Calibration of radiosonde humidity sensors at air ventilation speed of 5 $m \cdot s^{-1}$

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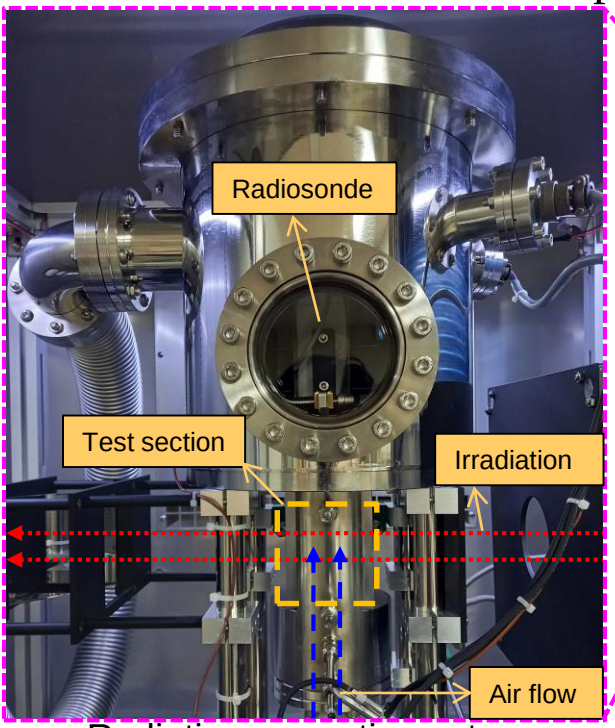
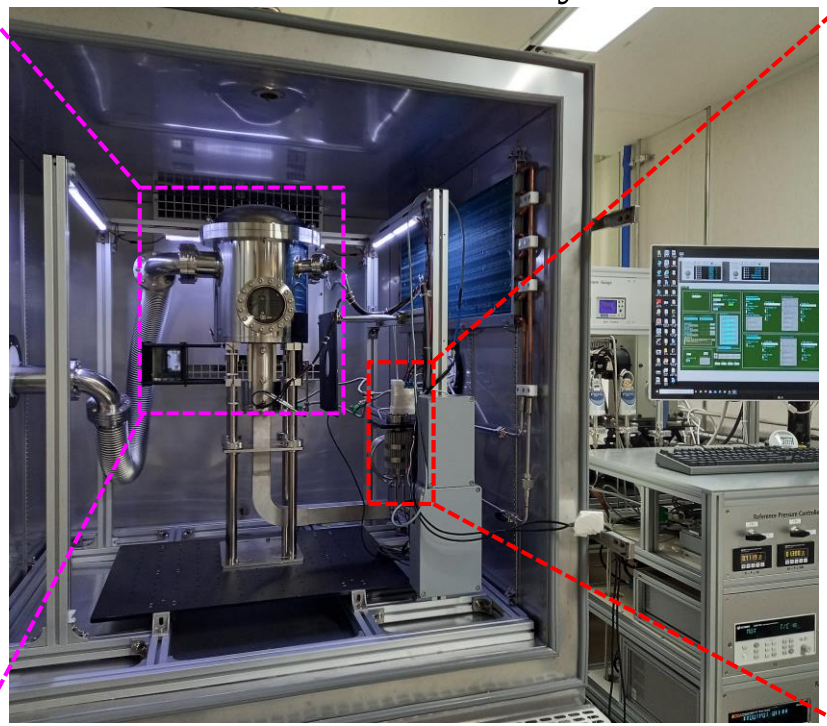
Upper air simulator (UAS) at KRISS

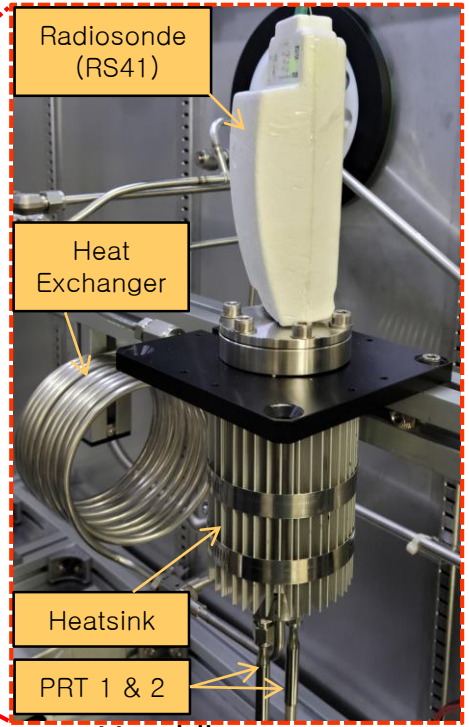
- Radiation correction of radiosonde temperature sensors
  - Control of temperature, pressure, ventilation, and irradiance (using dry air)
- Evaluation of radiosonde humidity sensors
  - Control of temperature and relative humidity at 1000 hPa



<Radiation correction setup>
Lee *et al.* Atm. Meas. Tech. **15**, 1107 (2022)



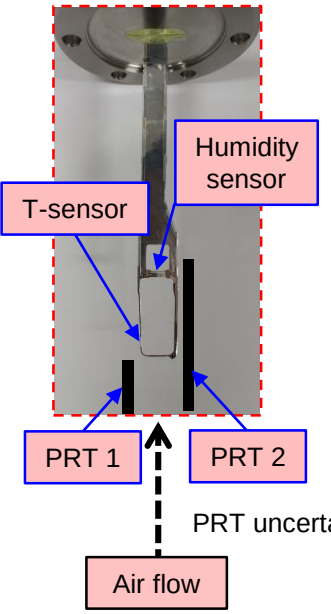
<Upper air simulator>

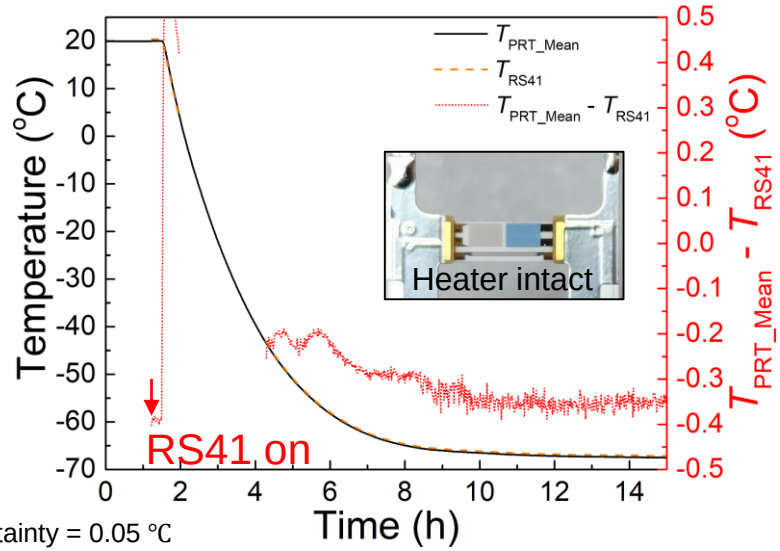


<Humidity setup>
Lee *et al.* Meteorol. Appl. **28**, e2010 (2021)

