Progress Towards a Frost Point Hygrometer GRUAN Data Product

Challenges

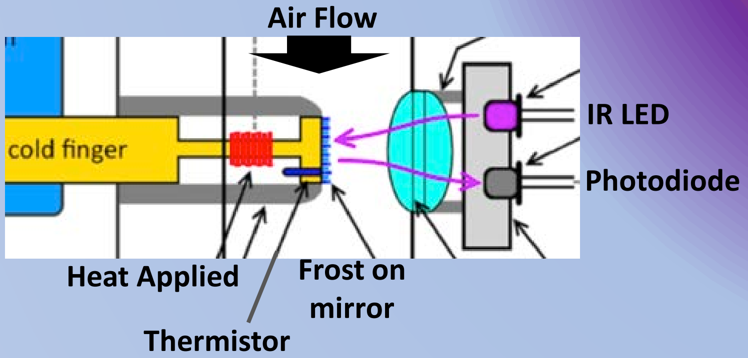
1. Can there be one GDP for all models of frost point hygrometers?
   - Data processing is straightforward and well-defined
   - Automated quality control of profile data (flagging) may be difficult
     - Each FP model may operate differently (e.g., frost control logic, mirror clears)
   - Estimation of uncertainties for each FP model may be different
     - Same statistical method may not be appropriate for every model
     - Uncertainties of GDP must include uncertainties of radiosonde P and T measurements
     - Any systematic errors for new FP models (unknown) must be quantified and removed

2. Existing statistical method of estimating uncertainties may be regarded as subjective
   - Two key parameters for uncertainties are difficult to estimate and change with FP temperature
   - For GRUAN, data processing and uncertainty estimates must be purely objective

Progress Towards a Frost Point Hygrometer GDP

Measurement Principle

- Maintain a stable frost layer on the cold mirror by intermittently applying heat
- When stable, frost layer is in equilibrium with moisture in the air flowing by the mirror
- FPH directly measures the mirror (FP) temperature with a small calibrated thermistor



Data Processing

- Calculate the partial pressure of water vapor (P_{wv}) from the frost point temperature
- Calculate the mixing ratio (mole fraction) by dividing P_{wv} by the ambient pressure of dry air (P_{air})

$$\chi_{wv} = P_{wv} / (P_{air} - P_{wv}) \qquad (\times 10^6 \text{ for ppm})$$

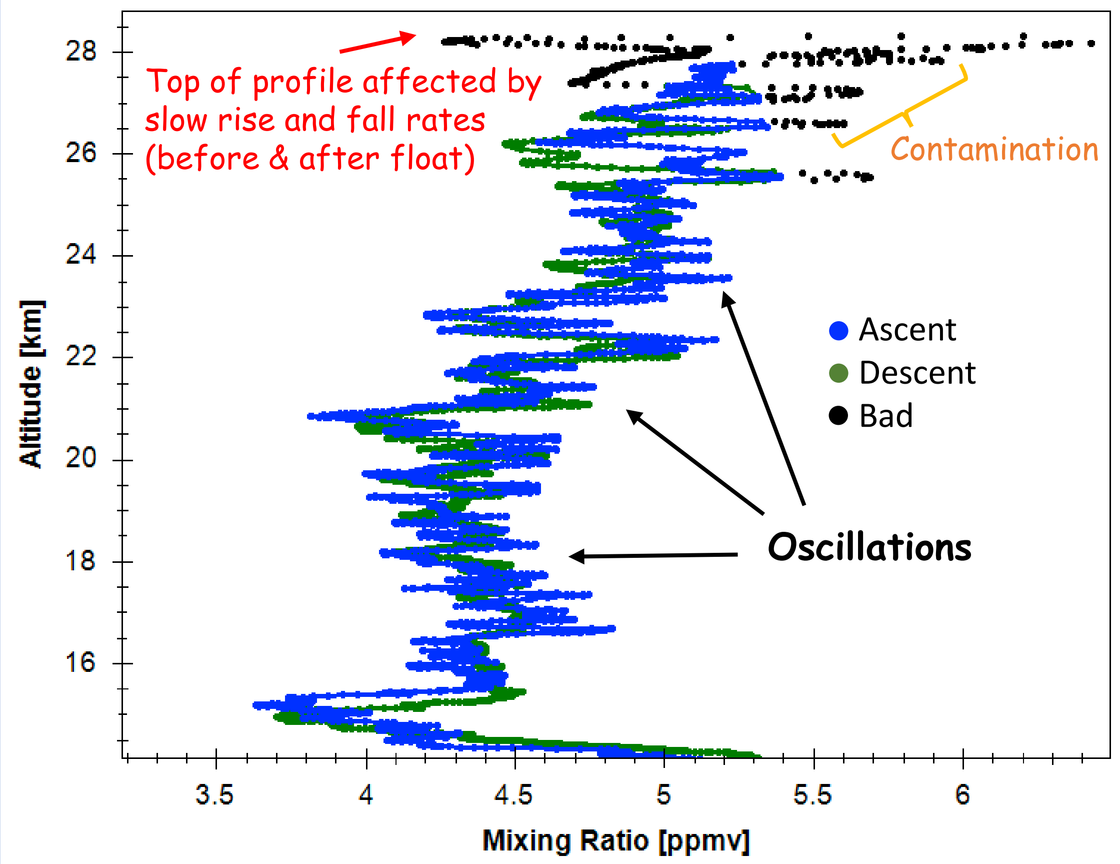
- Calculate RH from P_{wv} and the saturation vapor pressure over water/ice at ambient temperature (P_{sat})

