Calibration of RS41 humidity sensors using upper-air simulator at KRISS

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Calibration facilities for radiosonde humidity sensors

- Humidity measurement conditions in upper air
  - Temperature (< -80 ^{o}C)
  - Pressure (< 10 hPa)
  - Frost-point temperature (< -90 ^{o}C)
- Quality control of humidity measurements
  - SI-traceable calibration of humidity sensors using ground facilities
  - Low-pressure low-temperature humidity generators

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TEMPMEKO 2016

CrossMark

Low-Pressure and Low-Temperature Dew/Frost-Point Generator

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VTT in Finland

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Development of a low frost-point generator operating at sub-atmospheric pressure

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Development of a low-temperature low-pressure humidity chamber for calibration of radiosonde humidity sensors

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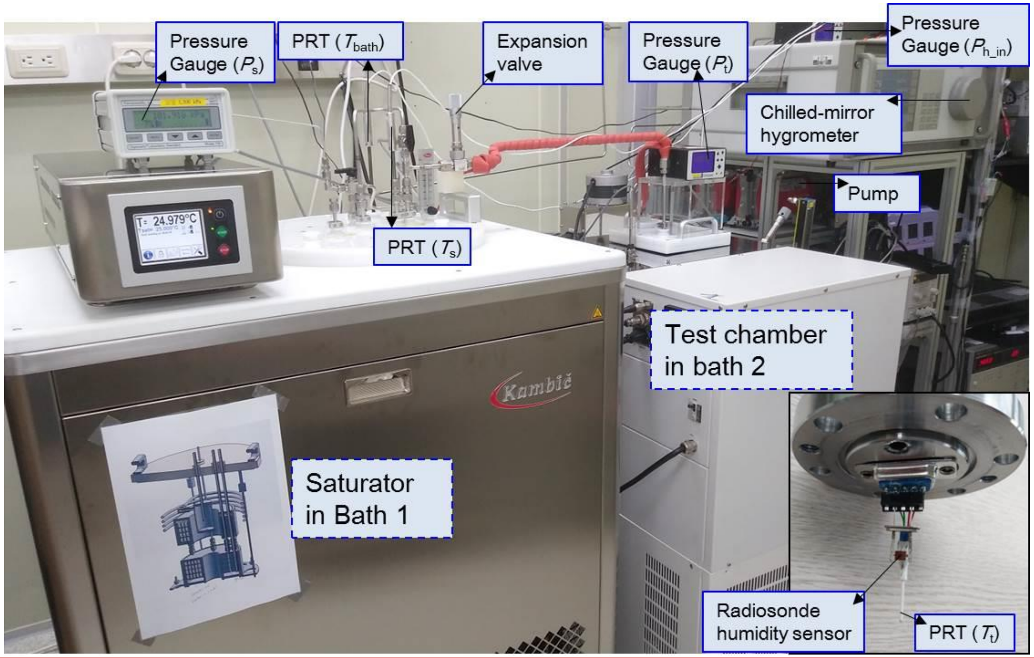
KRISS in Korea

Low-temperature low-pressure humidity chamber

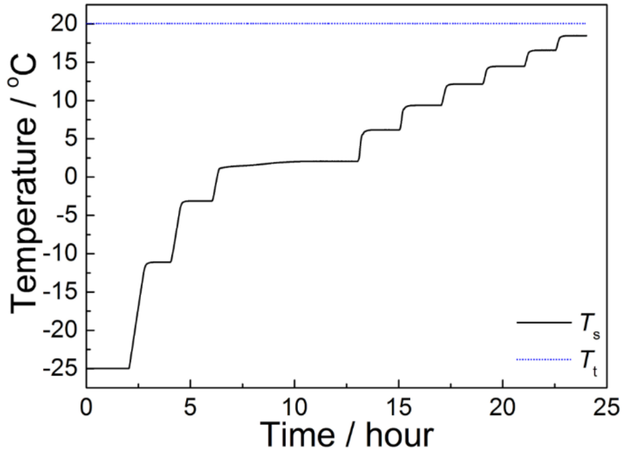
- Operation range in test chamber
  - The humidity sensor meets
    - Temperature: (-70 – 30) °C
    - Pressure: (50 – 1000) hPa
    - Dew/frost point temperature: (-90 – 20) °Cdp/fp
    - Relative humidity: (2 – 100) %rh