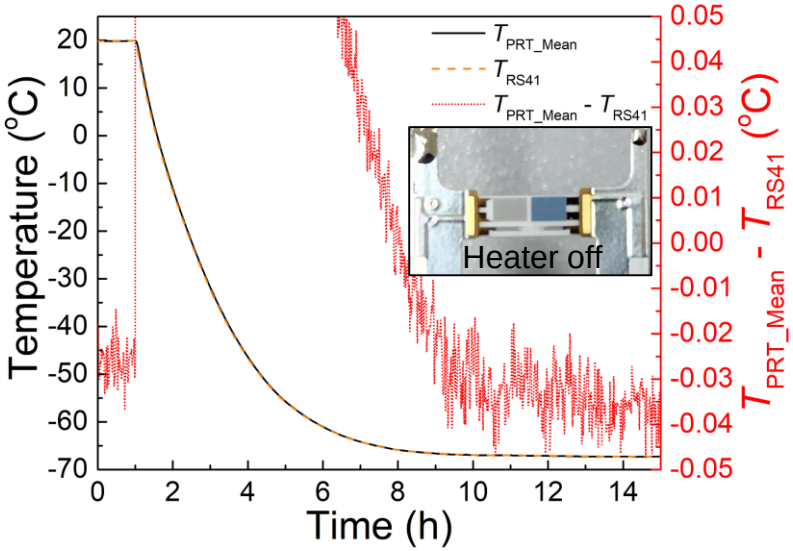
Effect of heater of RS41 humidity sensor

- Heater affects reference thermometers





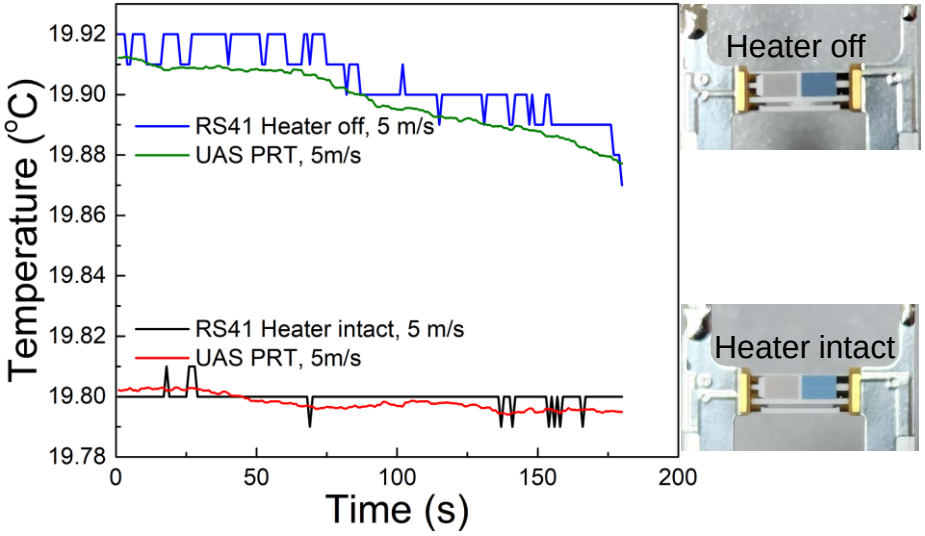
PRT uncertainty = 0.05 ℃

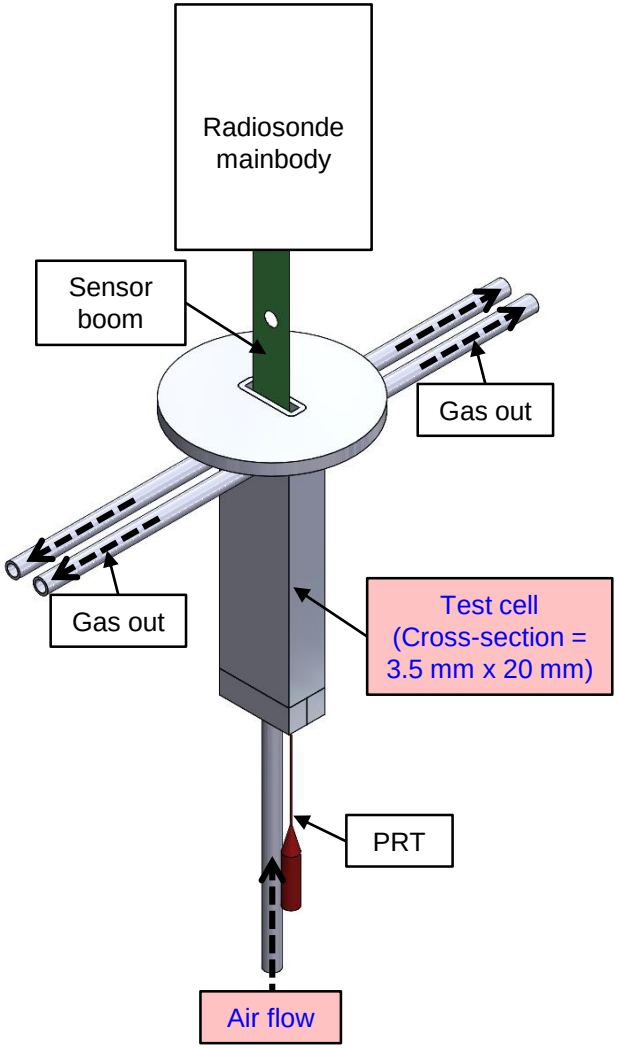


Air ventilation speed in the test cell was 1 L/min (~0.02 m/s)

