(I) Radiation experiments:
First results for RS41 from MOL wind channel setup

(II) Relative humidity time lag for RS41

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11th GRUAN Implementation and Coordination Meeting (ICM-11)
Singapore
May 2019

Outline

(I): Radiation tests (RS41)

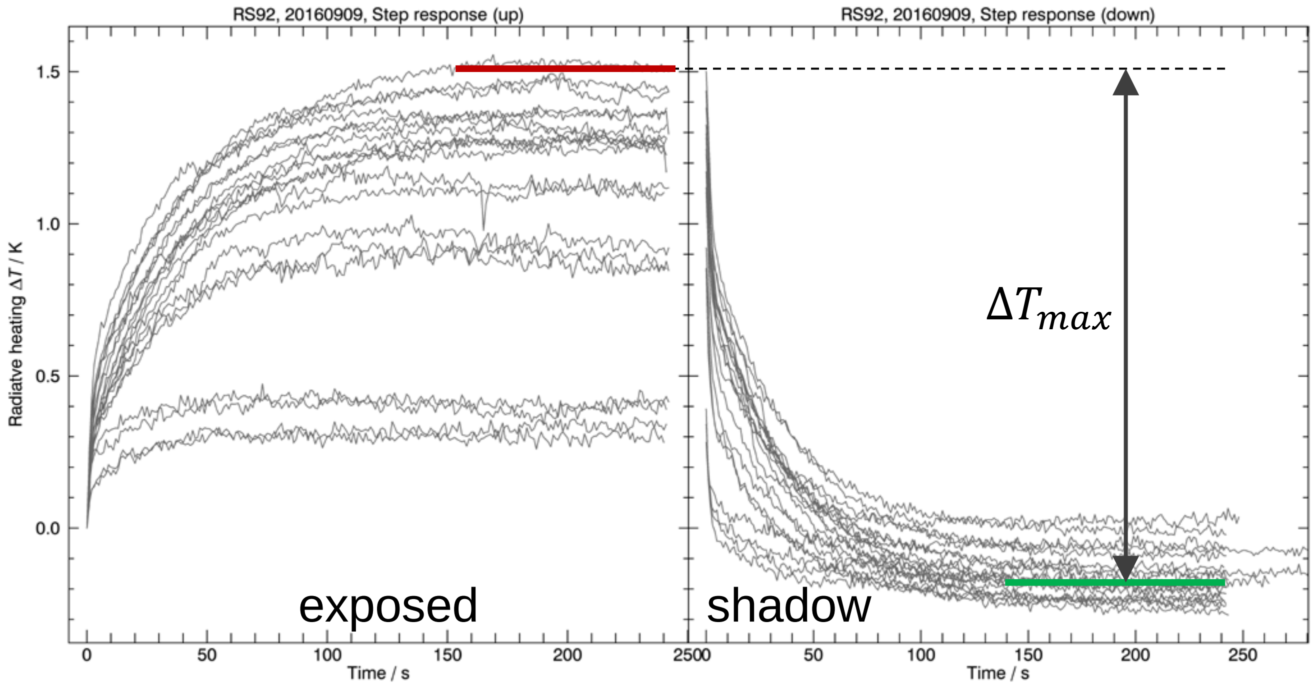
- Motivation: Restrictions of earlier results from ‘old’ chamber (current RS41-GDP-ALPHA.2)
- MOL wind channel:
  - Description of new setup
  - First results: T-response depending on irradiance, pressure, ventilation, ‘sun elevation angle’
  - Intended procedure for deriving a new radiation correction
- Conclusions

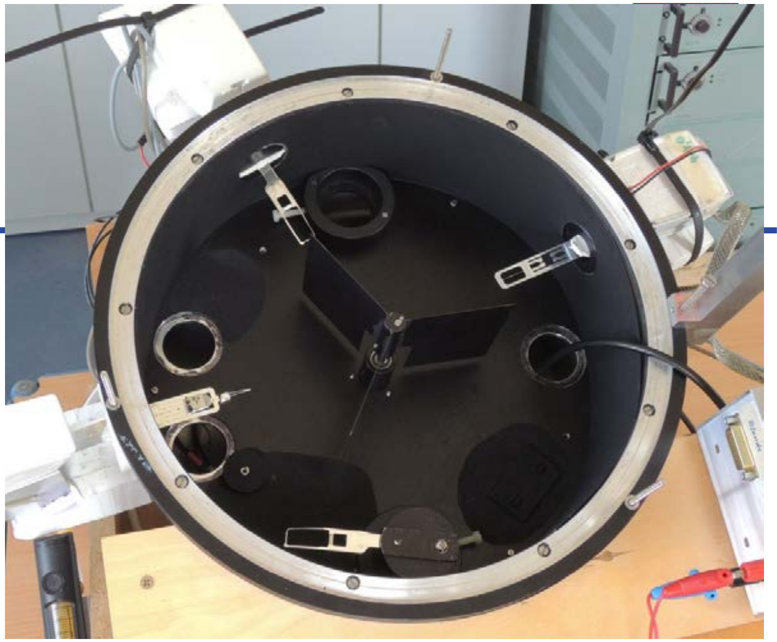
(II): Time lag for rel. humidity (RS41)

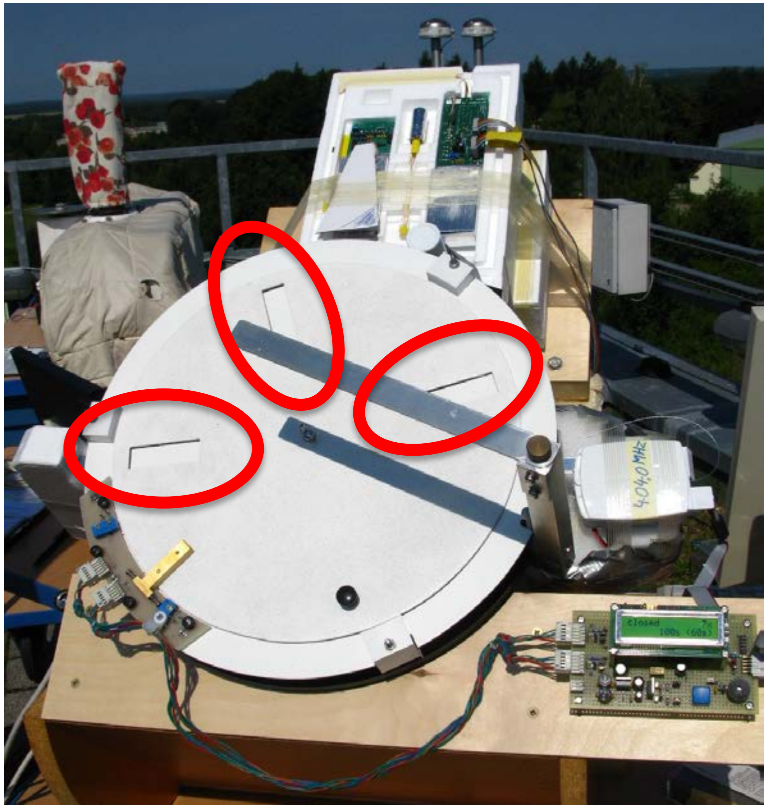
- Experimental setup
- Results
- Conclusions

(I) Radiation correction
Current approach (RS41-GDP-ALPHA.2)

- <u>Experimental basis:</u>
  Perpendicular irradiation of one side of **sensor boom** → maximum ΔT (thermal equilibrium)







(I) Radiation correction
Current approach (RS41-GDP-ALPHA.2)