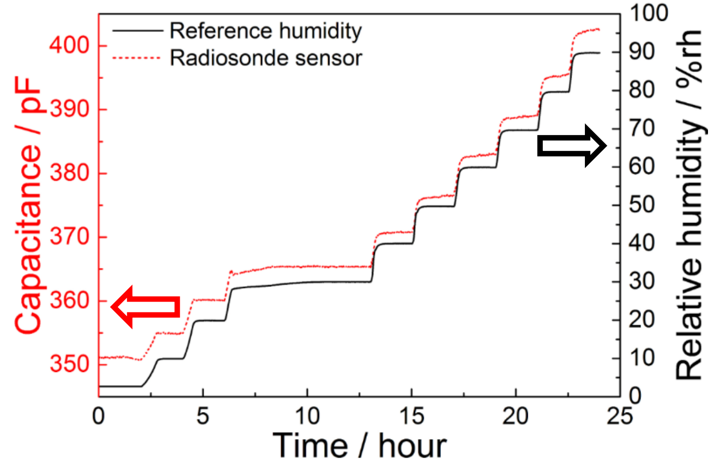


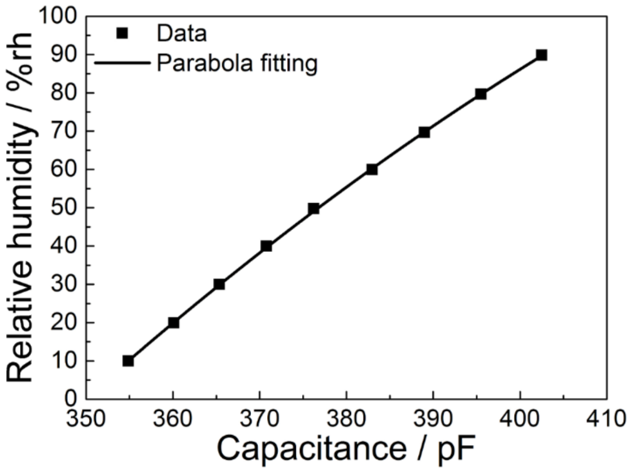
Calibration of a humidity sensor

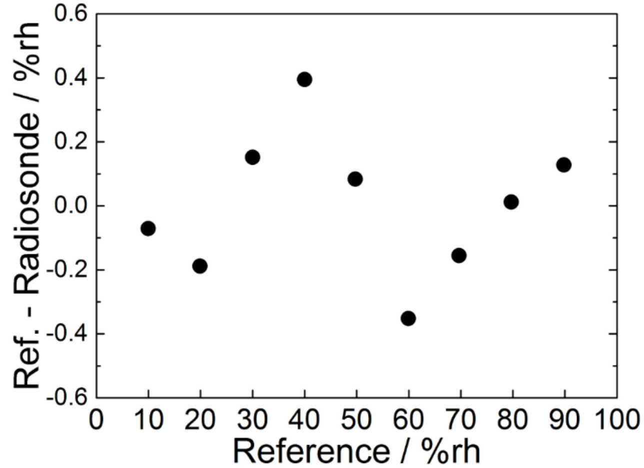
Calibration curve at room temperature

- 20 ^{o}C & 100 kPa





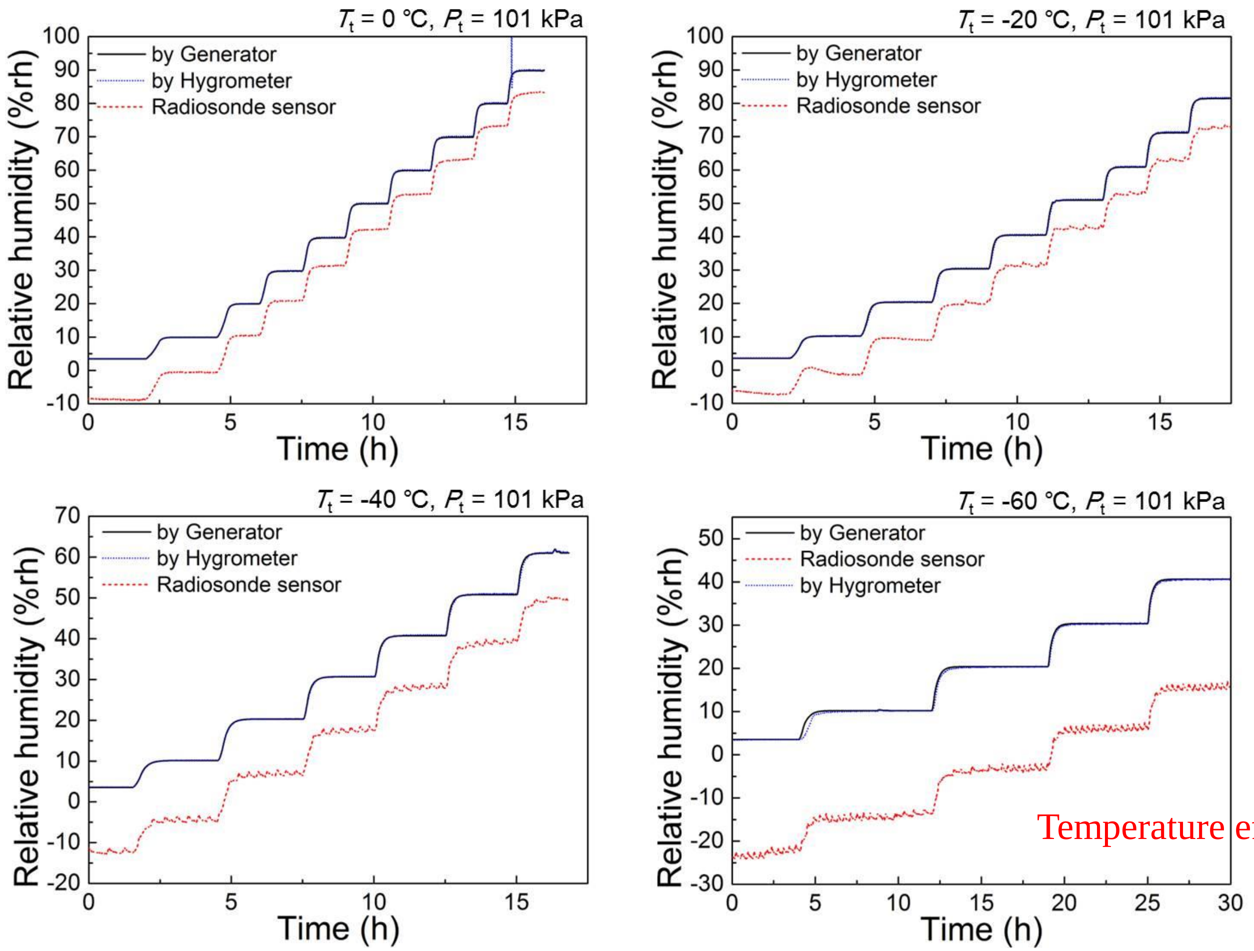




Calibration of a humidity sensor

□ Low-temperature effects

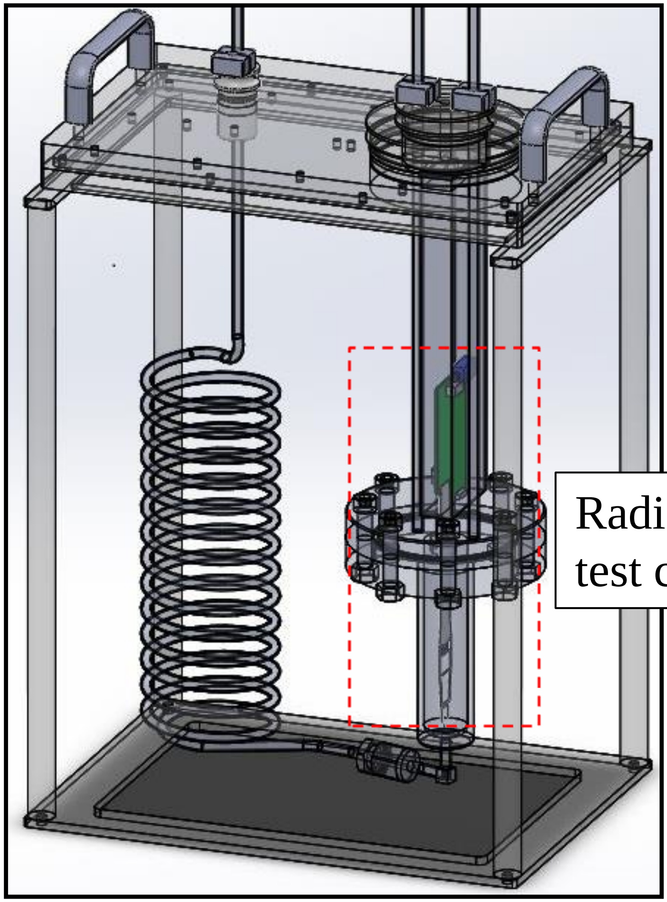
