values.

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InterMet iMet-1-RSB Measurements of Pressure, Temperature and Relative Humidity (PTU)

Pressure:
Resolution 0.01 hPa
Accuracy +/- 0.5 hPa

Temperature:
Resolution 0.01 K
Accuracy +/- 0.2 K
Relative Humidity:
Resolution 0.1% RH
Accuracy +/- 5 % RH

Geopotential Height: Calculated using radiosonde PTU measurements. Errors due to uncertainty in the PTU values.

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InterMet iMet-54 Measurements of Pressure, Temperature and Relative Humidity (PTU)

Pressure:
Resolution 0.01 hPa
Accuracy +/- 0.2 hPa 100 - 3 hPa; +/- 0.3 hPa 400 - 100 hPa; +/- 0.6 hPa 1100 - 400 hPa;

Temperature:
Resolution 0.01 K
Accuracy +/- 0.1 K > 100 hPa; +/- 0.25 K < 100 hPa

Relative Humidity:
Resolution 0.01% RH
Accuracy +/- 4 % RH

Geopotential Height: Calculated using radiosonde PTU measurements. Errors due to uncertainty in the PTU values.

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Frost Point Temperature:
Resolution 0.01 K
Accuracy +/- 0.1 K

Water Vapor Mixing Ratio:
Resolution 0.01 ppmv (<10), 0.1 ppmv (10-99.9), 1 ppmv (100- 999), 10 ppmv (1000-9990), 100 ppmv (10000-30000)
Accuracy +/- 1% below 20 km, 1-3% above 20 km*
*due to increasing relative accuracy estimates for radiosonde pressure measurements as atmospheric pressure decreases

Instrument History:
Boulder: Start date using VIZ “A” radiosondes and analog data recording: April 1980*
*Note that data from Apr 1980 to Feb 1991 are available from the PI only as 250-m vertical averages
Upgrade to Vaisala RS80 radiosondes and digital data acquisition: February 1991
Upgrade to modern electronics board and temperature-controlled optics block: March 2004
Upgrade to InterMet iMet-1-RSB radiosondes and digital frost control: May 2009
Transitioning away from HFC-23 FPH instruments on routine soundings: May 2023
Upgrade to InterMet iMet-54 radiosondes: January 2024

Hilo: Start date using InterMet iMet-1-RSB radiosondes: December 2010
Upgrade to InterMet iMet-54 radiosondes: March 2024
Transitioning away from HFC-23 FPH instruments in routine sounding: December 2023

Lauder: Start date using Vaisala RS80 radiosondes and modern electronics board: August 2004
Upgrade to InterMet iMet-1-RSB radiosondes and digital frost control: September 2009
Upgrade to InterMet iMet-54 radiosondes: August 2024
Transitioning away from HFC-23 FPH instruments in routine sounding: October 2024