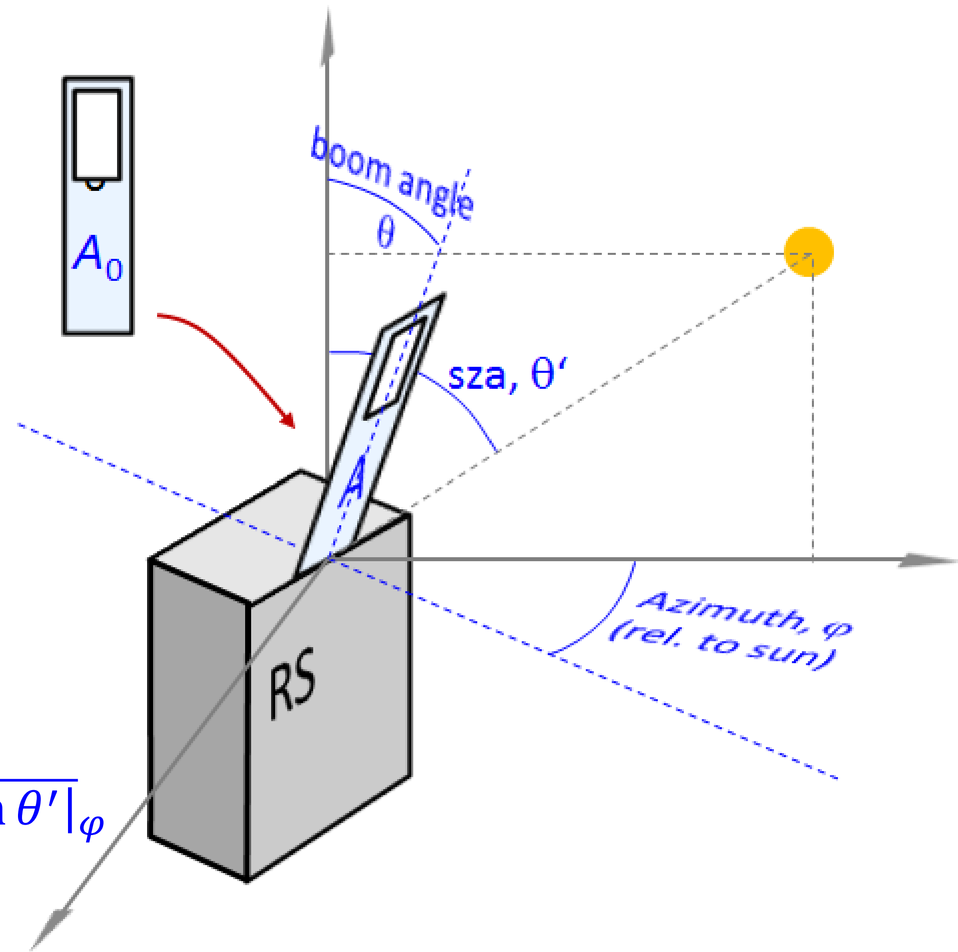
- Experimental data: $\Delta T_{\max}(I, p, v)$

- Model to transfer experimental results to operational correction:
  → Include orientation changes (sonde rotation)

Scale direct comp. of actinic flux with *effective* area of sensor boom as seen from sun *after averaging over a full φ-rotation* (I_{dir} and I_{diff} from RT-simulation):

$$I_a = I_{\text{diff}} + f_{\text{geo}} \cdot I_{\text{dir}}$$

$$f_{\text{geo}} = \overline{A/A_0}\Big|_{\varphi} = \overline{|\cos\theta\cos\theta' - \sin\theta\cos\varphi\sin\theta'|}_{\varphi}$$

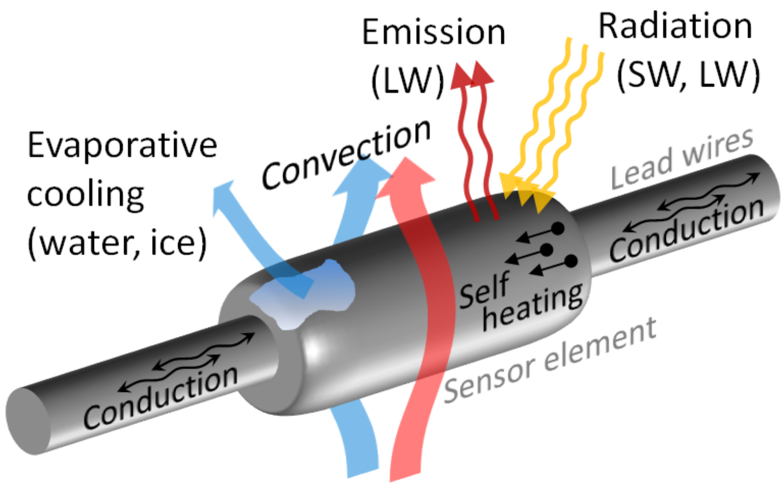


- T-bias (correction): $\Delta T = a \cdot \left(\frac{I_a}{p^j \cdot v^k}\right)^b$

a, b, j, k from fits to experimental data

(I) Radiation correction
Current approach
(RS41-GDP-ALPHA.2)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



- Problem: T-response result of numerous T-compensation processes:
  - Different parts of sensor boom heated to different extents
  - Overlay of different time constants for heat flow components

- Ascent: Irregular changes of rel. orientation to sun (rotation, pendulum)
  → Variance in effective irradiation and ventilation
  → Variable forcing and smoothing of T-signal; *probably never in equilibrium*

Simple model using f_{geo} does not include temporal behavior
(assumes *instantaneous* and *uniform* warming of boom and sensor element)

(I) Radiation correction
MOL wind channel: Setup

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- New experimental approach:

  Better reproduce real sounding conditions.

  1) Arrange direction of ventilation and radiation relative to the orientation of sensor boom similar to real soundings

  2) ‚Dynamical' measurements:
  Continuous rotation of test sonde during irradiation;
  Evaluate T-response as mean value over several (azimuthal) rotations

Empirical approach to measure the effective ΔT
(= average over some 10 s) directly

(I) Radiation correction
MOL wind channel: Setup

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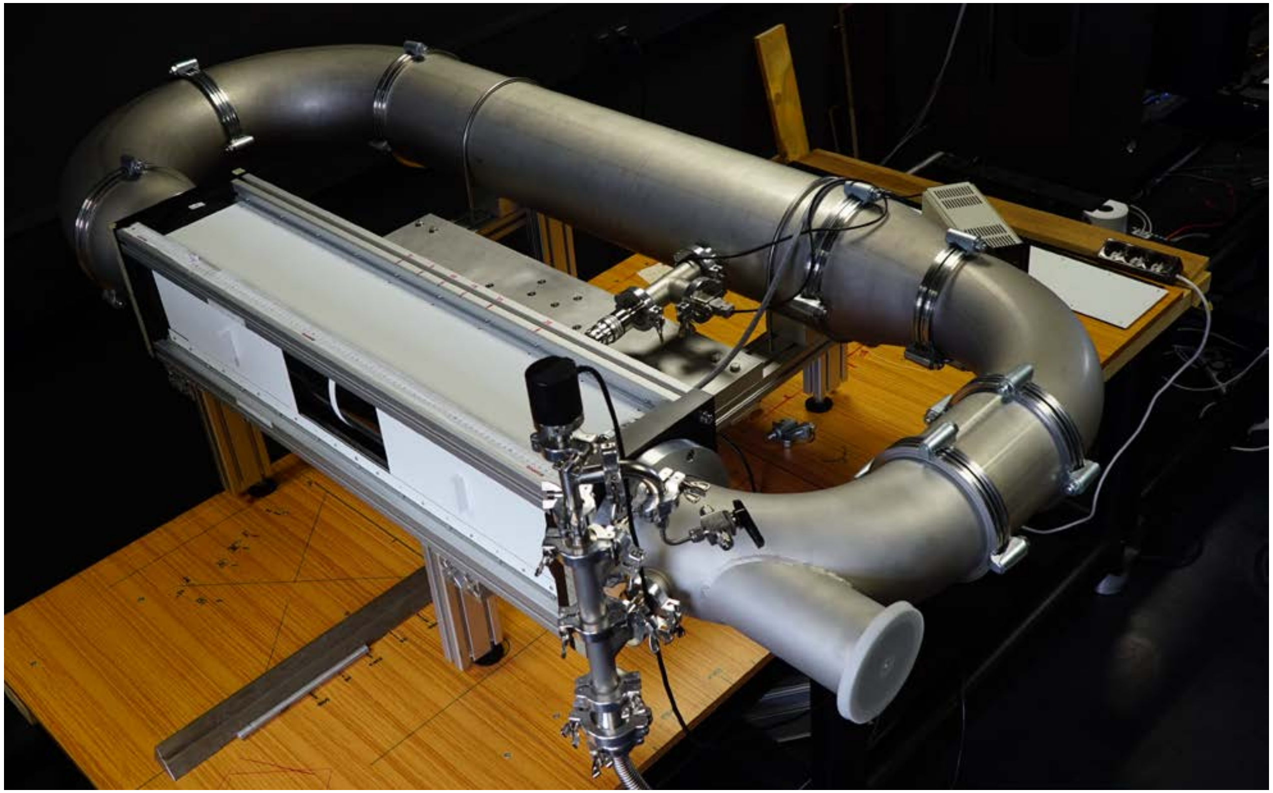
DWD



