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Calibration of the Vertical Cavity Surface Emitting Laser (VCSEL) water vapor hydrometer

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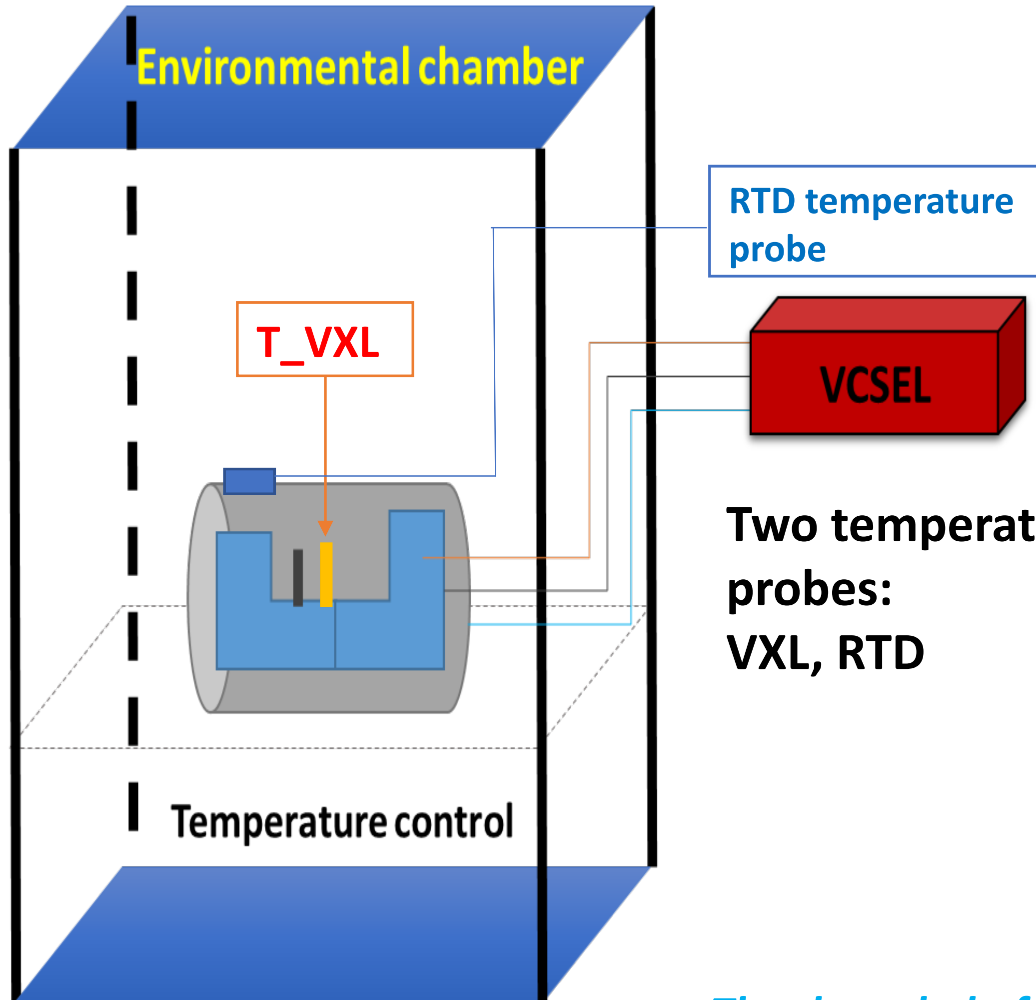
Outline

- 1. Laboratory calibration set-up
- 2. Calibration result
- 3. Application to the SOCRATES water vapor data
- 4. Relative humidity frequency distribution
- 5. Summary and future work

Laboratory experiment design



Two temperature probes: VXL, RTD

Fundamental physics:

Saturation vapor pressure (es) is determined by temperature only

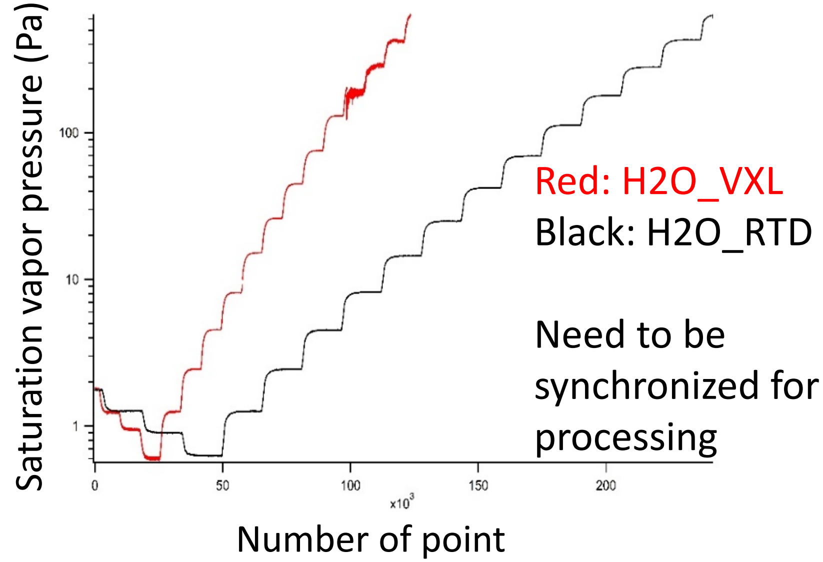
es_{ice} and es_{liq} are calculated based on Murphy and Koop (2005)

Thanks to help from Stuart Beaton, Laura Tudor and Hendrik Gilmer

Evaluation of the calibration system

1. Does temperature series vary when cooling down or warming up?

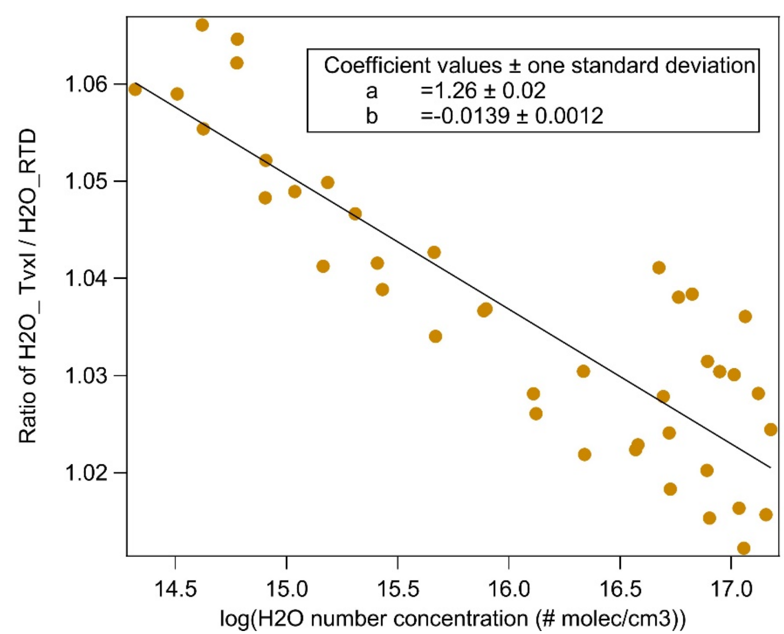
The differences are usually **less than 3%** when testing the same temperatures.