Modification of humidity test cell

$T_{RS41} = T_{PRT}$ at ventilation speed = 5 m/s in radiation correction setup



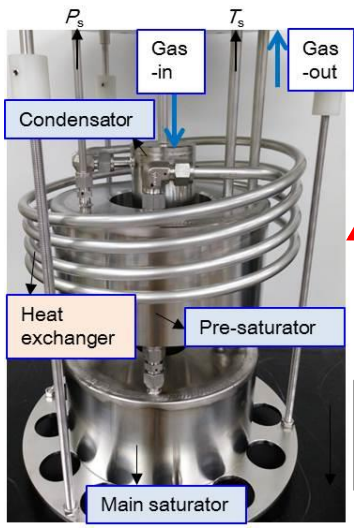


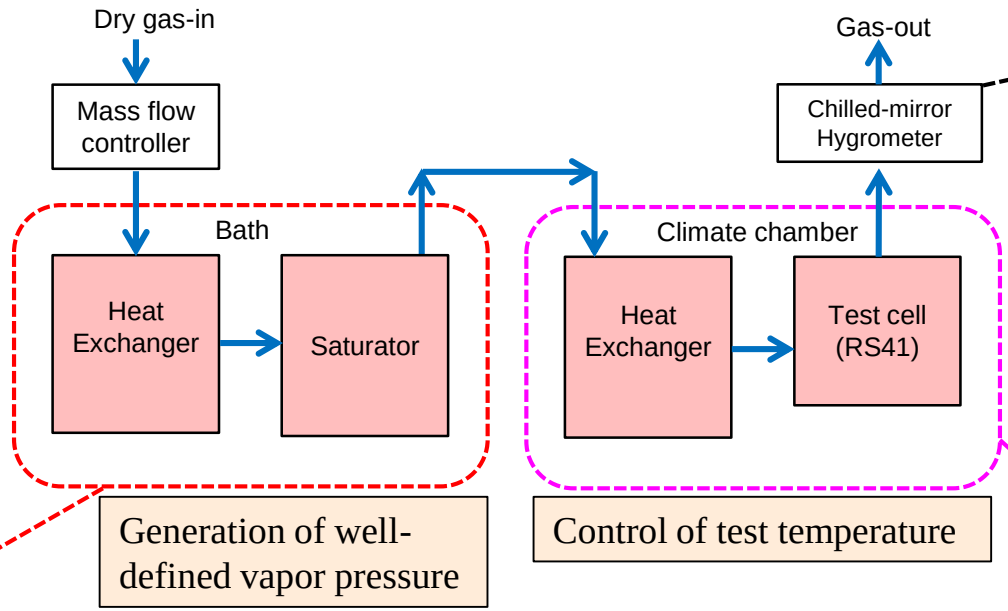
Cross sectional area of test cell is reduced while gas flow rate is increased.

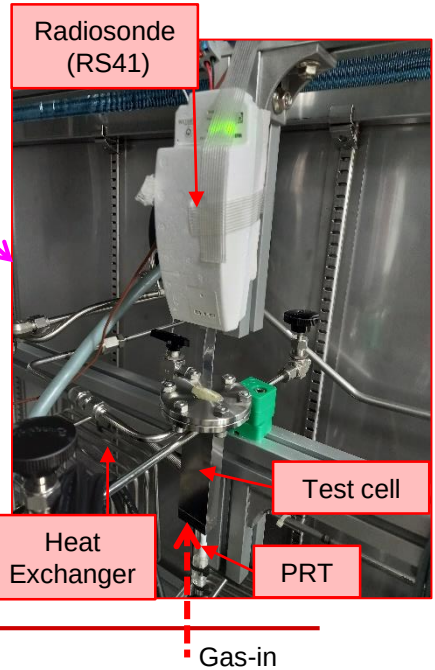
Layout of UAS humidity setup

- Two-temperature Two-pressure type humidity generator
  - $T_{\text{saturator}}$ & $T_{\text{test cell}}$
  - $P_{\text{saturator}}$ & $P_{\text{test cell}}$

Hygrometer: Validation







A copy of KRISS low frost point generator 2

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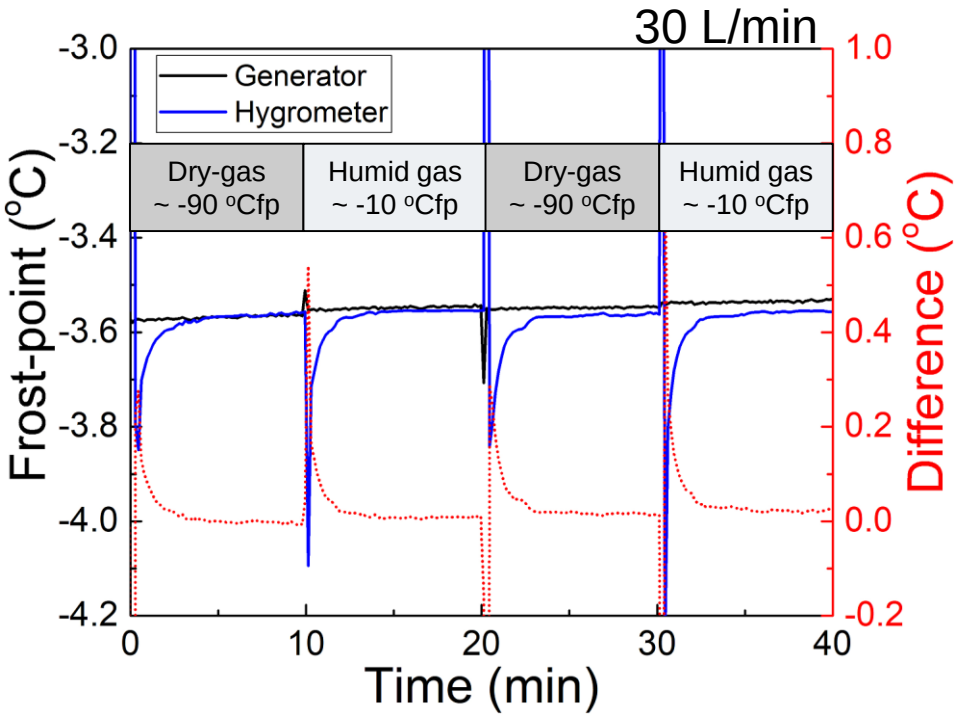
Saturation capacity of the saturator

- Input gas with different humidity levels



Saturation capacity of the saturator at 30 L/min (> 5 m/s in test cell) is checked.

Uncertainty of UAS humidity setup

Generated vapor pressure Pressure ratio

$$RH = \frac{e_{ws}(T_s)}{e_{ws}(T_t)} \times \frac{f(T_s, P_s)}{f(T_t, P_t)} \times \frac{P_t}{P_s} \times 100\ (\%rh)$$

Saturation vapor pressure

T_s = saturator temperature, P_s = saturator pressure

T_t = test chamber temperature, P_t = test chamber pressure

$e_{is}(T_s)$ = saturation vapour pressure over ice in saturator

$e_{ws}(T_t)$ = saturation vapour pressure over water in test chamber

$f(T_s, P_s)$ = enhancement factor in saturator

$f(T_t, P_t)$ = enhancement factor in test chamber

Table 2. Uncertainty budget on relative humidity of UAS at T_t = -67.8 ºC.