- Evacuable wind tunnel, p = (3 to 1000) hPa
- Quartz glass tube (l=1 m, Ø180 mm) as test volume: sonde installation (w/o housing)
- Air flow: circulating, control by fan revolution
- Variable angles of incident radiation: free rotation of sonde (azimuth) + simulation of SEA

(I) Radiation correction
MOL wind channel: Setup

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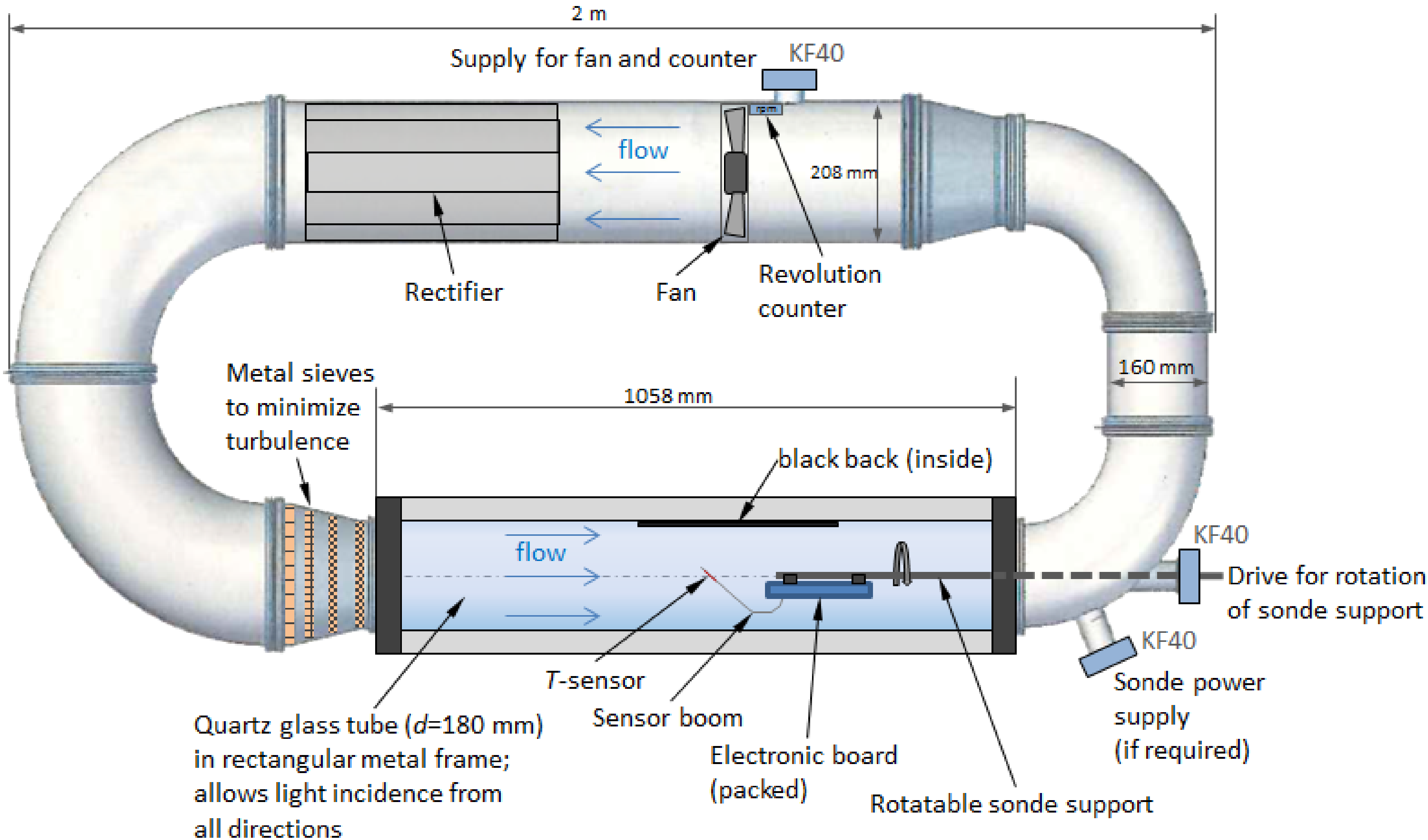
Wetter und Klima aus einer Hand



(I) Radiation correction
MOL wind channel: Setup

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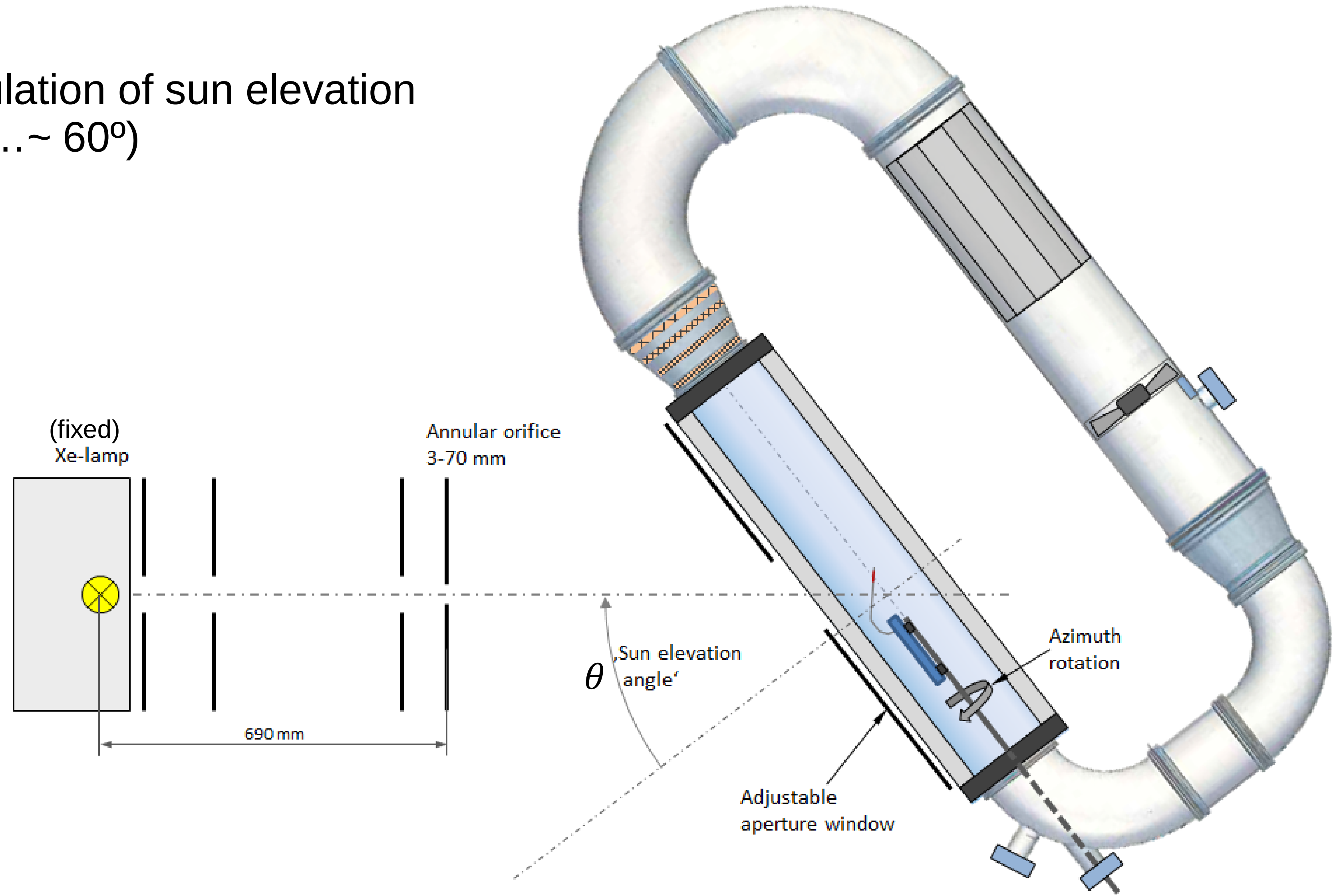
Simulation of sun elevation
(0º…~ 60º)