- 0 °C, -20 °C, -40 °C, -60 °C (at 100 kPa)



Temperature effect is significant !

Sensor only vs. Radiosonde?

- Compensation of a whole radiosonde
  - Just a humidity sensor → a whole radiosonde

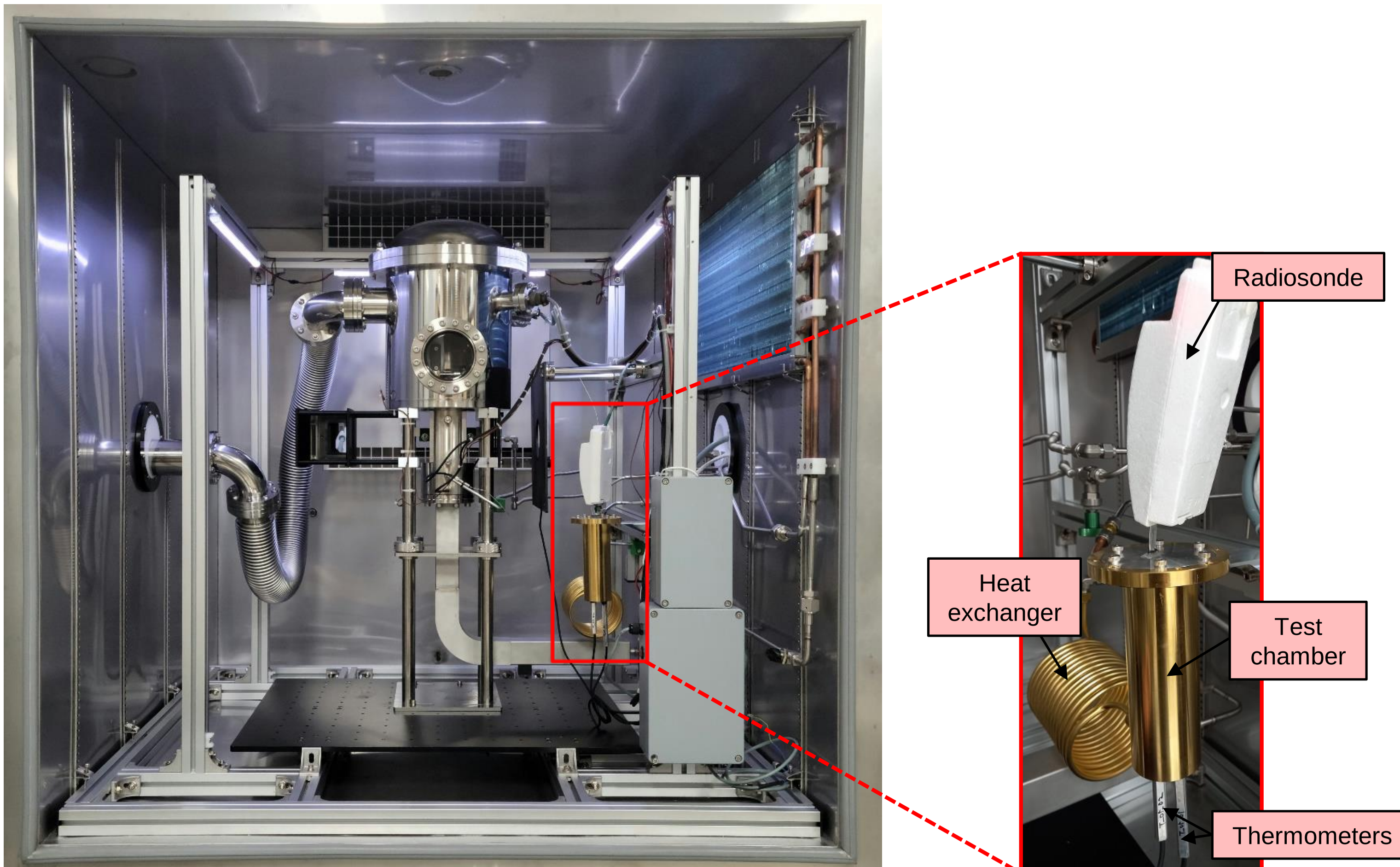


Radiosonde in test chamber

Upper air simulator; humidity calibration setup

☐ Upper air simulator (UAS)