Relative humidity at T_t = -67.8 ºC	%rh	9.5	19.0	28.3	37.4	9.5	19.0	28.3	37.4	9.5	19.0	28.3	37.4
Uncertainty component	**Unit**	**Standard uncertainty**				**Sensitivity coefficient**				**Contribution to uncertainty**			
Saturator temperature, $u(T_s)$	ºC	0.027	0.027	0.027	0.027	1.549	2.958	4.289	5.565	0.042	0.080	0.116	0.150
Saturator pressure, $u(P_s)$	kPa	0.177	0.177	0.177	0.177	0.093	0.185	0.275	0.363	0.016	0.033	0.049	0.064
Saturation vapour pressure in saturator, $u_r(e_{is}(T_s))$	Pa	0.00014	0.00025	0.00036	0.00046	139.823	139.527	139.689	139.116	0.019	0.036	0.050	0.064
Enhancement factor in saturator, $u_r(f(P_s,T_s))$		0.00049	0.00046	0.00044	0.00043	9.474	18.911	28.130	37.185	0.005	0.009	0.012	0.016
Test chamber temperature, $u(T_t)$	K	0.063	0.063	0.063	0.063	-1.301	-2.596	-3.861	-5.102	-0.082	-0.164	-0.243	-0.321
Test chamber pressure, $u(P_t)$	kPa	0.182	0.182	0.182	0.182	0.095	0.189	0.281	0.371	0.017	0.034	0.051	0.068
Saturation vapour pressure in test chamber, $u_r(e_{ws}(T_t))$	Pa	0.002	0.002	0.002	0.002	13.623	27.138	40.411	53.200	0.032	0.063	0.094	0.124
Enhancement factor in test chamber, $u_r(f(T_t,P_t))$		0.00081	0.00081	0.00081	0.00081	-9.485	-18.928	-27.975	-37.207	-0.008	-0.015	-0.023	-0.030
Saturator efficiency, u (Efficiency)	ºC	0.006	0.006	0.006	0.006	1.547	2.955	4.285	5.562	0.010	0.019	0.027	0.036
Adsorption/desorption, u(Ads./Des.)	ºC	0.100	0.100	0.060	0.060	1.547	2.955	4.285	5.562	0.155	0.296	0.257	0.334
Combined standard uncertainty, $u_c(RH)$ (k=1)	%rh									0.2	0.4	0.4	0.5
Expanded uncertainty, $u(RH)$ (k=2)	%rh									**0.4**	**0.7**	**0.8**	**1.0**

%rh

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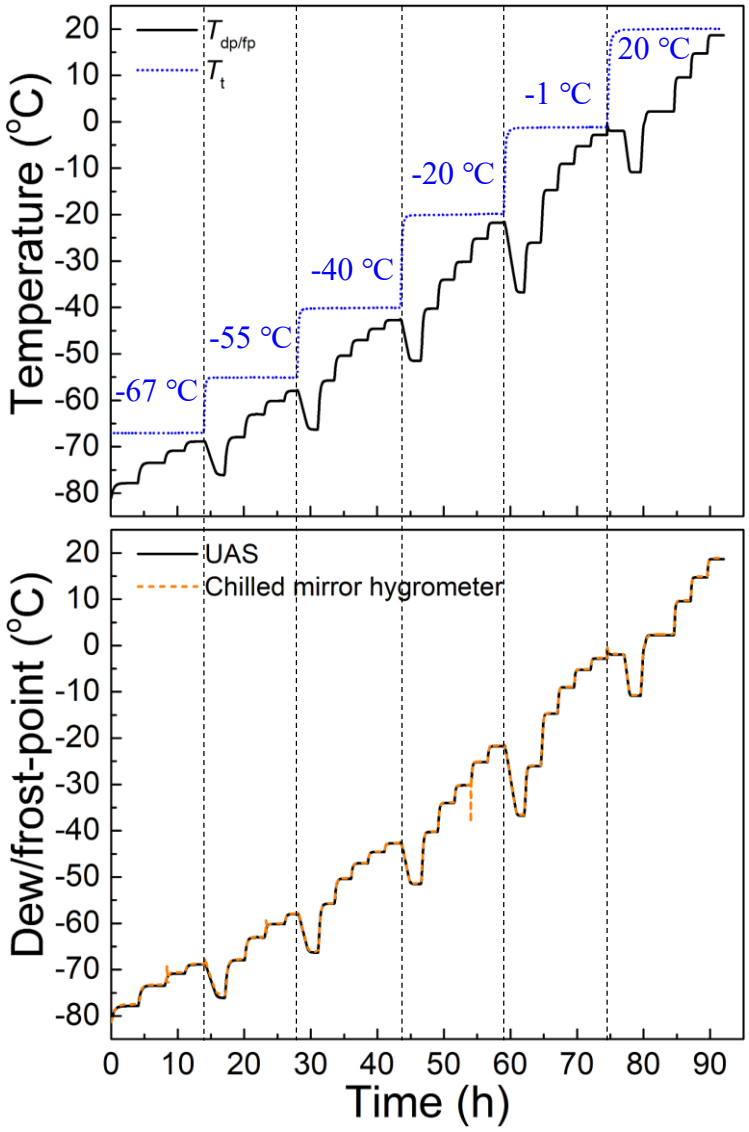
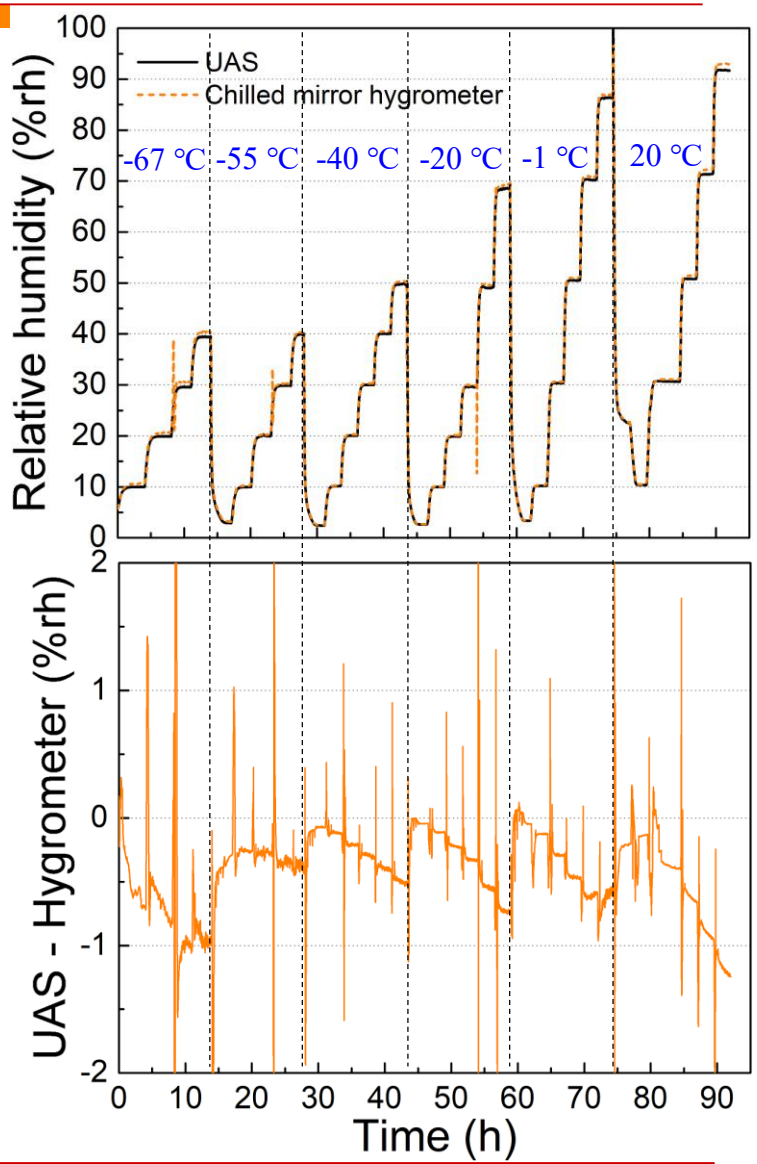
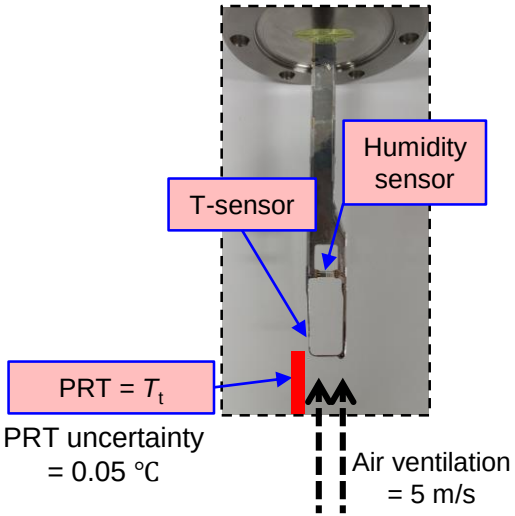
Operation of UAS humidity setup