2. Does temperature reach equilibrium between the inner and outer walls of the calibration housing?

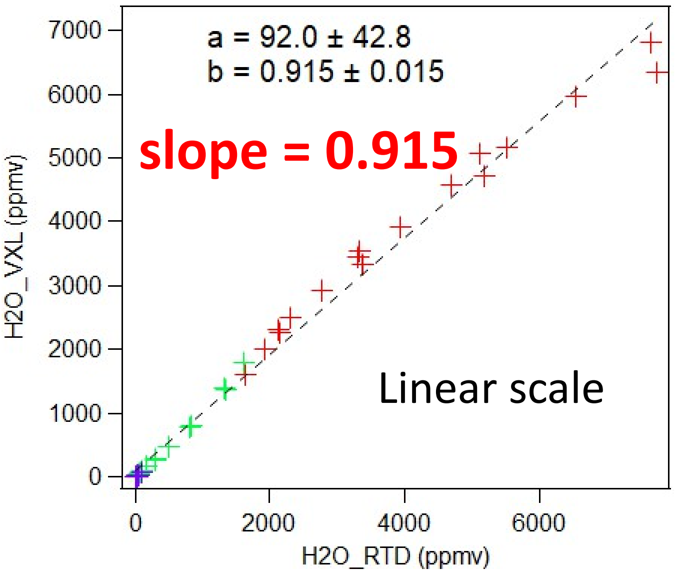
Uncertainties range from **1% - 6%**, when the number concentration of water vapor molecules range from 1.51e+17 to 2.09e+14 #molec/cm^3, respectively.

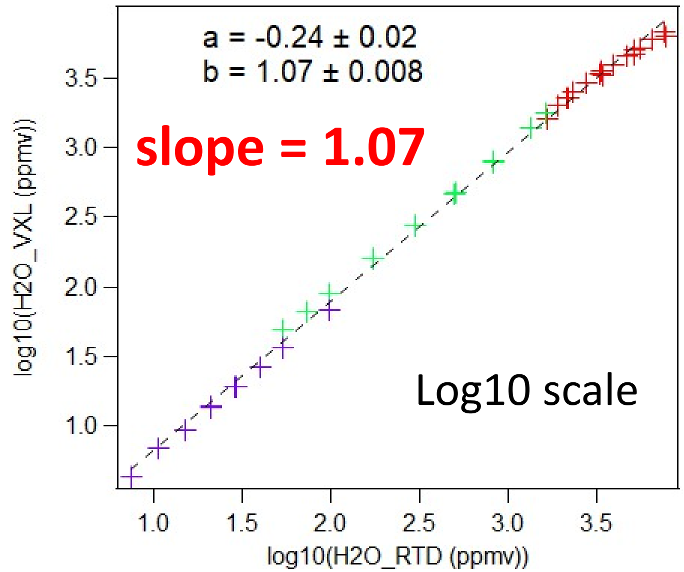
A **maximum ± 6%** uncertainty when using this system at **0 to -65°C**.



Comparison of H_2O from VCSEL and derived H_2O from RTD

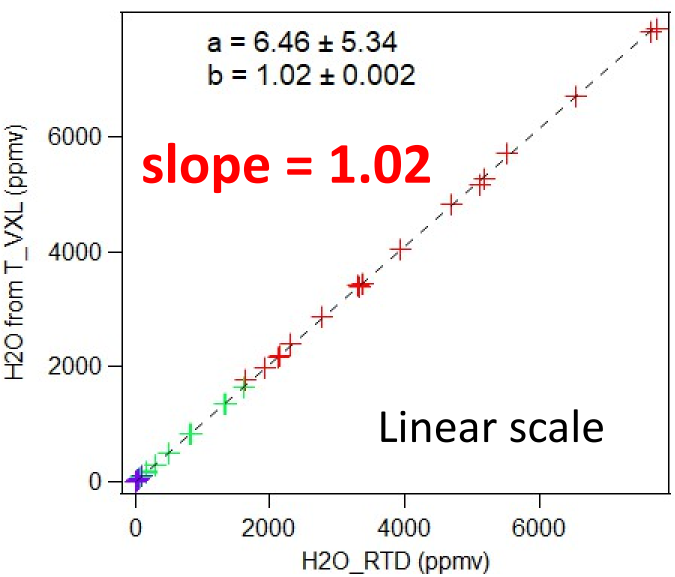
(1) H_2O_VXL (v.2013.Princeton) vs H_2O_RTD temperature probe