- Humidity calibration setup with a radiosonde in UAS

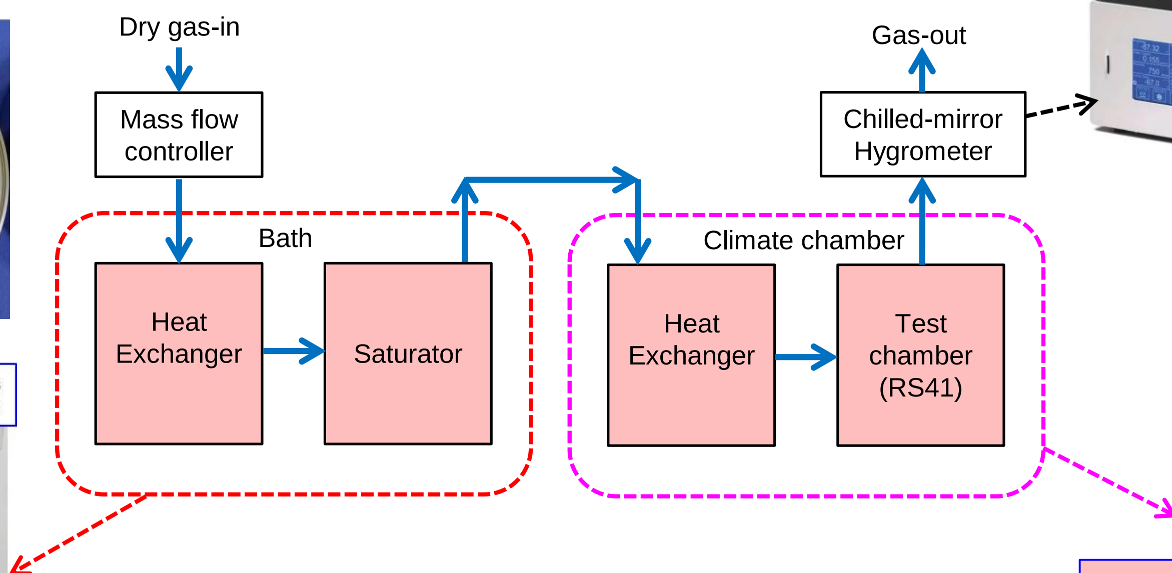


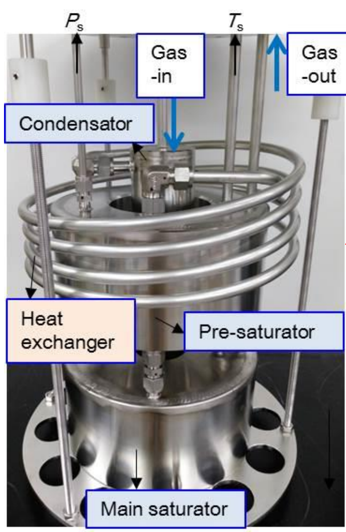
Operation principle

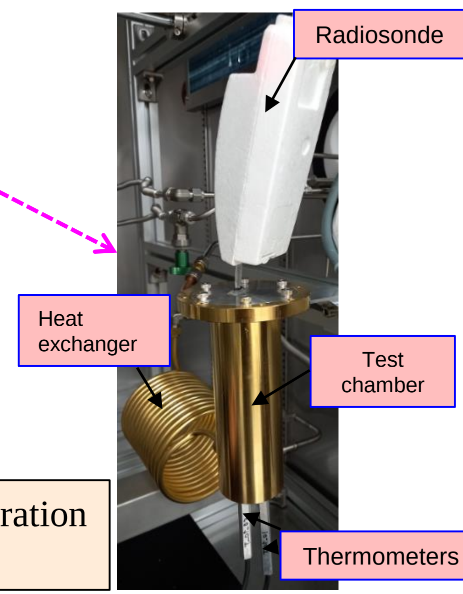
Two-temperature type humidity generator

- $T_{\text{saturator}}$ & $T_{\text{test chamber}}$

Hygrometer: Validation



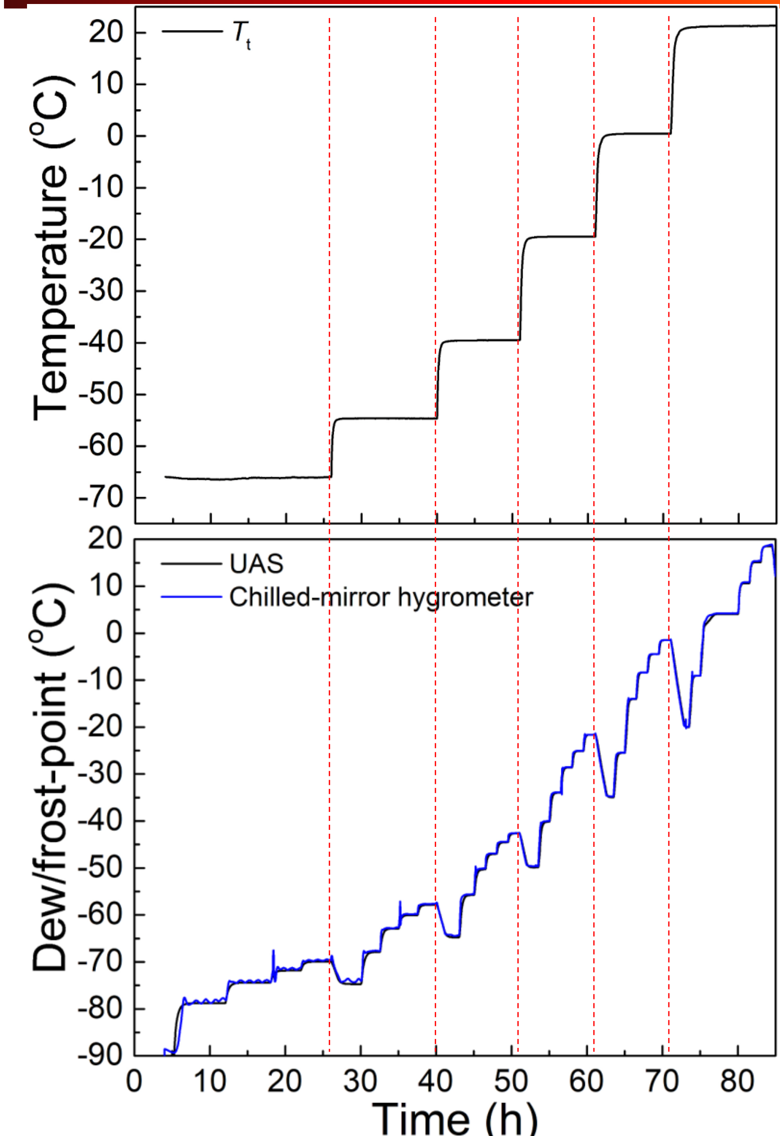




Saturator: Generation of well-defined vapor pressure

Test chamber: Calibration of radiosondes

Operation of humidity generator



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

T_s = saturator temperature, P_s = saturator pressure

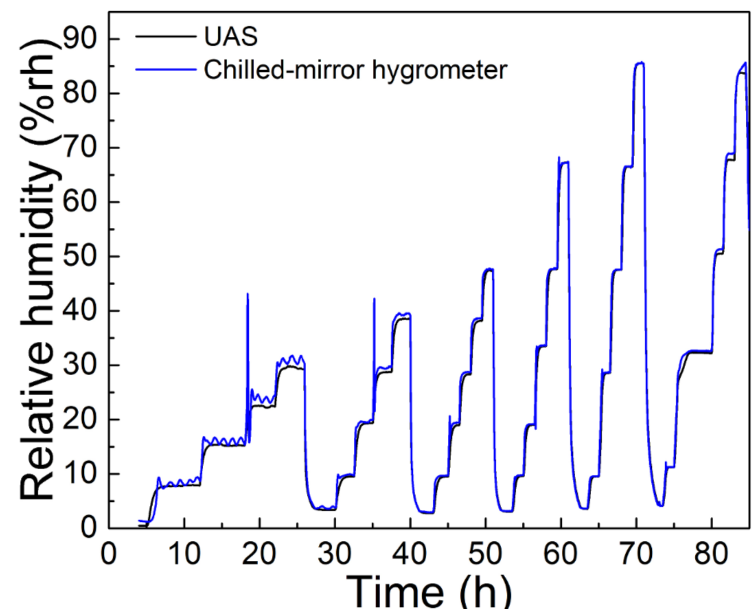
T_t = test chamber temperature, P_t = test chamber pressure

$e_{is}(T_s)$ = 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



Uncertainty of UAS humidity generator

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

- $u(T_s) \times \{\partial e_s(T)/\partial T\}|_{T_s} \times [\ ] \times 100$
- $u(P_s) \times \{-1/P_s^2\} \times [\ ] \times 100$
- $u_r(e_s(T_s)) \times [\ ] \times 100$
- $u_r(f(P_s, T_s)) \times [\ ] \times 100$
- $u(T_t) \times (-1/e_s^2(T_t)) \times \{\partial e_s(T)/\partial T\}|T_t \times [\ ] \times 100$
- $u(P_t) \times [\ ] \times 100$
- $u_r(e_s(T_t)) \times (-1/e_s^2(T_t)) \times [\ ] \times 100$
- $u_r(f(T_t, P_t)) \times (-1/f(T_t, P_t)^2) \times [\ ] \times 100$
- u (Efficiency)
- u(Adsorption/Desorption)