(I) Radiation correction
New experimental setup: First results

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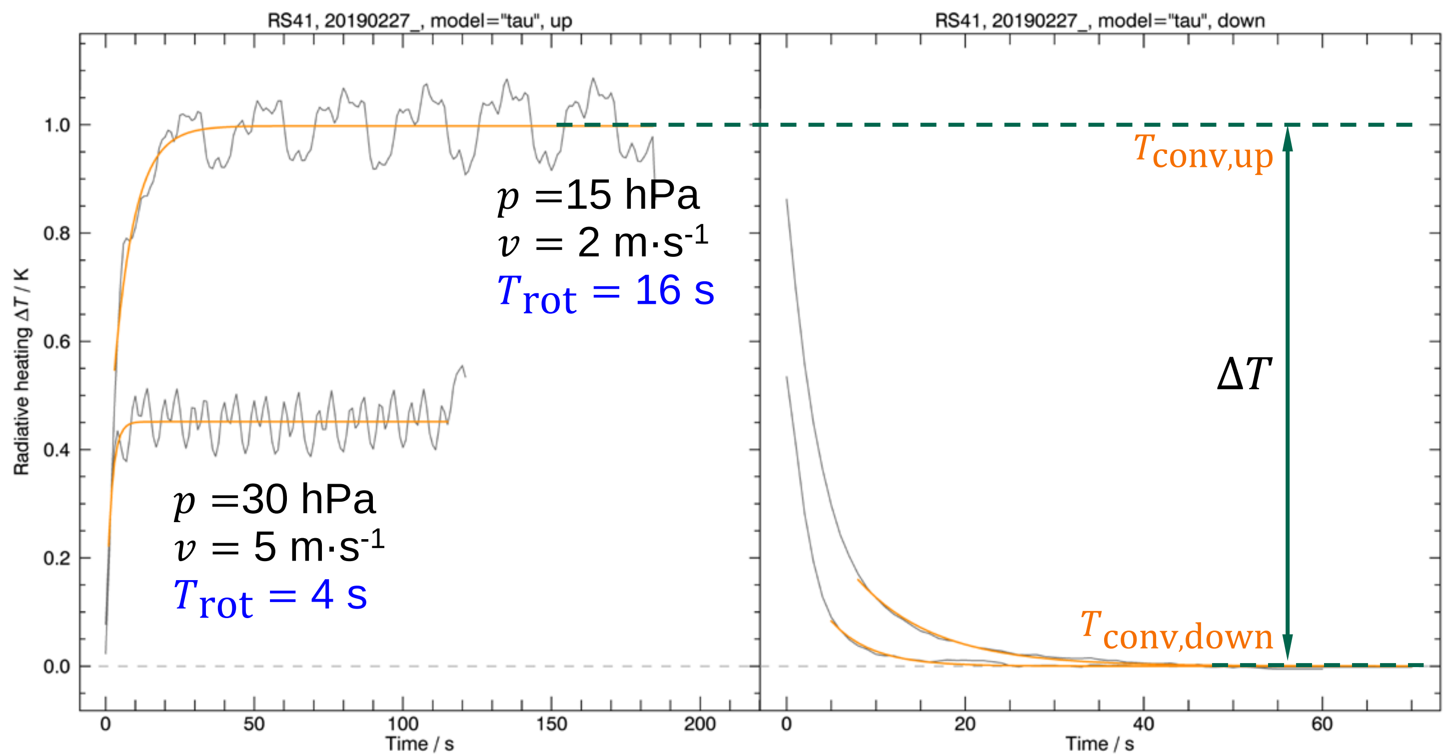
- Continuous rotation:
  - Uniform turning of sonde during periods of light incident
  - Irradiation period until quasi-equilibrium (‚constant‘ oscillation)
  - ΔT determined by average value over oscillation

Fit function (‘up‘ an ’down‘):