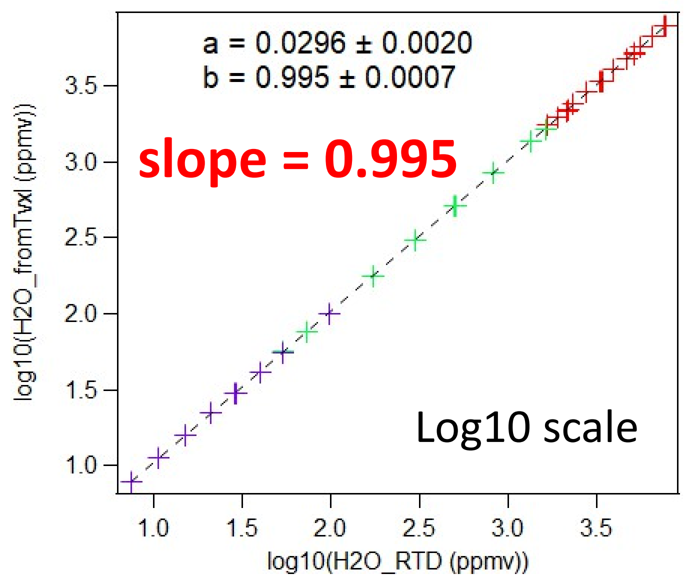




Red: weak mode
Green: direct mode
Purple: strong mode

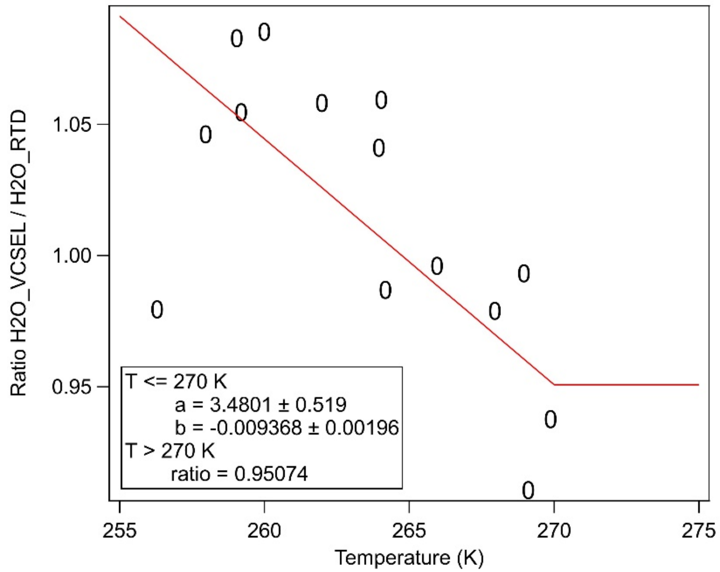
(2) H_2O_Temp vxl vs H_2O_RTD temperature probe



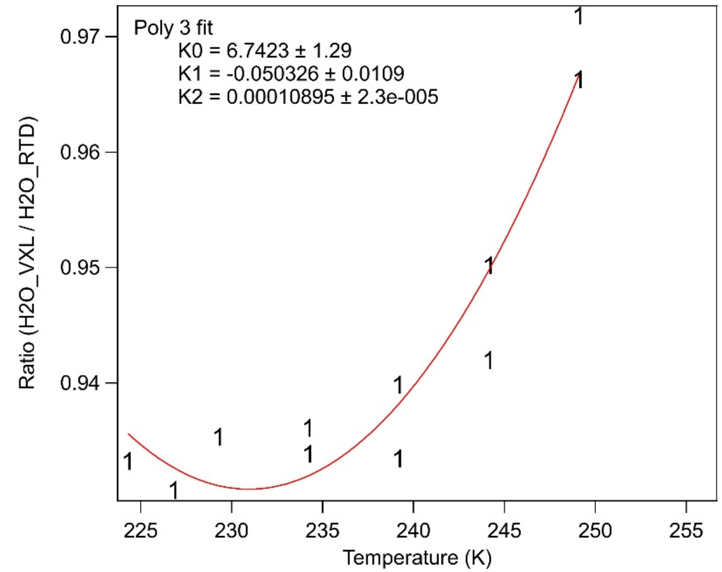


Calibration equations of three modes for the VCSEL hygrometer

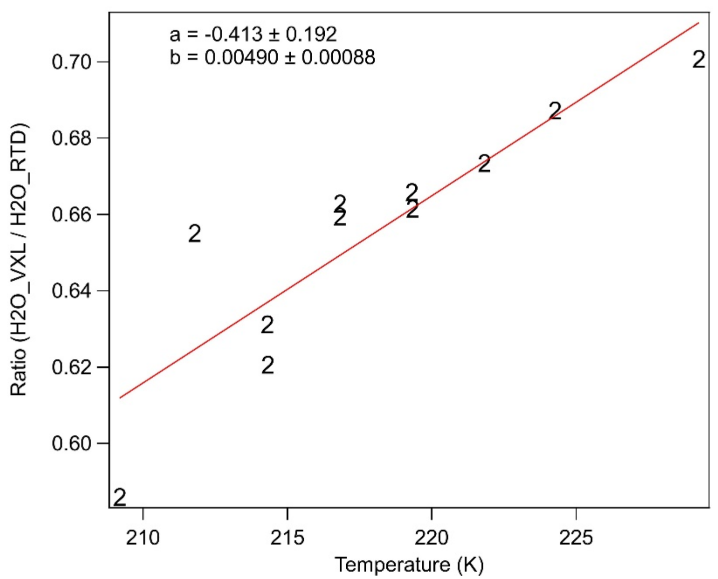
Weak mode (Linear fit)



Direct mode (Poly-3 fit)