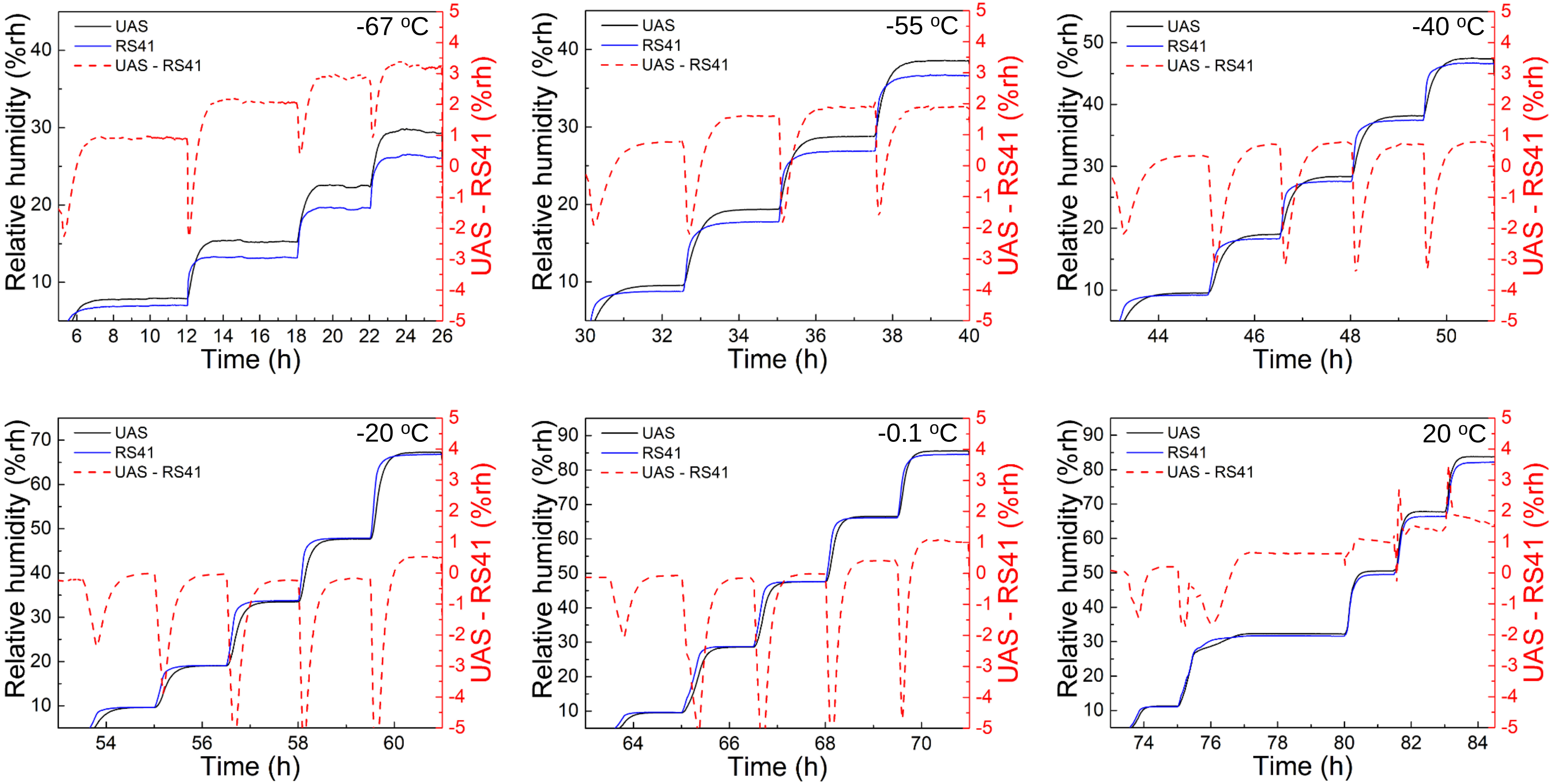
Table 2. Uncertainty budget on relative humidity of UAS at T_t = -67.8 ºC.

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

Calibration of RS41 humidity sensor

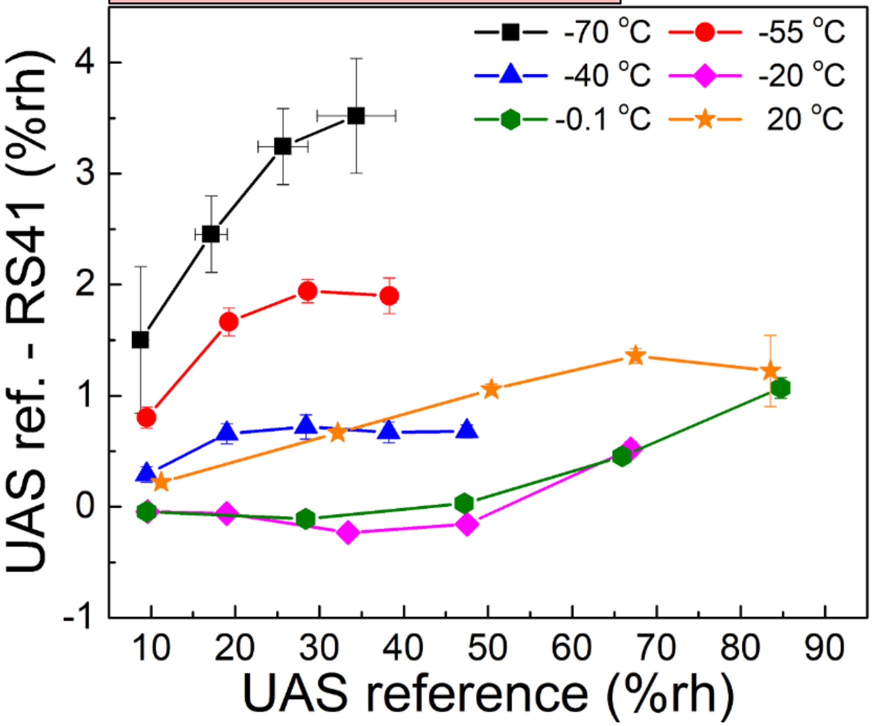
- Temperature dependent measurements



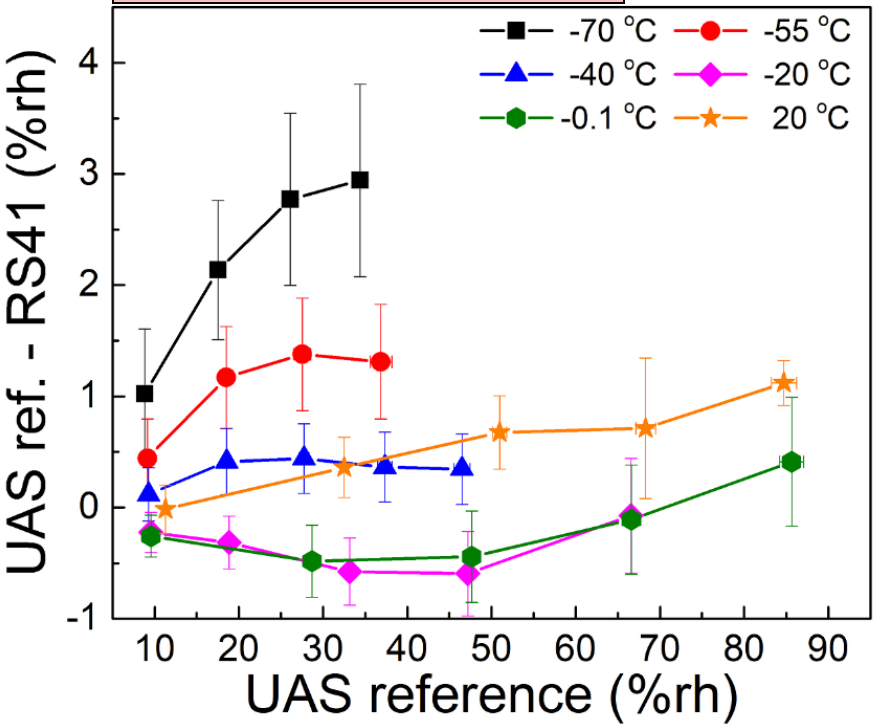
Calibration result; repeatability & reproducibility