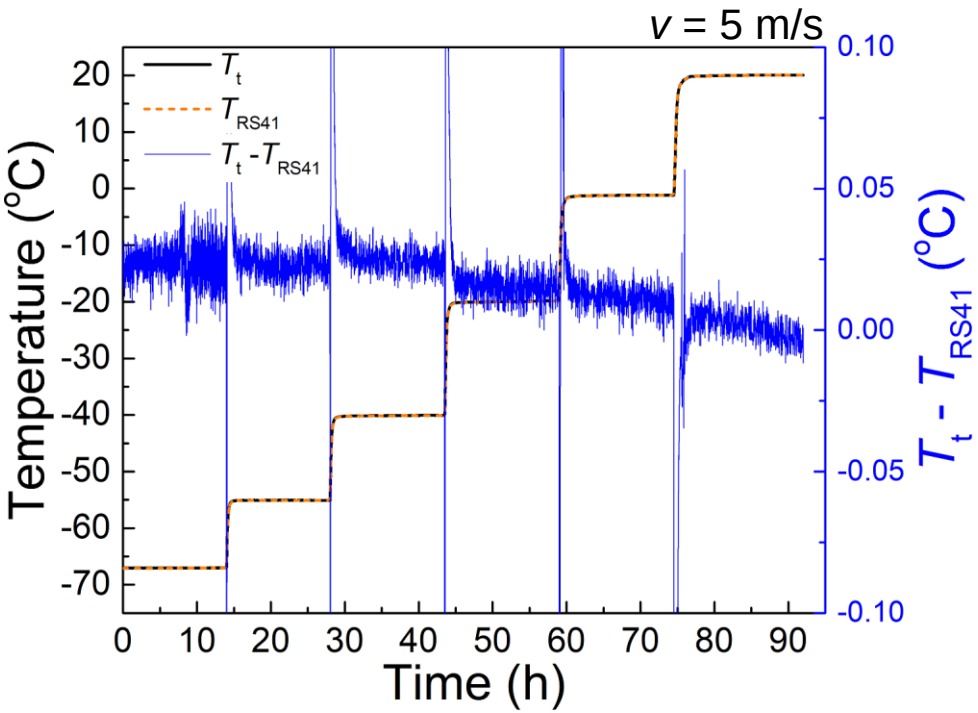




UAS (input humidity) → **Radiosonde** → **CM hygrometer (output humidity)**

Temperature of reference thermometer

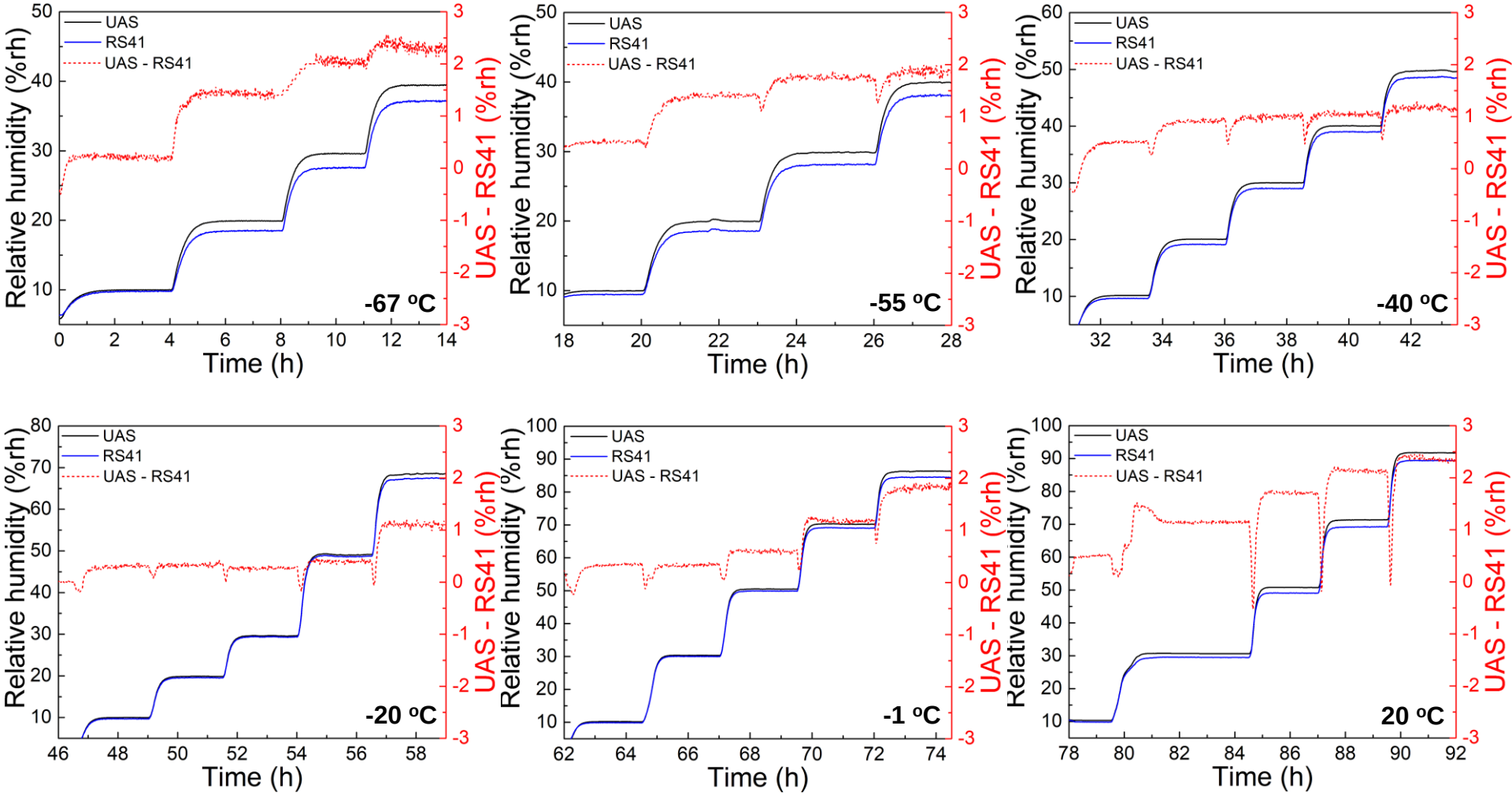




Difference between reference PRT and RS41 is within the uncertainty of the PRT