$$\Delta T = T_{\mathrm{conv}} + c \cdot \exp\left(\frac{t}{\tau}\right)$$



(I) Radiation correction
New experimental setup: First results

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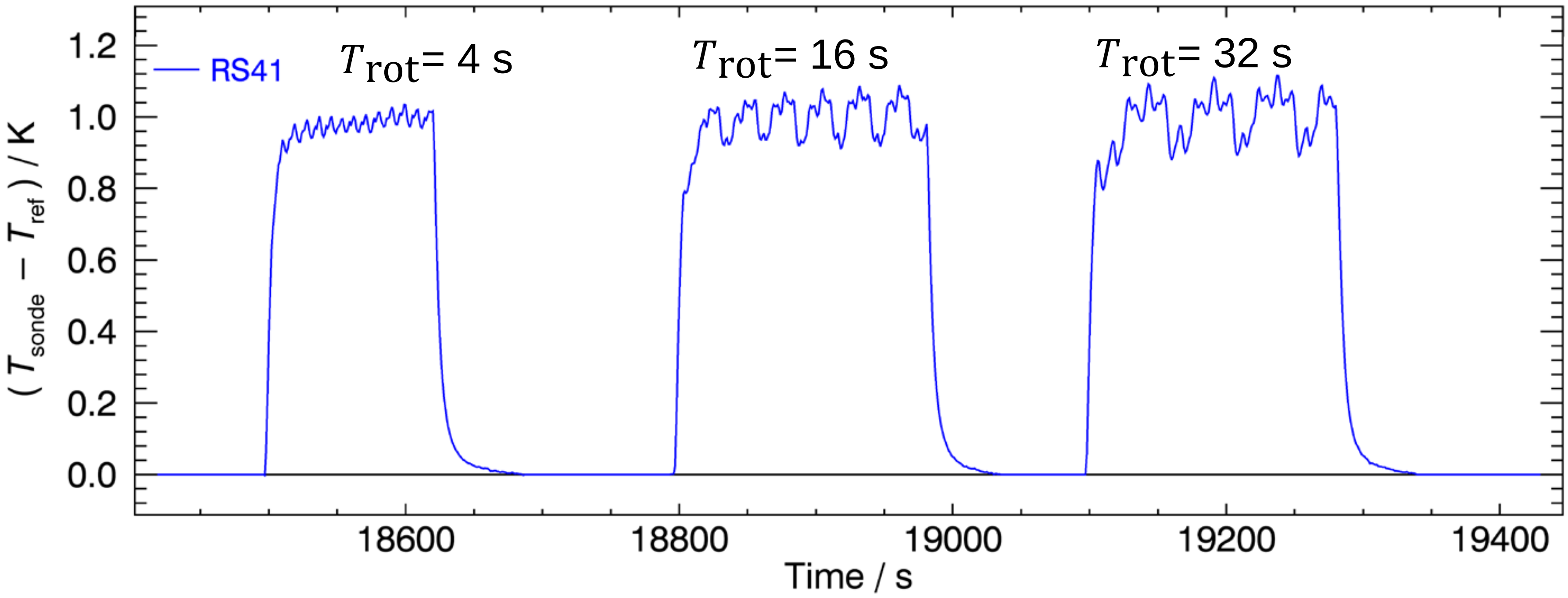
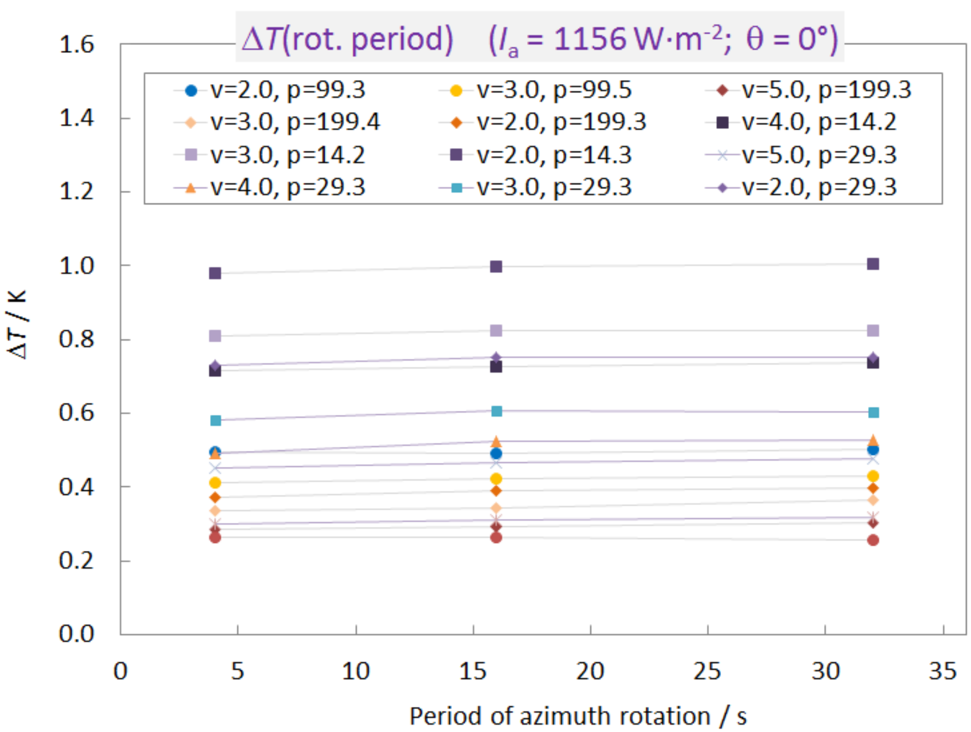
- Continuous rotation:
  - Test of different frequencies for φ-rotation: $T_{\mathrm{rot}} = 4$, 16, 32 s
    → ΔT sensitive to T_{rot} ?

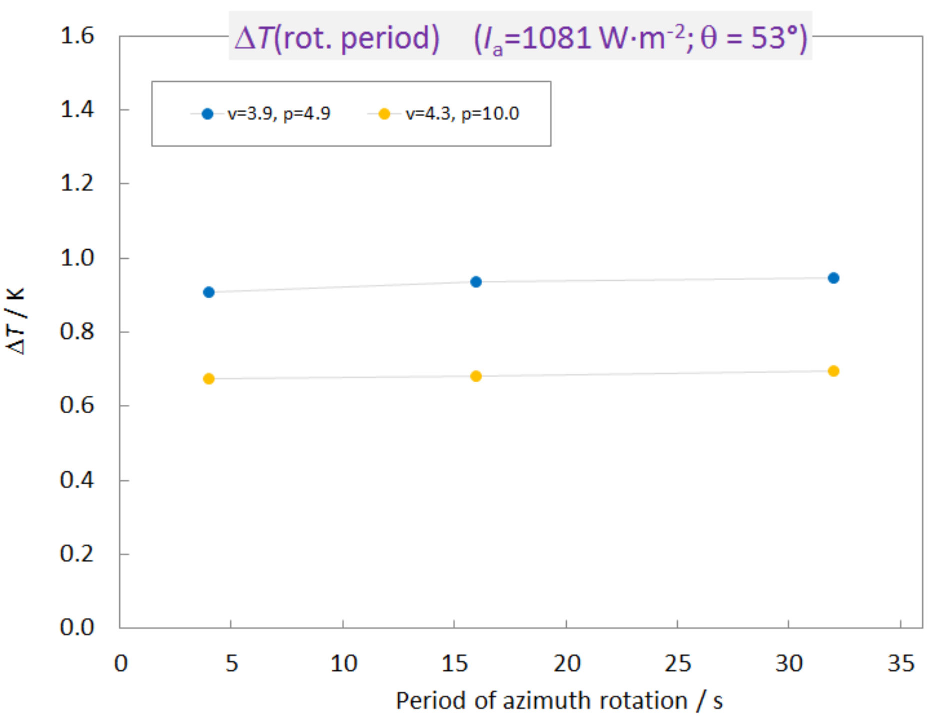
$v = 2$ m·s^{-1}, $p = 15$ hPa, $I_a = 1156$ W·m^2, SEA = 0º



(I) Radiation correction
New experimental setup: First results

- Continuous rotation:
  - Test of different frequencies for φ-rotation: T_{rot} = 4, 16, 32 s
    → ΔT sensitive to T_{rot} ? → No.