- Repeatability and Reproducibility of RS41

Three measurements of a RS41 unit
Mean ± Standard deviation



Measurements of three RS41 units
Mean ± Standard deviation



Calibration result; calibration value & uncertainty

- Calibration value & Uncertainty of a single unit of RS41

Temperature (℃)	-67.1	
Reference (%rh)	RS41 (%rh)	Ref. – RS41 (%rh)
9.0	7.5	1.5
17.0	14.5	2.5
26.0	22.8	3.2
34.0	30.4	3.6
Uncertainty (k = 2)		1.3 (%rh)

Temperature (℃)	-54.6	
Reference (%rh)	RS41 (%rh)	Ref. – RS41 (%rh)
10.0	9.1	0.9
19.0	17.3	1.7
29.0	27.1	1.9
38.0	36.1	1.9
Uncertainty (k = 2)		1.1 (%rh)

Temperature (℃)	-39.5	
Reference (%rh)	RS41 (%rh)	Ref. – RS41 (%rh)
10.0	9.7	0.3
19.0	18.3	0.7
28.0	27.3	0.7
38.0	37.3	0.7
47.0	46.3	0.7
Uncertainty		1.0 (%rh)

Temperature (℃)	-19.4	
Reference (%rh)	RS41 (%rh)	Ref. – RS41 (%rh)
10.0	10.0	0.0
19.0	19.1	-0.1
33.0	33.2	-0.2
48.0	48.2	-0.2
67.0	66.5	0.5
Uncertainty (k = 2)		1.0 (%rh)

Temperature (℃)	0.6	
Reference (%rh)	RS41 (%rh)	Ref. ('
9.0	9.0	
28.0	28.1	
47.0	47.0	
66.0	65.5	
85.0	83.9	
Uncertainty (k = 2)		('

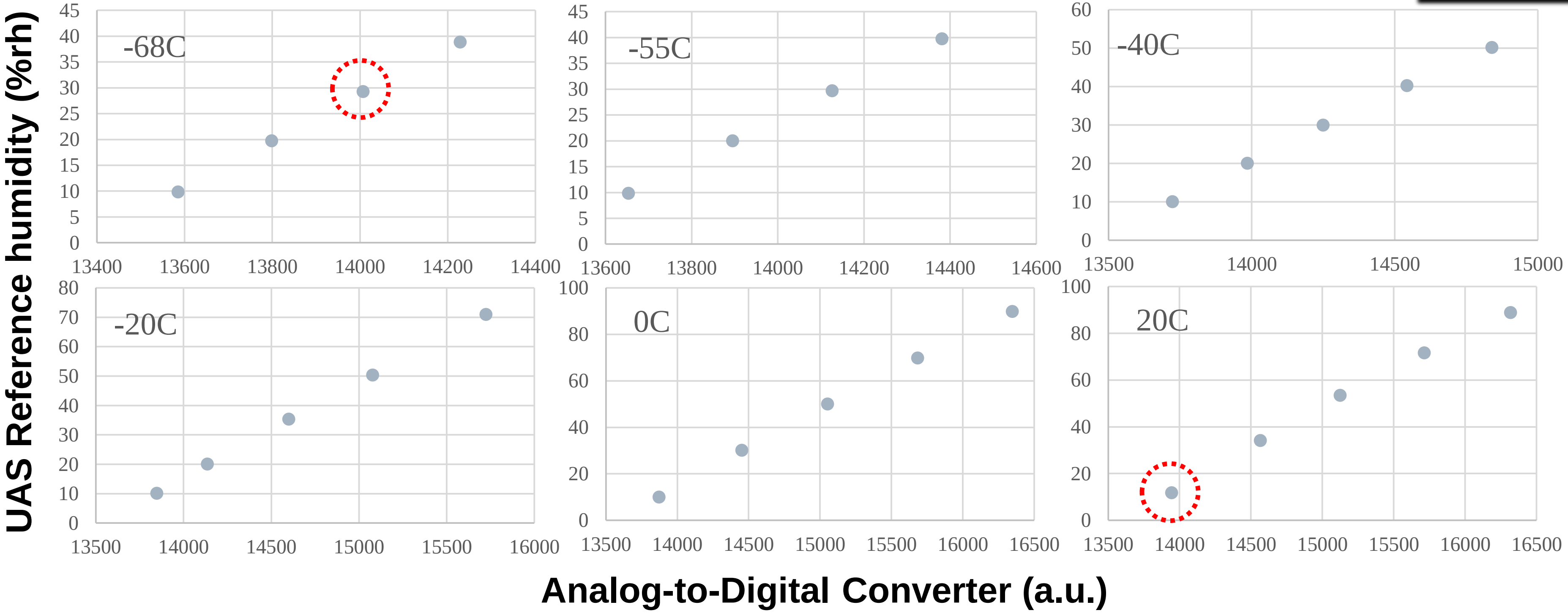
Humidity Sensor	
Type	Thin-film Capacitor
Measurement range	0 to 100% RH
Resolution	0.1% RH
Response time	
6 m/s, 1000 hPa, +20°C	< 0.3 s
6 m/s, 1000 hPa, -40°C	< 10 s
Accuracy	
Repeatability in calibration	2% RH
Combined uncertainty after ground preparation	3% RH
Combined uncertainty in sounding	4% RH
Reproducibility in sounding*	2% RH