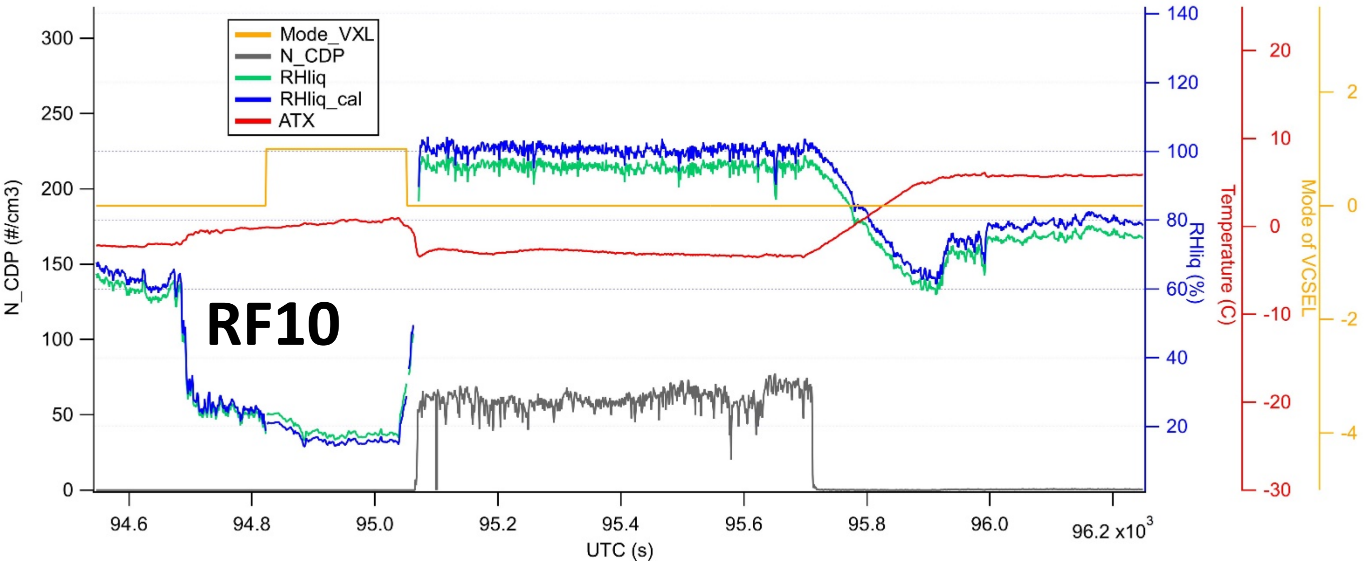


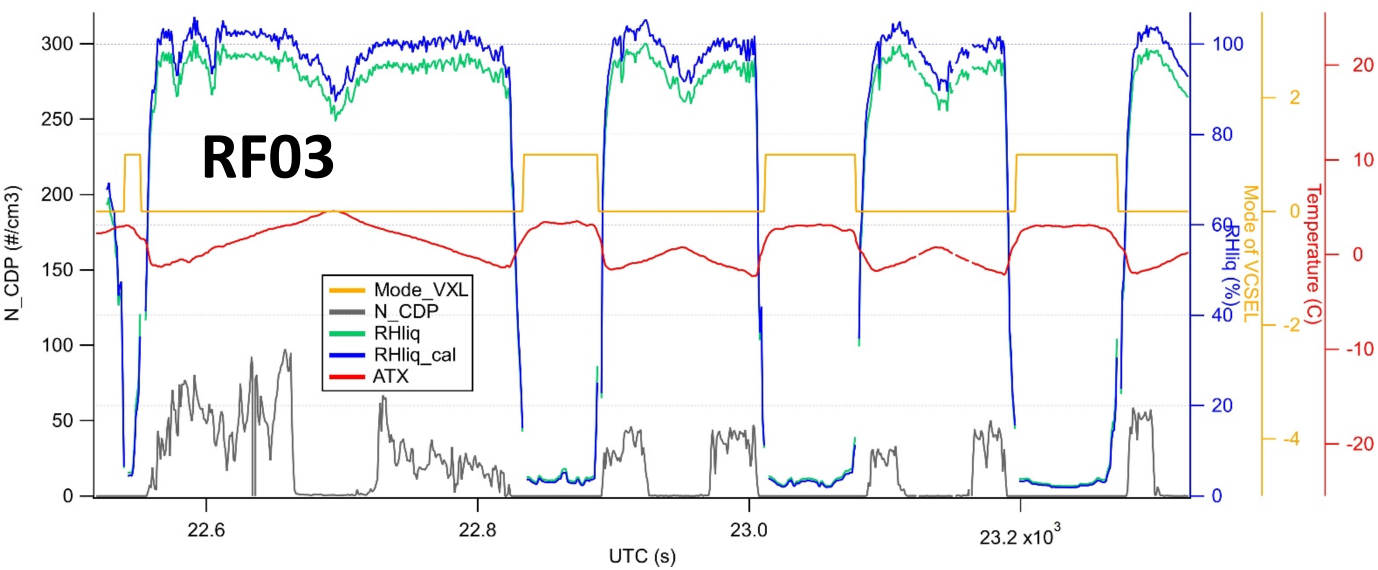
Strong mode (Linear fit)



1. Regressions of ratio of H2O_VXL / H2O_RTD versus temperature (K)
2. Each mode has its own calibration
3. New water vapor data (version.2018.1.Diao) are calculated by applying the adjustments to the current water vapor data (version.2013.Princeton)

Comparisons of the calibrated (v.2018.1.Diao) and current water vapor data (v.2013.Princeton)