(I) Radiation correction
New experimental setup: First results

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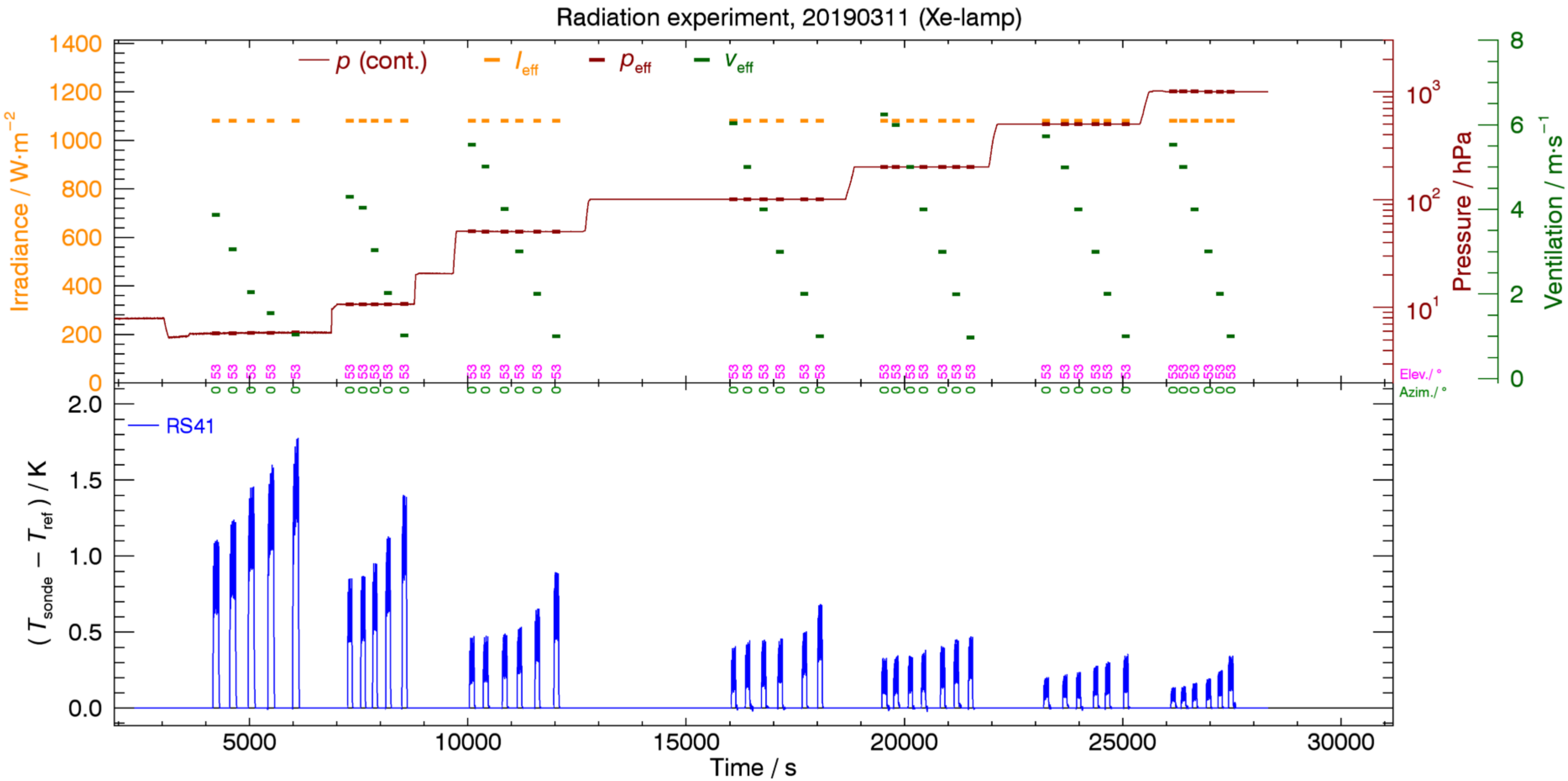
- Example for $I_a = 1081$ W·m², θ(=SEA) = 53º, p and v variable



(I) Radiation correction
New experimental setup:
First results

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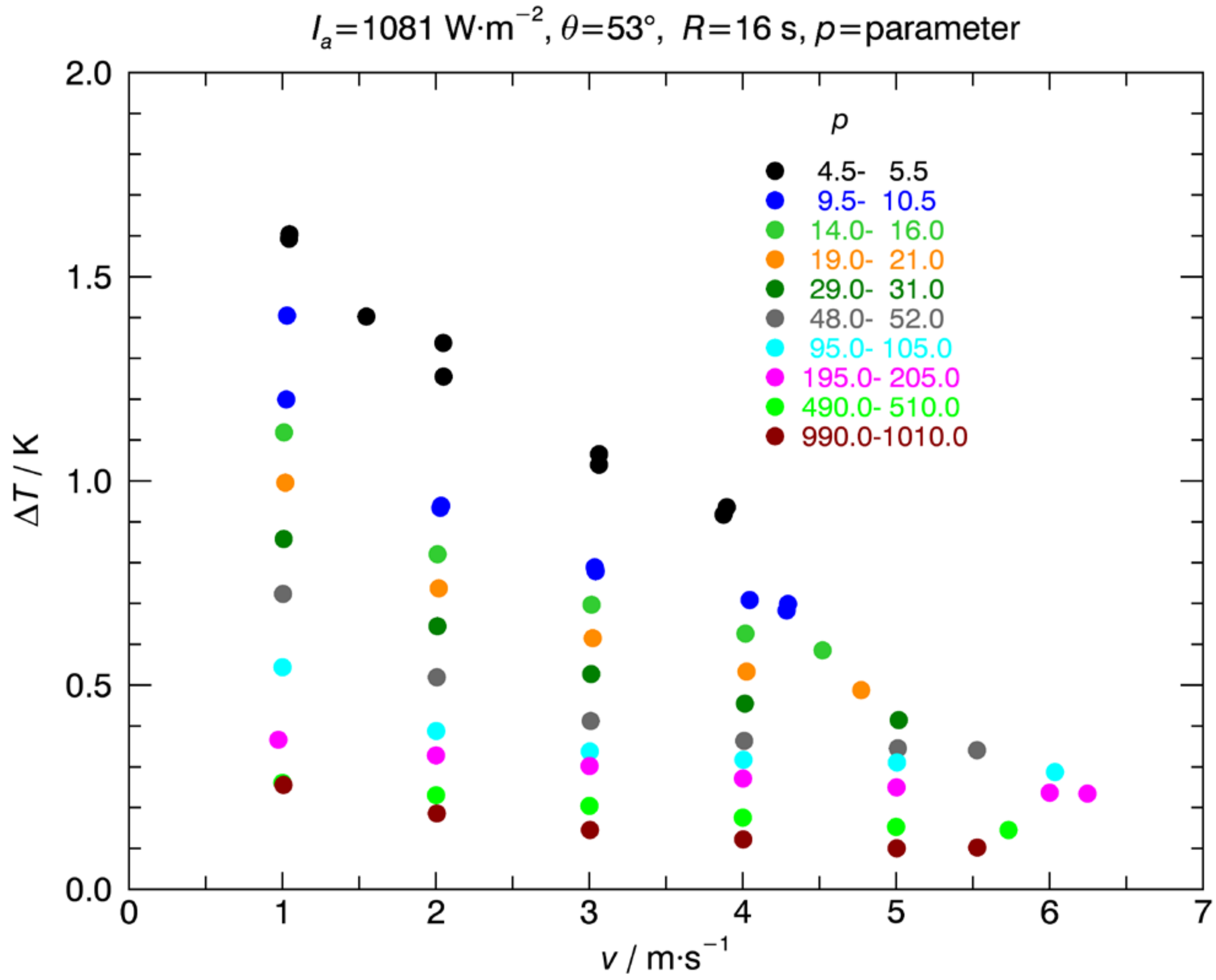
- Ventilation