* Standard deviation of differences (k=1) in twin-soundings, ascent rate > 3 m/s

The given specifications are valid for the temperature range -60 to +60°C

Humidity calibration of other radiosondes

- Temperature dependent measurements
  - WxR-301D radiosonde (Weathex, Korea)

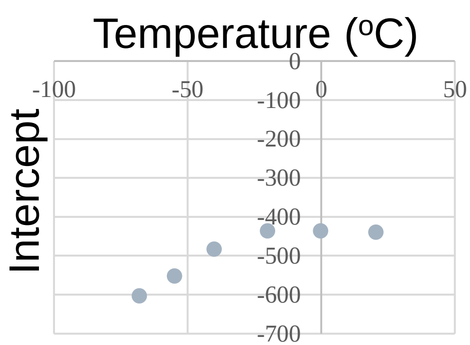


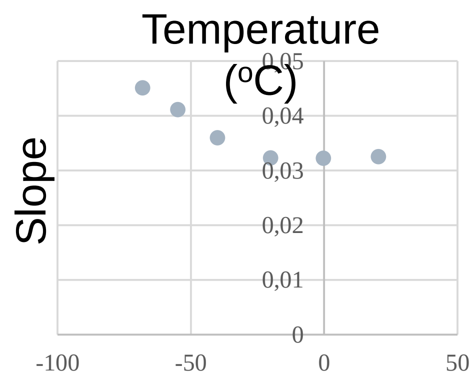
Measurement formula & Residuals

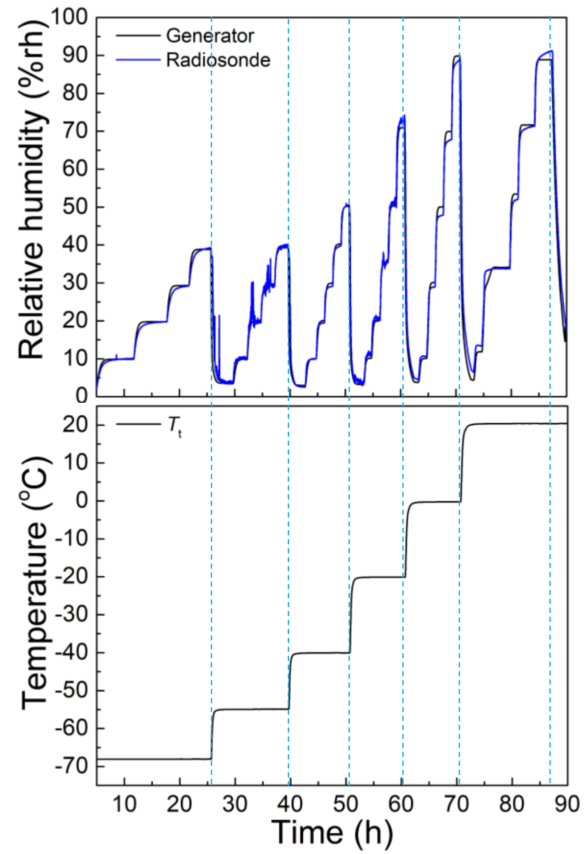
Compensation of temperature effect

Linear empirical fittings

Temperature (^{o}C)	Intercept	Slope
-68.1	-603.2	0.0451
-54.9	-551.9	0.0412
-40.0	-483.3	0.0360
-20.1	-436.5	0.0323
-0.2	-436.5	0.0323
20.4	-439.9	0.0325

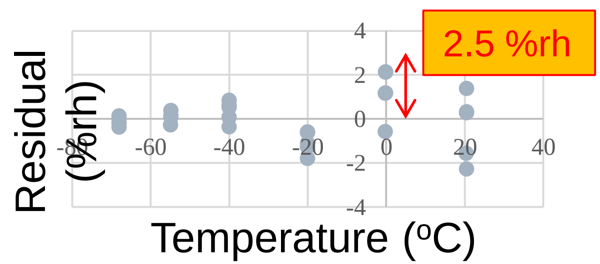






$$RH\,(T) = (a_0 + b_0 \cdot T + c_0 \cdot T^2) + (a_1 + b_1 \cdot T + c_1 \cdot T^2)\ \mathrm{x}\ \mathrm{ADC}$$

c_0	b_0	a_0	c_1	b_1	a_1
-427.1	-0.004	-0.039	0.032	-0.00000161	0.00000295



Korea Research Institute of Standards and Science

Summary

- Humidity calibration setup is developed in upper air simulator
  - Operating at low-temperature (-70 – 20) ^{o}C at atmospheric pressure
  - Generating dew/frost point temperature (-90 – 20) ^{o}C
  - Generating relative humidity (2 – 100) %rh
  - Generated humidity is validated by an independent hygrometer
  - Expanded uncertainty of the humidity chamber is less than 1 %rh (k = 2).
- RS41 humidity sensor is calibrated using the setup
  - Calibration range: (-70 – 20) ^{o}C & (10 – 90) %rh
  - Mean calibration value: 3 %rh at -70 ^{o}C, 2 %rh at -55 ^{o}C, 1 %rh at (-40 - 20) ^{o}C
  - Repeatability of a single unit: 0.5 %rh
  - Reproducibility of three units: 0.9 %rh
  - Expanded uncertainty of a RS41 humidity sensor is (1 - 1.3) %rh (k = 2).
  - SI-traceable humidity calibration of other radiosondes is available at KRISS

Thank you for your attention

More discussions to sangwook@kriss.re.kr