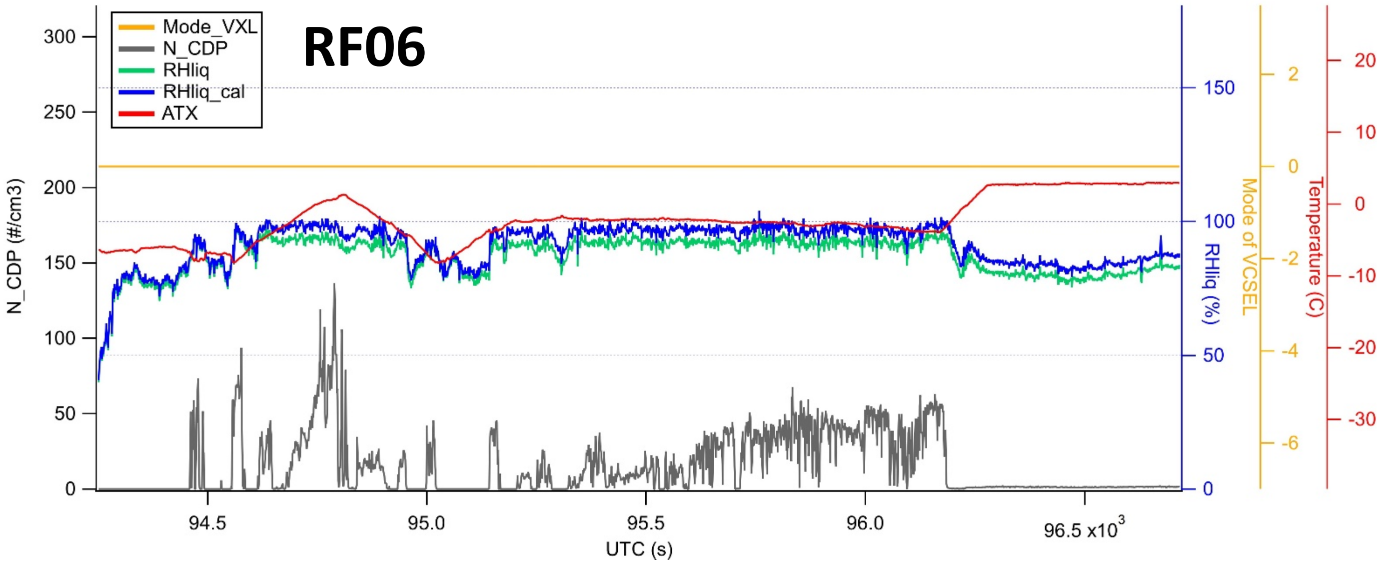


1. Water vapor data are generally adjusted to be **higher** at warmer temperatures

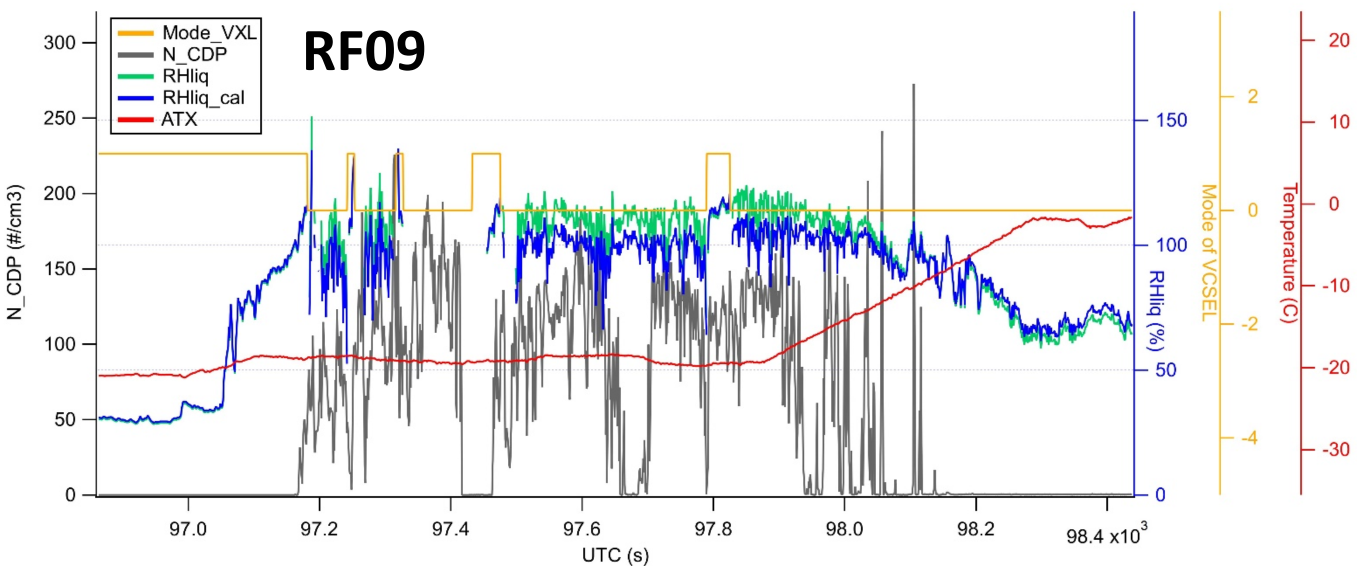
2. Most of the in-cloud conditions at warmer T show **liquid saturation** with v.2018.1.Diao

3. For cumulus sampling, **good synchronization** between RHliq and CDP number concentration

Other examples of improvements with the calibration

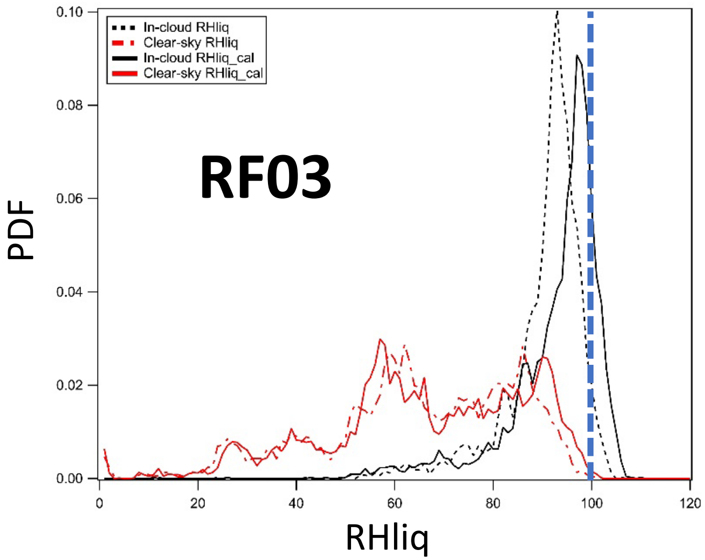


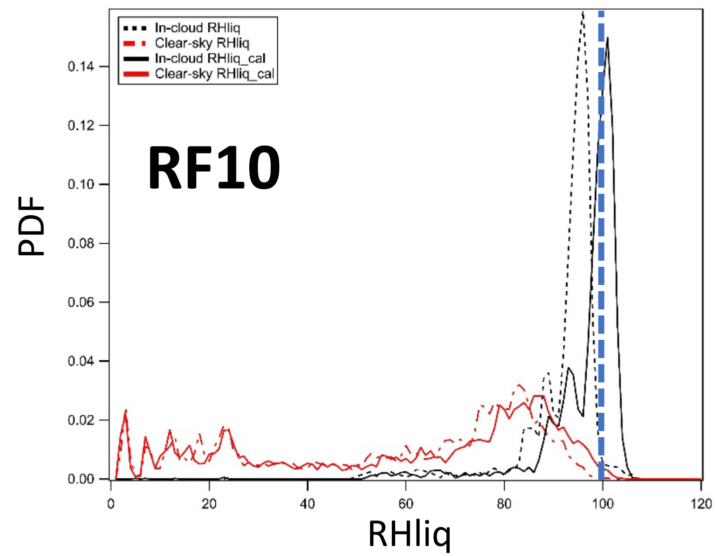
RF06: in-cloud leg around -5°C is adjusted to be higher, reaching liquid saturation after calibration



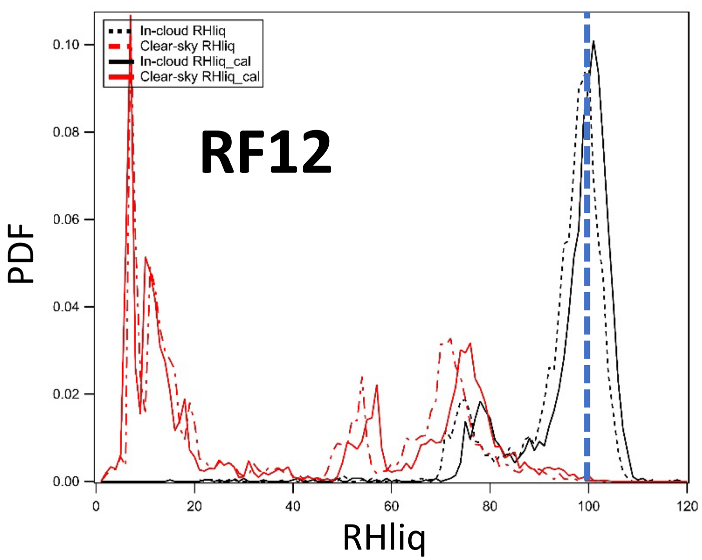
RF09: in-cloud leg around -20°C is adjusted to be lower, closer to liquid saturation after calibration