(I) Radiation correction
New experimental setup:
First results

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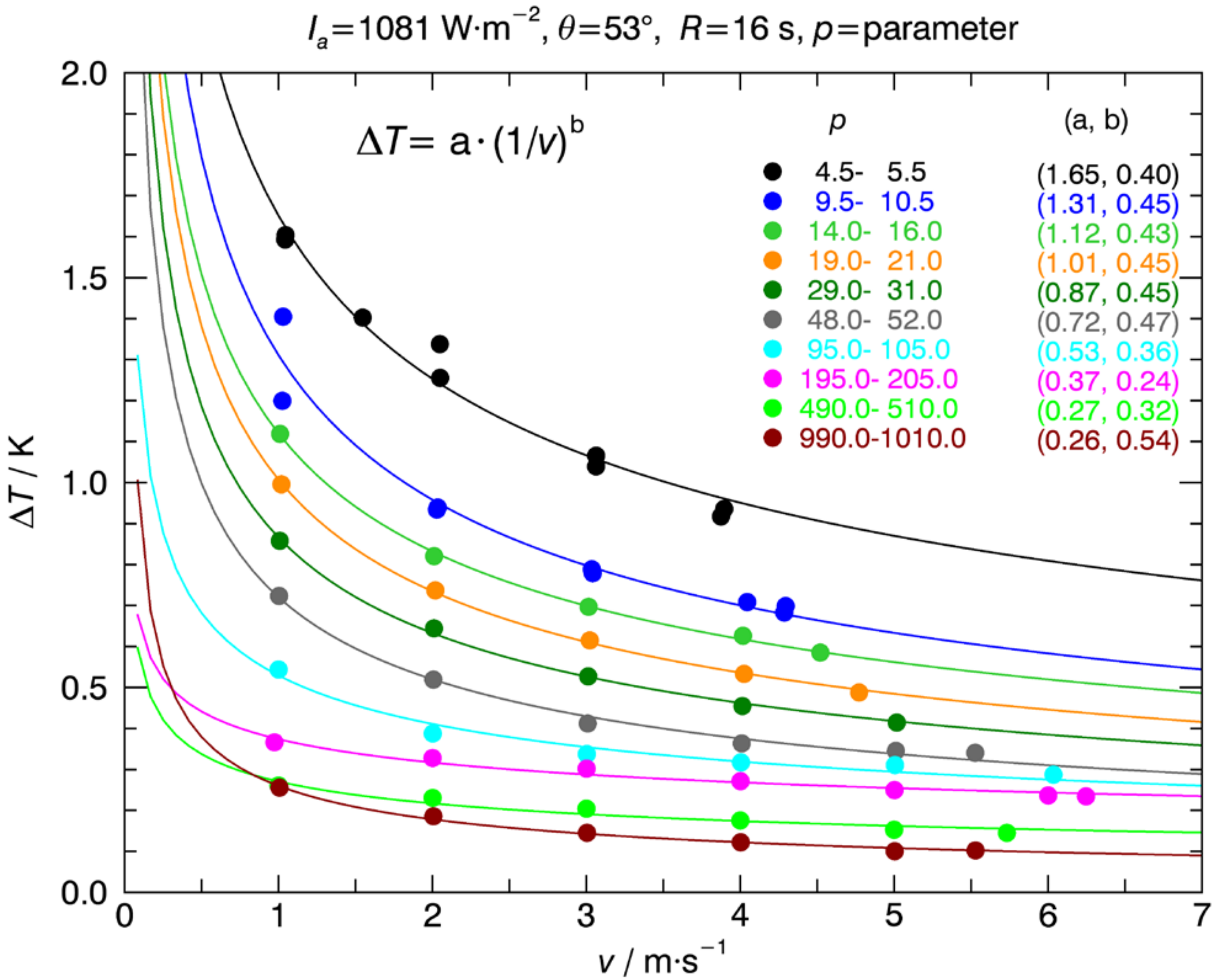
- Ventilation



(I) Radiation correction
New experimental setup: First results

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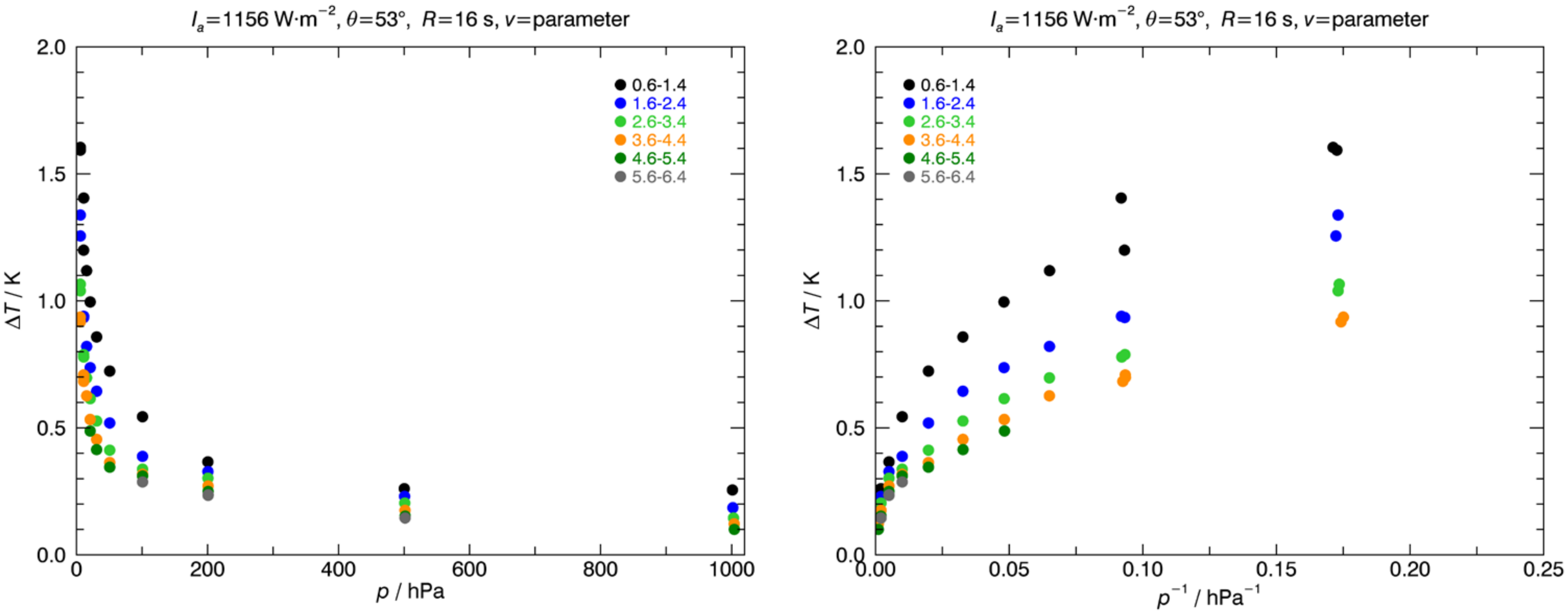
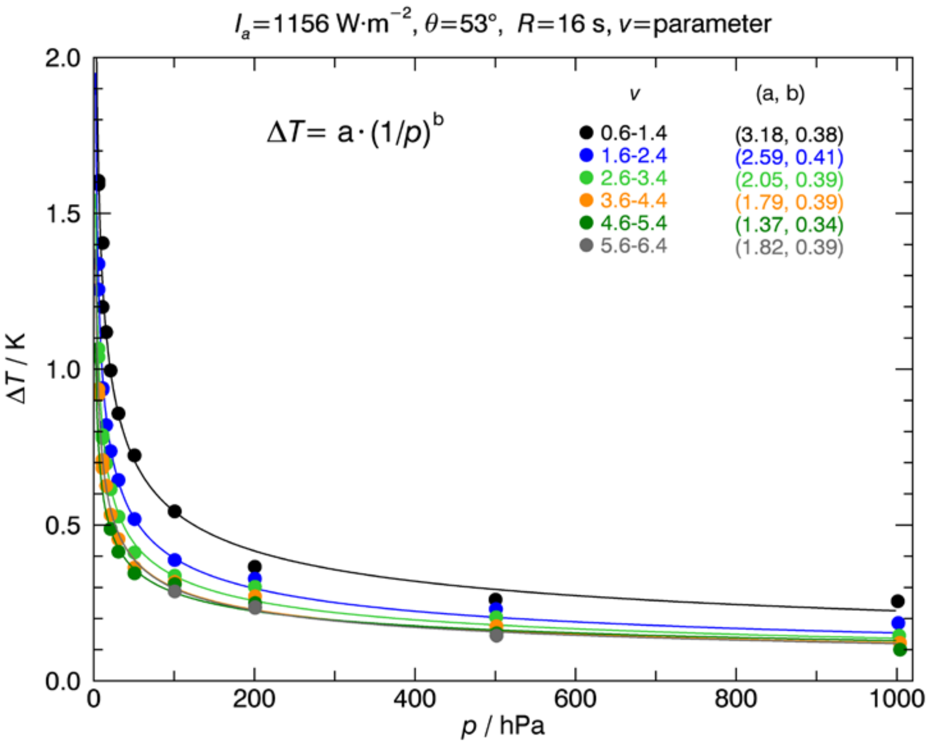
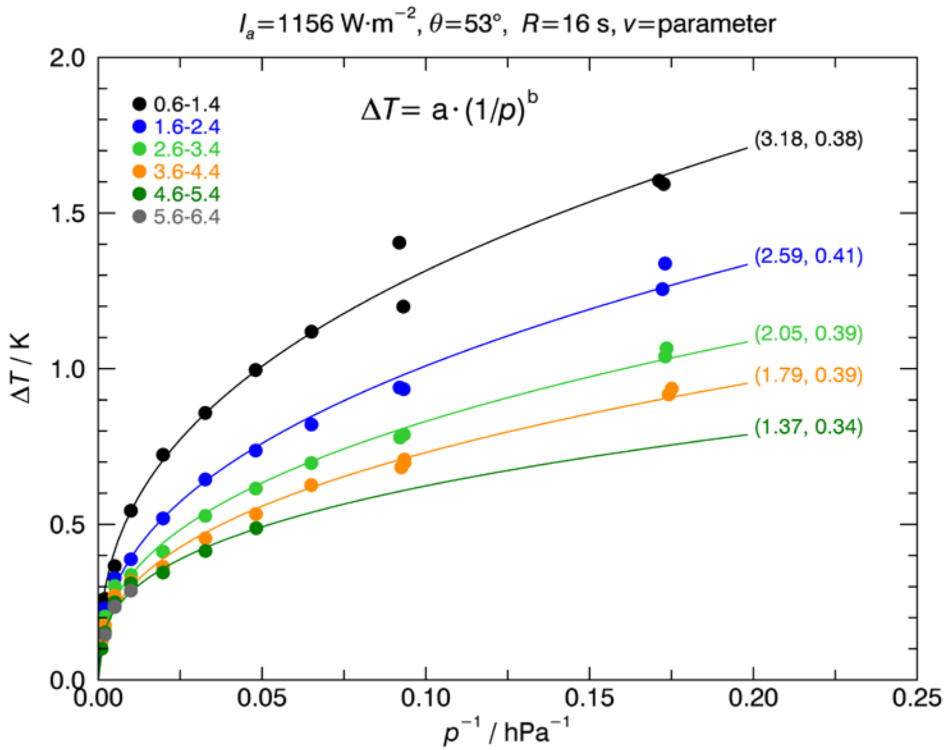
- Pressure