RS41 RH measurement

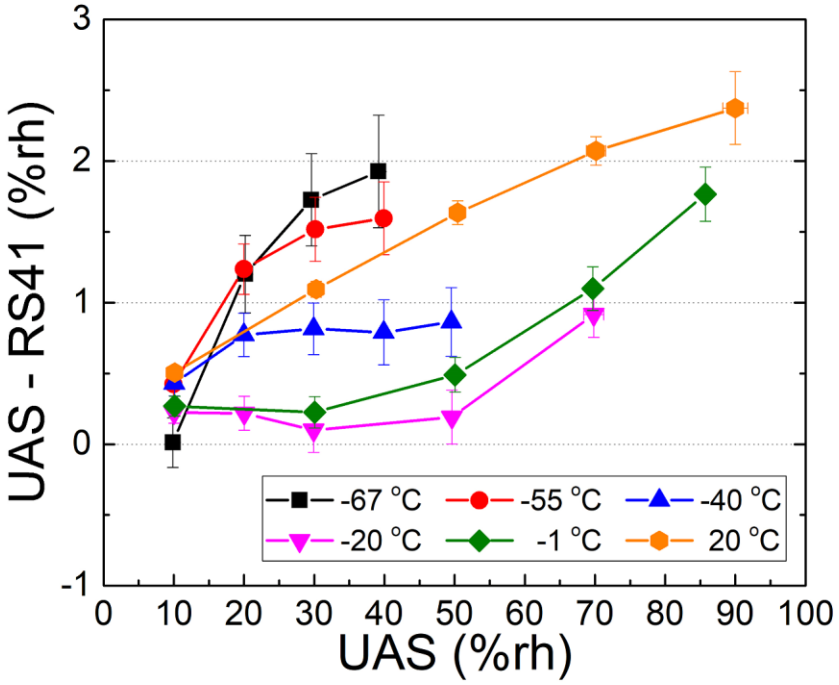
- UAS RH generation vs. RS41 RH measurement



Reproducibility & Individuality

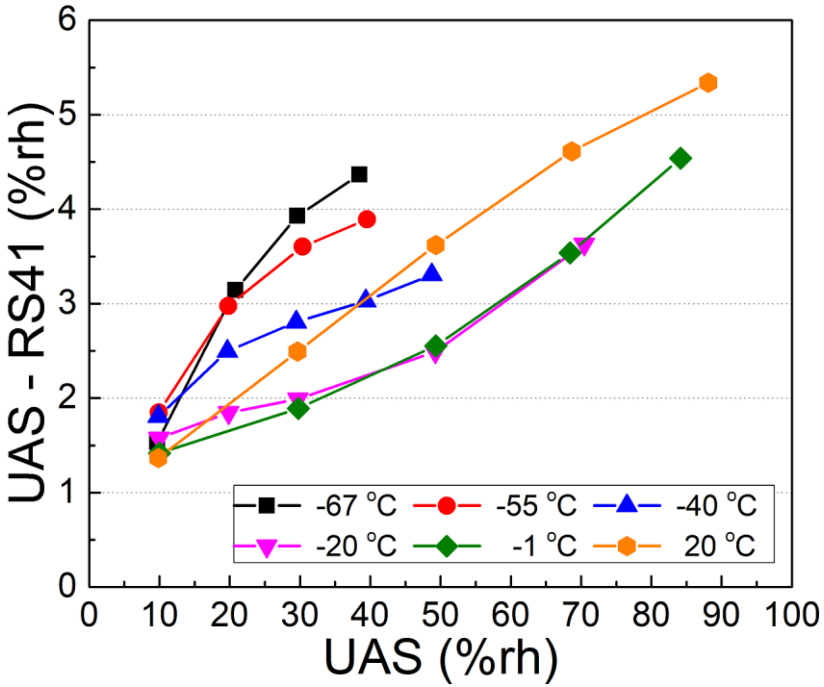
Reproducibility & Individuality of RS41

Three measurements of a RS41 unit
Mean ± Standard deviation (S.D.)