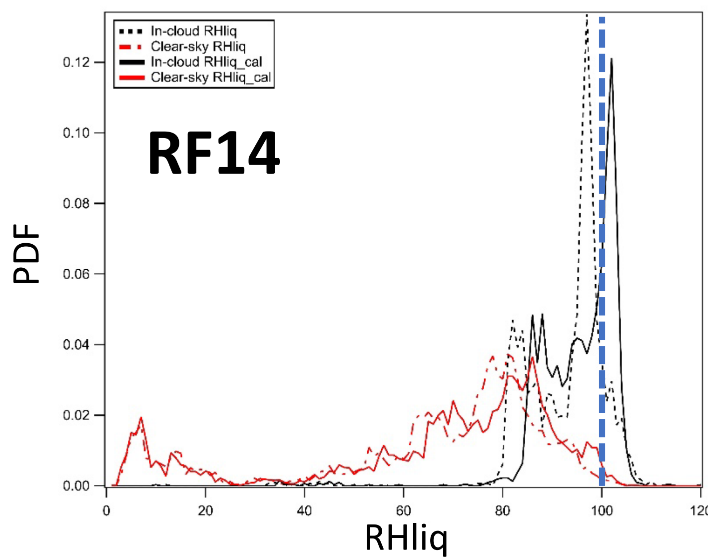
Relative humidity frequency distribution for in-cloud conditions at temperature > -15°C





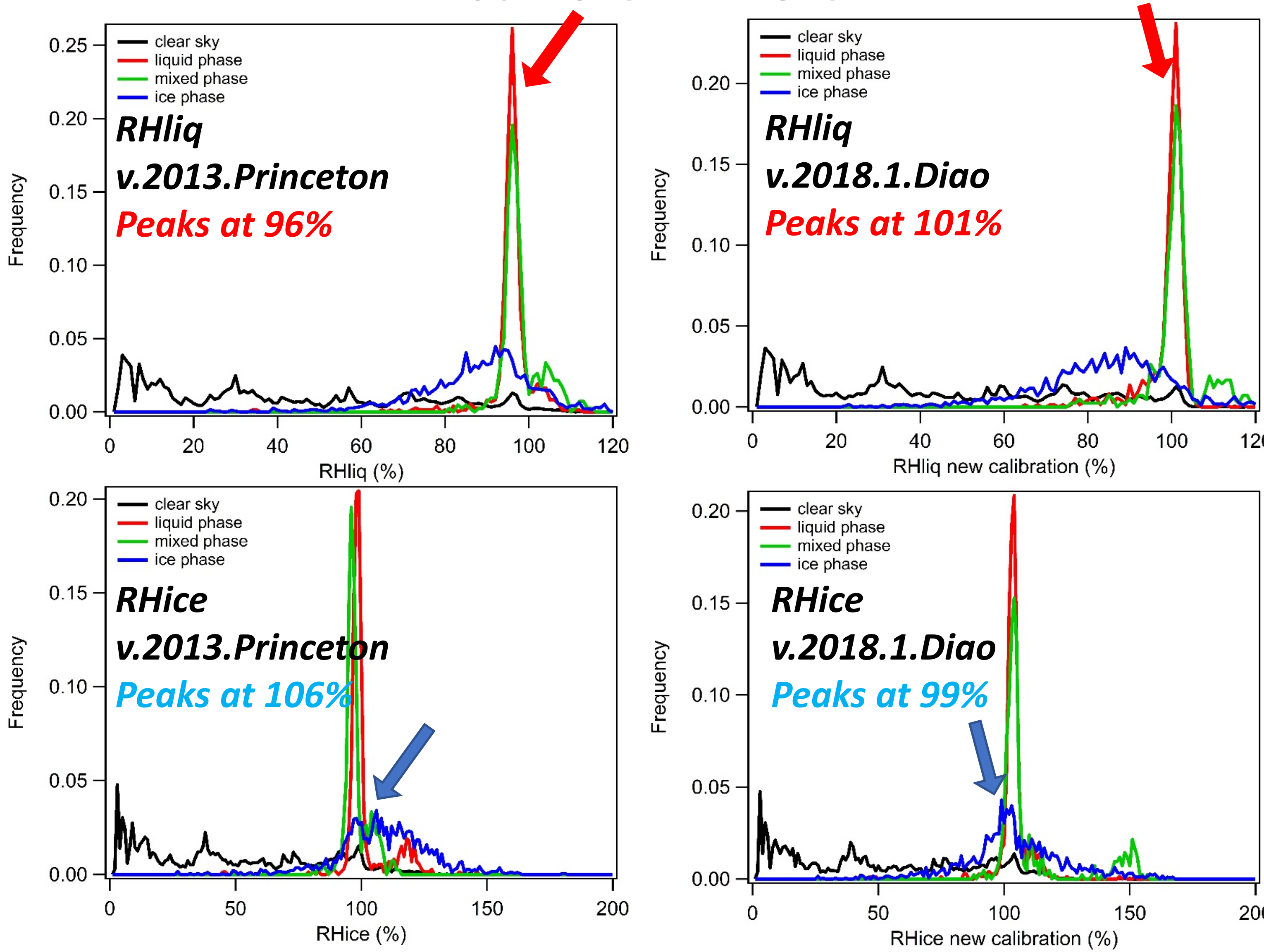
In-cloud:
CDP > 1 cm^{-3}
or, Fast-2DC > 0 L^{-1}





SOCRATES RF10: RH distribution in different cloud phases at -40°C < T ≤ 0°C

Diao and Yang (SJSU)



Cloud phase id method: D'Alessandro, J., M. Diao, C. Wu,, X. Liu, B. Stephens, and J.B. Jensen, "Cloud phase and relative humidity distribution over the Southern Ocean based on in-situ observations and global climate model simulations", *Journal of Climate, in revision.*