$$RH_{ice} = P_{wv} / P_{sat} \qquad (\times 10^2 \text{ for } \%)$$

RH_{ice} is more useful for UTLS

Progress Towards a Frost Point Hygrometer GDP

Quality Control (Data Flagging)



Oscillating frost control?

Amplitude varies from flight to flight

or

Intermittent contamination of the air stream? (ascent only)

Moisture shedding from balloon and flight train

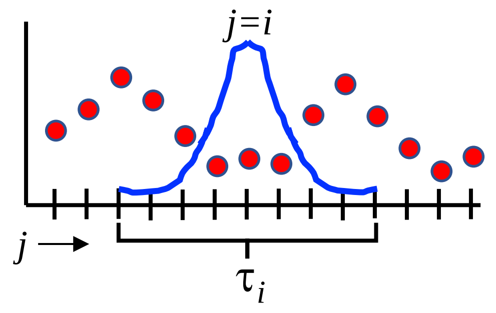
Descent data help

to verify any real profile structure without contamination influences

Useful after controller recovers from balloon burst or float

Progress Towards a Frost Point Hygrometer GDP

Quantification of uncertainties due to controller instability



Gaussian-weighted mixing ratio average at time *i*

$$\overline{\chi}_i = \sum_j c_{i,j}\chi_j$$

$C_{i,j}$ is the Gaussian weight at time j

$$c_{i,j} = e^{-\left({t_i - t_j}/{\tau_i}\right)^2} \Big/ \sum_j e^{-\left({t_i - t_j}/{\tau_i}\right)^2}$$

τ_i is the averaging window for central time i which varies with FP temps (3 to 30 s)

Standard error of the Gaussian-weighted mean mixing ratio average at time *i* =1

$$\sigma_{\overline{\chi}_1}{}^2 = \frac{n}{n-1}\left[\sum_j \left(c_{i,j}\chi_j - \overline{c}_1\overline{\chi}_i\right)^2 - 2\overline{\chi}_i \sum_j \left(c_{i,j} - \overline{c}_1\right)\left(c_{i,j}\chi_j - \overline{c}_1\overline{\chi}_i\right) + \overline{\chi}_i{}^2 \sum_j \left(c_{i,j} - \overline{c}_1\right)^2\right]$$

Errors due to controller instability are considered random. This may not always be true!

Autocorrelation increases the weighted standard error

$$\sigma_{\dot{\overline{\chi}}_1}{}^2 = \sigma_{\overline{\chi}_1}{}^2 \Big/ \left[1 - \left(e^{\frac{-1}{\lambda}}\right)^2\right]$$

λ is the instrumental lag time

λ = 10 s in stratosphere

λ < 1 s at the surface

Progress Towards a Frost Point Hygrometer GDP

Subjective Parameters (may be different for unique FP models)

Averaging windows (τ_i) vary with FP temperature (3 s at surface to 30 s in stratosphere)

$$c_{i,j} = e^{-\left({t_i - t_j}/{\tau_i}\right)^2} \Big/ \sum_j e^{-\left({t_i - t_j}/{\tau_i}\right)^2}$$

Uncertainties depend on $C_{i,j}$ weights, which in turn depend on τ_i.
Increasing τ_i reduces standard error of the mean and the vertical resolution of measurements but increases the autocorrelation of measurements.