Difference = (0 – 2.4) %rh
Maximum S.D. = 0.4 %rh

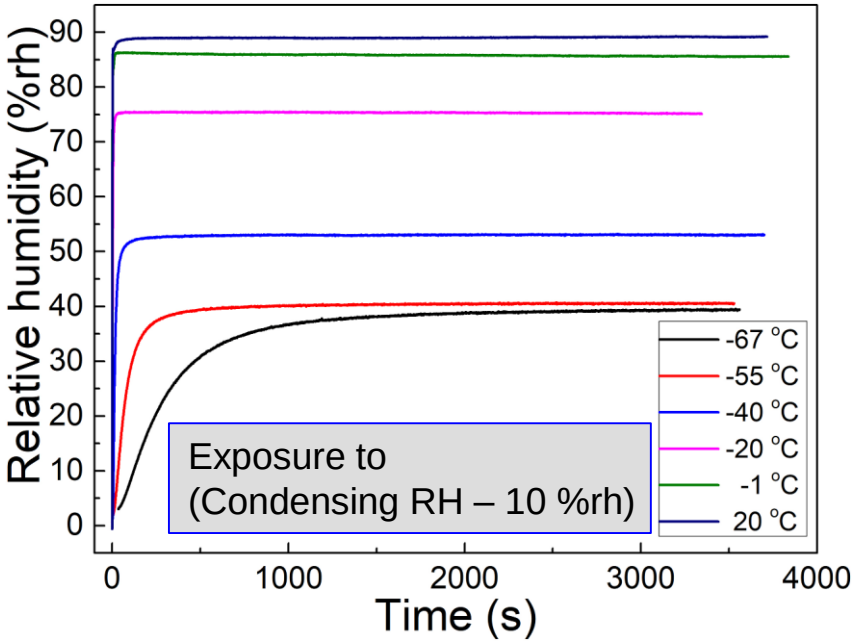
Another unit of RS41

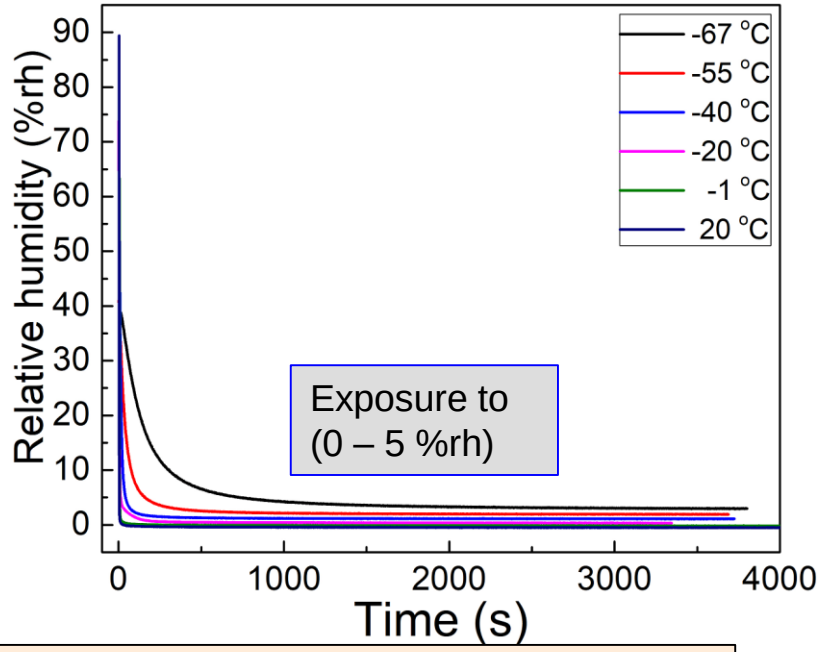


Difference = (1.4 – 5.3) %rh

Response time; high RH

- Sorption/desorption of water at varying temperatures
  - Temperature of test cell = (-67 - +20) ^{o}C
  - Pressure of test cell = 1000 hPa
  - Air ventilation rate in test cell = 5 m/s
  - (Condensing RH – 10) %rh at each temperature



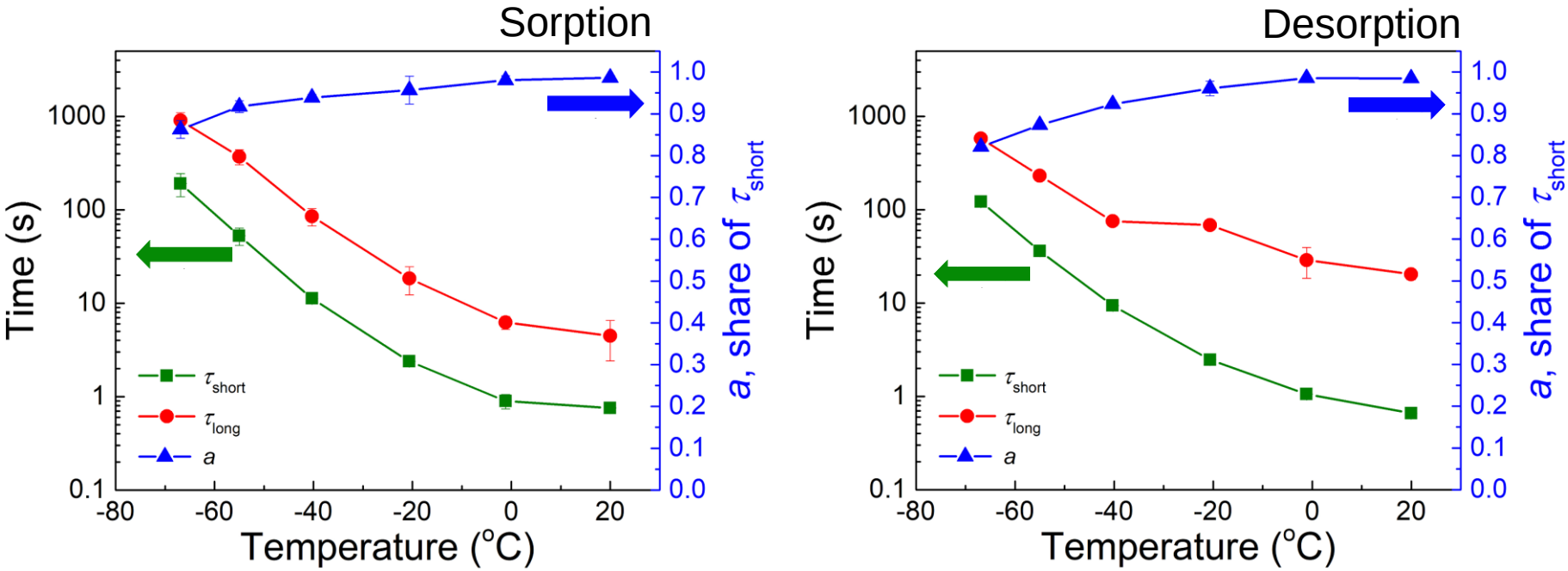


Sorption/desorption of water is getting slower at lower temperatures

Response time; high RH

- Fitting with a double exponential function

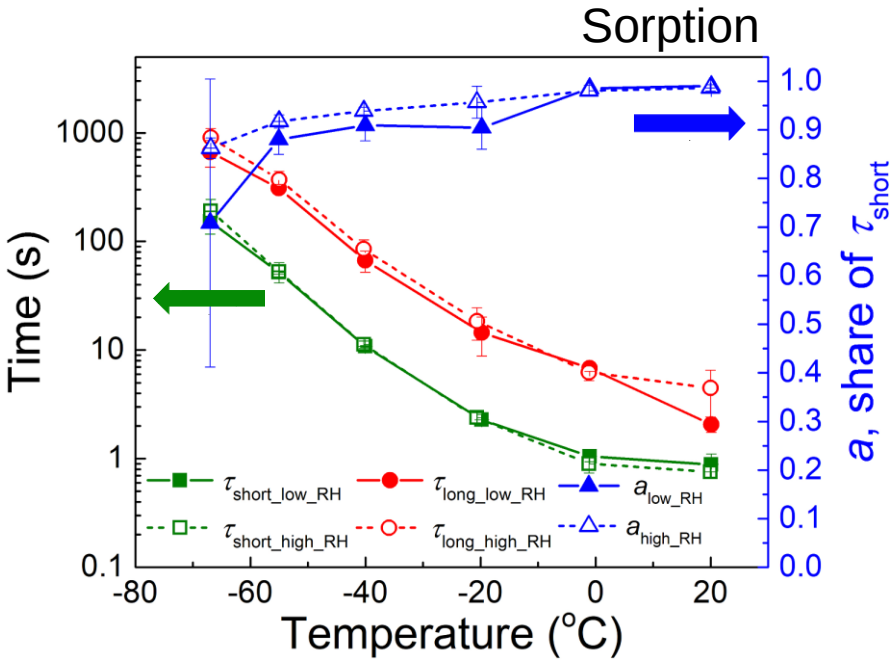
$$U(t) = U_\infty - (U_\infty - U_0)[\boldsymbol{a(T)}\cdot\exp(-(t-t_0)/\boldsymbol{\tau_{short}(T)}) + (1-\boldsymbol{a(T)})\cdot\exp(-(t-t_0)/\boldsymbol{\tau_{long}(T)})]$$