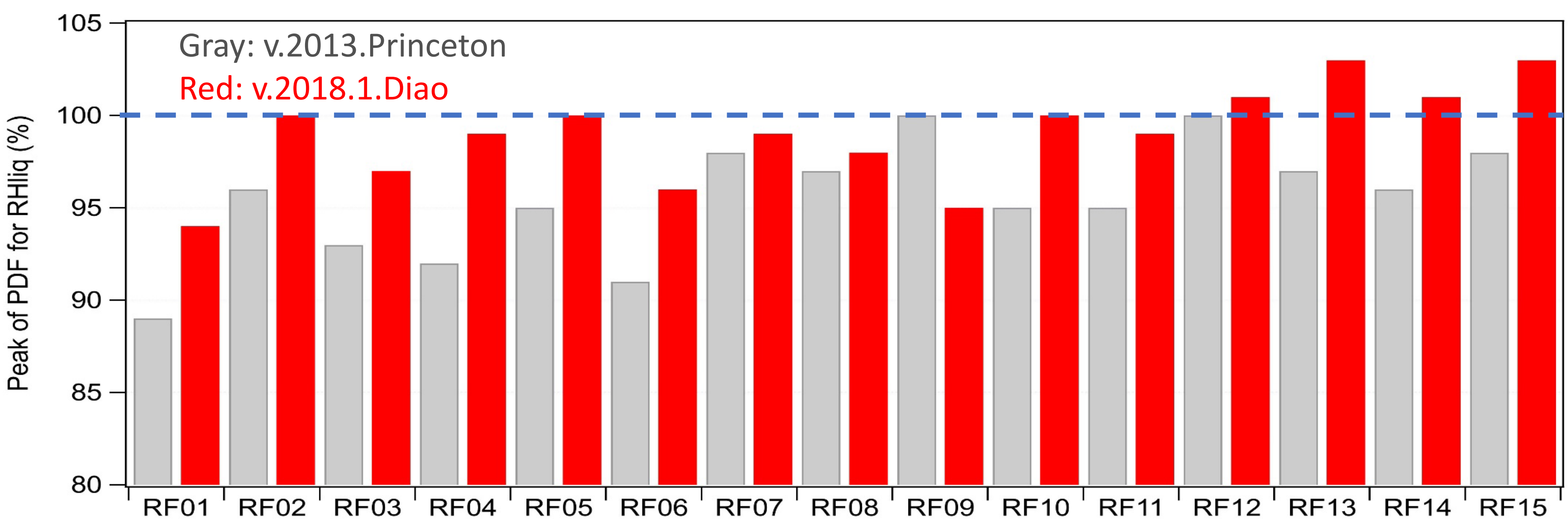
Summary of new calibration (v.2018.1.Diao)

1. Only temperature is considered as the factor; Overall, the calibration ***improves*** the statistical distributions of RHliq

2. Calibrated water vapor data (v.2018.1.Diao)

- increase H_2O mixing ratio at $T > 265$ K
- decrease H_2O mixing ratio at $255 \text{ K} < T \leq 265$ K
- Increase H_2O mixing ratio at $225 \text{ K} < T \leq 255$ K
- Increase H_2O mixing ratio at $210 \text{ K} < T \leq 225$ K