Instrument response times (λ) < 1 s at the surface, 10 s in stratosphere

$$\sigma_{\dot{\overline{\chi}}_1}{}^2 = \sigma_{\overline{\chi}_1}{}^2 \Big/ \left[1 - \left(e^{\frac{-1}{\lambda}}\right)^2\right]$$

Uncertainties due to autoregression depend on instrumental response times.
λ is very difficult to quantify and strongly depends on frost control parameters.
Need simultaneous data from a faster response instrument.

Unlikely to be the same for different FP models!

Is there a quantitative relationship between τ_i and λ?

Progress Towards a Frost Point Hygrometer GDP

Calibration Uncertainties

FP measurements are **Temperature** measurements!

Mirror thermistors are carefully calibrated against:

- High-accuracy reference(s) certified by metrology institutes
- An archive of previously calibrated thermistors

Variations in >40 calibrations of 5 archived thermistors are <0.02 °C and show no evidence of long-term drift

Real-world tests: FP temperature diffs between 2 FPs on the same balloon

Average FP temperatures in vertical layers to minimize any frost control differences between the two instruments

- Standard deviations of differences in FP temperature averages:
  <0.11 °C in troposphere <0.09 °C in stratosphere

"Calibration" uncertainties are small compared to frost control uncertainties

Progress Towards a Frost Point Hygrometer GDP

Uncertainty contributions from radiosonde P measurements

Water Vapor Mixing Ratio (χ_{wv})

$\chi_{wv} = P_{wv} / (P_{air} - P_{wv}) \approx P_{wv} / P_{air}$ then $\varepsilon(\chi_{wv}) = \mathrm{sqrt}[\varepsilon^2(P_{air}) + \varepsilon^2(P_{wv})]$

Optimal pressure offset for every radiosonde flight is calculated by comparing geopotential height with GPS (geometric) altitude adjusted for variations in **g**

- This constant offset is applied to pressure measurements for the entire flight

P_{air} will likely have both systematic and random uncertainties!

Pressure errors for radiosondes will differ between models and pressure ranges

Progress Towards a Frost Point Hygrometer GDP

Uncertainty contributions from radiosonde T measurements

Relative Humidity (RH) based on FP measurements

$RH = P_{wv} / P_{sat}$ where P_{sat} is the T-dependent saturation vapor pressure over ice

P_{sat} is a complex f(T) there are many formulations

$\varepsilon(RH) = sqrt[(\varepsilon^2(P_{sat})\cdot\varepsilon^2(P_{wv})]$ where $\varepsilon(P_{sat}) = sqrt[(\delta P_{sat}/\delta T)^2 \cdot \varepsilon^2(T)]$

Systematic uncertainties in T are reduced if measurements are corrected for solar radiation effects

- A 0.3 °C bias in T produces errors of 2-5% relative to the RH value

Random uncertainties in T measurements are difficult to estimate

T errors for radiosondes will differ between models and pressure ranges

Progress Towards a Frost Point Hygrometer GDP

The Way Forward

FP GDP team was recently assembled:

Dale Hurst, Ruud Dirksen, Masatomo Fujiwara, Takuji Sugidachi

Other interested parties are welcome to join and contribute!

Team evaluation of assumptions, procedures and equations in Voemel et al. (2016)

Decide if one GDP will be suitable for different FP models

If a similar uncertainty estimation approach is agreed upon:

- Attempt to quantitatively relate τ (averaging kernel width) and λ (time response of FP) to reduce the subjective choices of these parameters

Determine if different thermistor calibration procedures require separate evaluations of calibration uncertainties

Decide if there can be a systematic approach to estimating uncertainties of P and T measurements by different radiosonde models

Progress Towards a Frost Point Hygrometer GDP

Questions?

Comments?

Points for discussions?

Get me out of here, it's time for a coffee break?