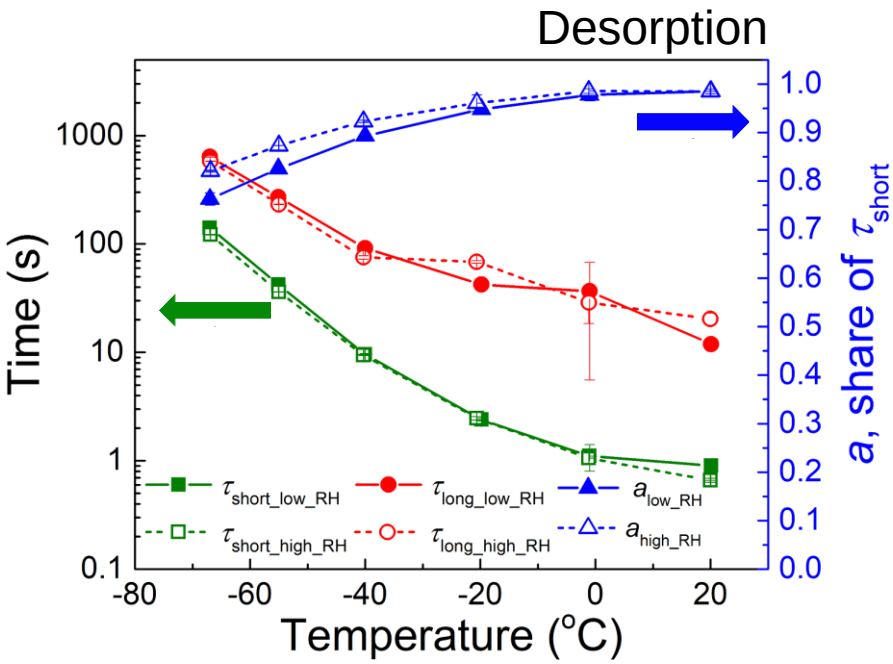


τ_{short} for sorption and desorption are similar.

Response time; low RH

- High RH vs. Low RH (half of high RH)



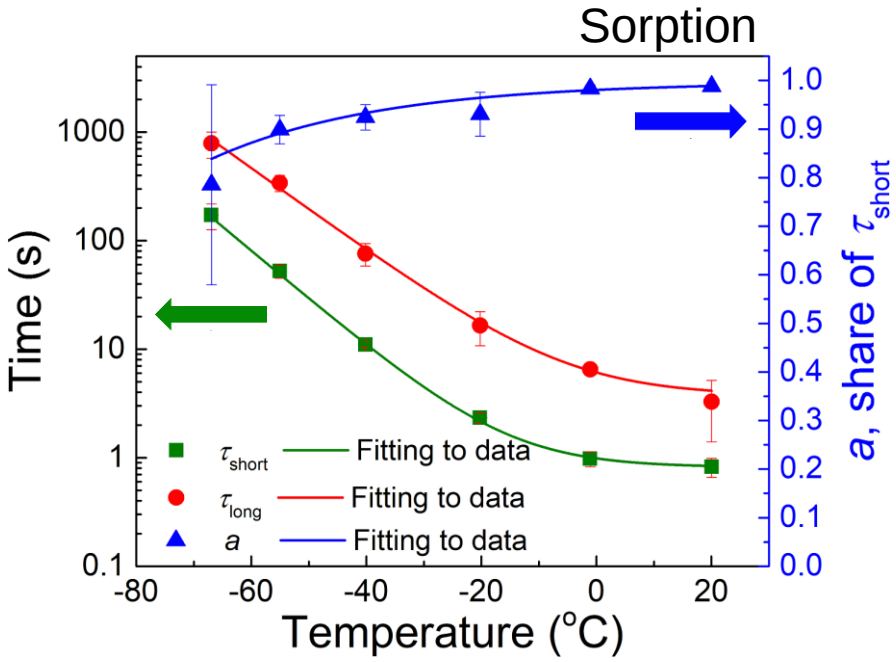


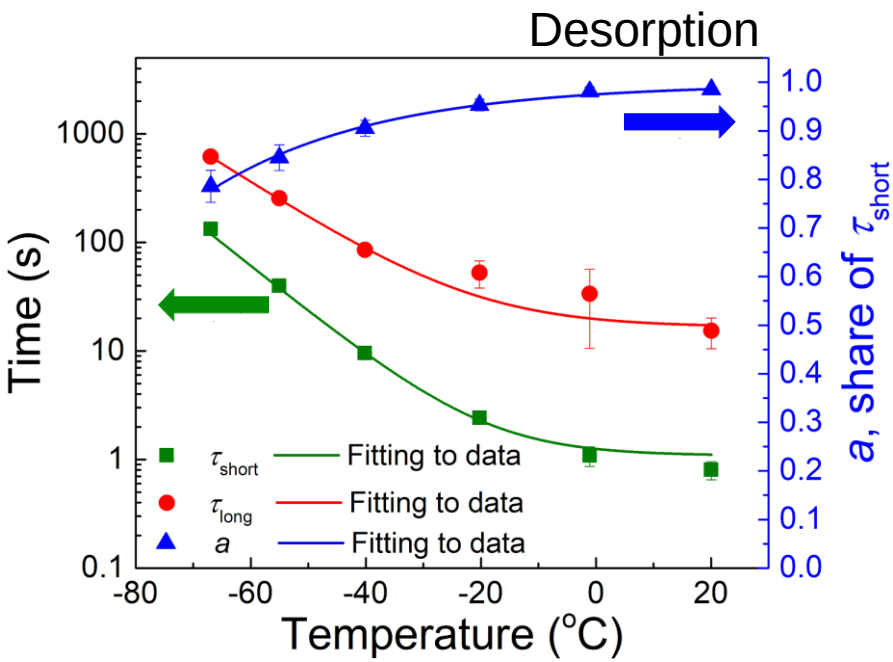
Time constants for low and high RH are similar.

But, the share of τ_{short} for low RH is slightly smaller.

Response time; average of high & low RH

- Formulation with a single exponential function
  - τ_{short}, τ_{long}, & $a = A \cdot \exp(-T / t) + y_0$





Sorption				Desorption			
	τ_{short}	τ_{long}	a		τ_{short}	τ_{long}	a
A	0.169	2.363	-0.016	A	0.167	3.052	-0.022
t	9.738	11.367	29.532	t	10.198	12.681	29.131
y_0	0.818	3.743	0.997	y_0	1.087	16.629	0.997

Summary

RS41 RH measurement at 5 m·s^{-1} using the UAS

- UAS humidity setup was modified to produce v = 5 m·s^{-1}.
- Effect of the heater was reduced at 5 m·s^{-1} (→ Ref. PRT ≈ RS41 T-sensor).
- Reproducibility of a single unit of RS41 was tested (Max. S.D. = 0.4 %rh).
- Individuality was tested using another unit (Max. difference = 5.3 %rh).

Response time during sorption and desorption

- Response time was measured using high RH and low RH.
- Measurement curves were fitted with a double exponential function (τ_{short}, τ_{long}, and a).
- τ_{short} and τ_{long} for high and low RH were similar but, the share for τ_{short} (a) is slightly lower at low RH.
- The mean of τ_{short}, τ_{long}, and a were formulated for time-lag correction.

Thank you for your attention.

Questions or comments?