3. Table of individual peaks of in-cloud RHliq PDF (temperature > -15°C)

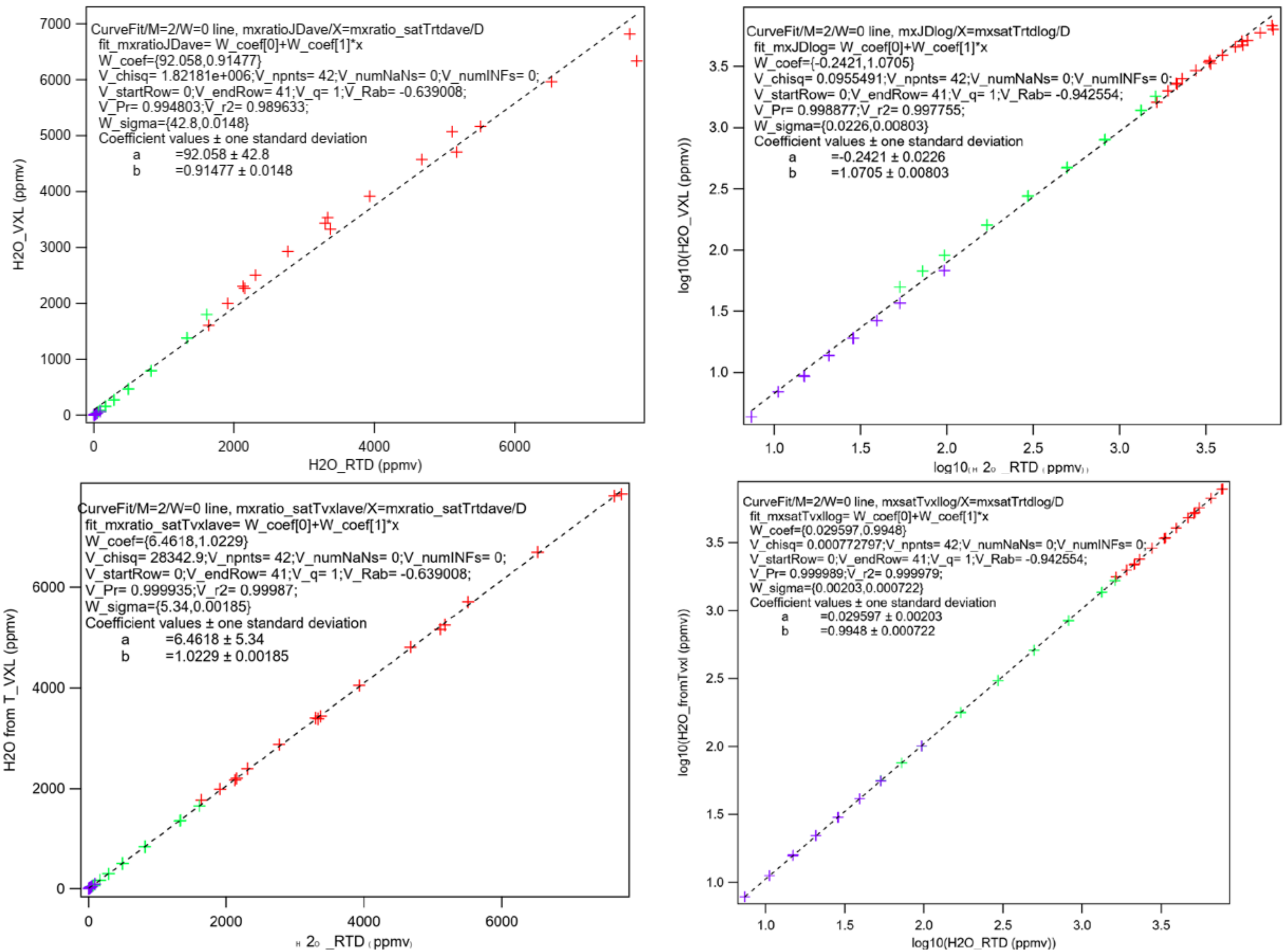


Future work

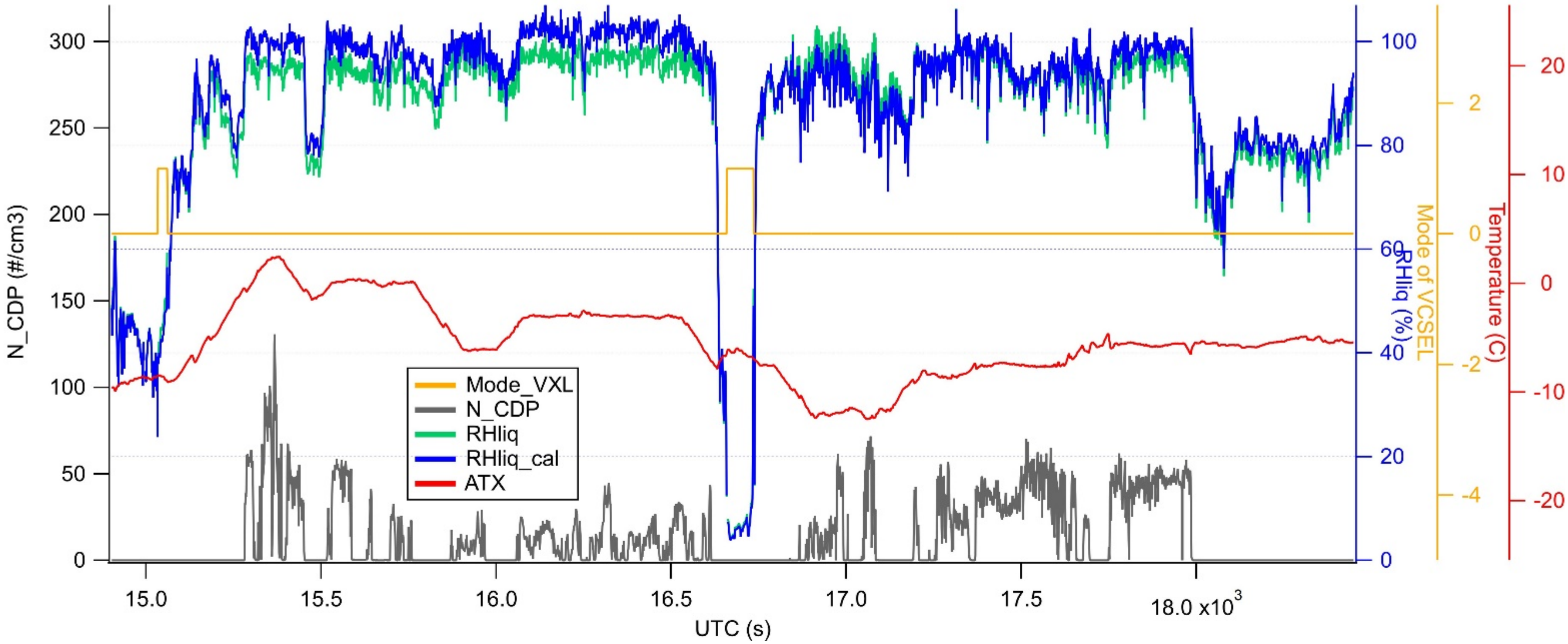
- **Factors that remain to be addressed**
    - pressure
    - water vapor (sub-saturated conditions)
    - laser intensity
- **Use a different calibration system** – test the Princeton calibration chamber
- **Use additional water vapor source** - add a dewpoint generator for even warmer temperatures (> 0°C)
- **Hysteresis when switching modes** – more time series focusing on transitions

Acknowledgement

1. NCAR Advanced Study Program Faculty Fellowship 2018 and 2016
2. NSF Office of Polar Program grant #1744965
3. Thanks to EOL and RAF scientists for hosting my group in the summer of 2018 and 2016.
4. Many thanks **to Stuart Beaton** and **Laura Tudor** for setting up the laboratory experiments


CurveFit/M=2/W=0 line, mxratioJDave/X=mxratio_satTrtdave/D
fit_mxratioJDave= W_coef[0]+W_coef[1]*x
W_coef={92.058,0.91477}
V_chisq= 1.82181e+006;V_npnts= 42;V_numNaNs= 0;V_numINFs= 0;
V_startRow= 0;V_endRow= 41;V_q= 1;V_Rab= -0.639008;
V_Pr= 0.994803;V_r2= 0.989633;
W_sigma={42.8,0.0148}
Coefficient values ± one standard deviation
a =92.058 ± 42.8
b =0.91477 ± 0.0148
H2O_VXL (ppmv)
H2O_RTD (ppmv)
CurveFit/M=2/W=0 line, mxJDlog/X=mxsatTrtdlog/D
fit_mxJDlog= W_coef[0]+W_coef[1]*x
W_coef={-0.2421,1.0705}
V_chisq= 0.0955491;V_npnts= 42;V_numNaNs= 0;V_numINFs= 0;
V_startRow= 0;V_endRow= 41;V_q= 1;V_Rab= -0.942554;
V_Pr= 0.998877;V_r2= 0.997755;
W_sigma={0.0226,0.00803}
Coefficient values ± one standard deviation
a =-0.2421 ± 0.0226
b =1.0705 ± 0.00803
log10(H2O_VXL (ppmv))
log10(H2O_RTD (ppmv))
CurveFit/M=2/W=0 line, mxratio_satTvxlave/X=mxratio_satTrtdave/D
fit_mxratio_satTvxlave= W_coef[0]+W_coef[1]*x
W_coef={6.4618,1.0229}
V_chisq= 28342.9;V_npnts= 42;V_numNaNs= 0;V_numINFs= 0;
V_startRow= 0;V_endRow= 41;V_q= 1;V_Rab= -0.639008;
V_Pr= 0.999935;V_r2= 0.99987;
W_sigma={5.34,0.00185}
Coefficient values ± one standard deviation
a =6.4618 ± 5.34
b =1.0229 ± 0.00185
H2O from T_VXL (ppmv)
H2O_RTD (ppmv)
CurveFit/M=2/W=0 line, mxsatTvxllog/X=mxsatTrtdlog/D
fit_mxsatTvxllog= W_coef[0]+W_coef[1]*x
W_coef={0.029597,0.9948}
V_chisq= 0.000772797;V_npnts= 42;V_numNaNs= 0;V_numINFs= 0;
V_startRow= 0;V_endRow= 41;V_q= 1;V_Rab= -0.942554;
V_Pr= 0.999989;V_r2= 0.999979;
W_sigma={0.00203,0.000722}
Coefficient values ± one standard deviation
a =0.029597 ± 0.00203
b =0.9948 ± 0.000722
log10(H2O_fromTvxl (ppmv))
log10(H2O_RTD (ppmv))

RF03



Mode_VXL
N_CDP
RHliq
RHliq_cal
ATX
N_CDP (#/cm3)
RHliq (%)
Mode of VCSEL
Temperature (C)
UTC (s)
0
50
100
150
200
250
300
15.0
15.5
16.0
16.5
17.0
17.5
18.0 x10[3]
20
40
60
80
100
-4
-2
2
-20
-10
10
20