(I) Radiation correction
New experimental setup:
First results

- Pressure





(I) Radiation correction
Measurement plan and intended derivation of radiation correction

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- ΔT shows smooth and systematic dependence on p and v

1) Select fixed setting for I_a, ~(1000-1500) Wm^{-2}
2) - Measure ΔT as function of p and v for
   $p =$ (5, 10, 15, 20, 30, 50, 100, 200, 500, 1000) hPa
   $v =$ (1, 2, 3, 4, 5, 6, 7, 8, …) $\mathrm{m\,s}^{-1}$
   as average over continuous azimuth rotation with T_{rot} =16 s;

   - Derive expression for $\Delta T(p, v)$ (2D-non linear regression)
3) Repeat 2) for several settings of SEA ($= \theta$)
4) Create look-up table from 3) to interpolate for any θ
5) Scale ΔT linearly with I_a

Conclusions (I)

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- New setup for radiation experiments operational
  (some constructive issues to be finished)
- First results for RS41 from ‚dynamical' measurements auspicious
- To be discussed/resolved:
  - Role of absolute temperature (see KRISS experiments)
  - More information about sonde movements (rotation) during real ascents needed to support exp. approach
- Time line:
  - Continuation of measurements with RS41 in Summer/Autumn 2019; evaluation and derivation of radiation correction; implementation in RS41-GDP

(II) RH Time lag RS41: Objective

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Wetter und Klima aus einer Hand

- Objective:

  Long response times of polymer sensor at low T,
  → considerable time lag (smoothing) in UT and tropopause (especially tropics)

- Solution: Apply time-lag correction based on measured sensor response behavior

- Experimental approach / evaluation:
  - Measure step response of rel. humidity over atmospheric T-range;
    Assumption: response can be described with single time constant $\lambda = 1/\tau$
  - Evaluate response time τ as '63 %'-time for each step
  - Parameterize response time $\tau(T)$

(II) RH Time lag RS41: Setup

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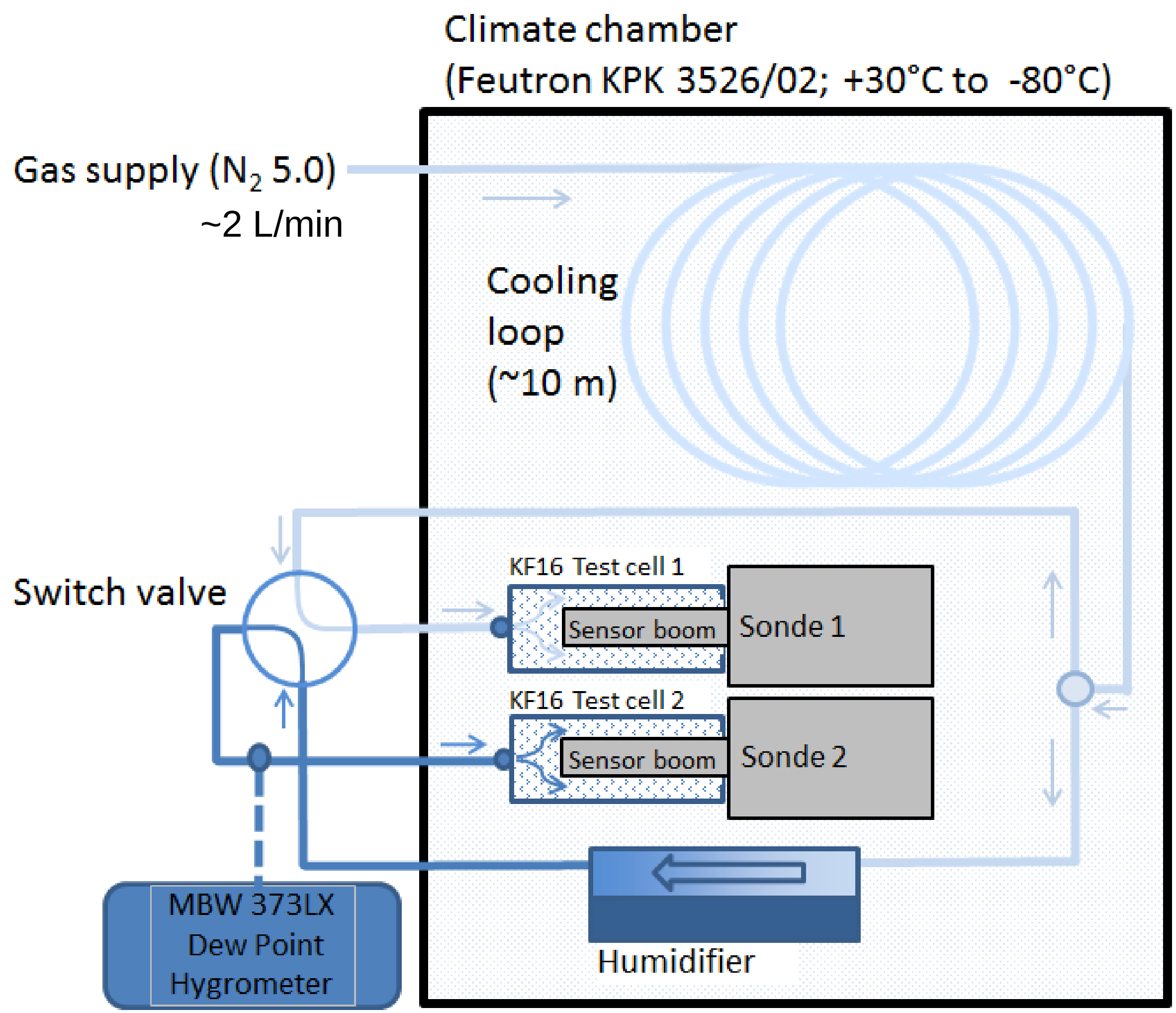
- Step-like humidity changes by quick switches from dry to humid air flow over sensor boom
- Efficiency of humidifier not controlled
- Selection of T-points during self-warming of chamber (-70 ºC … -10 ºC; T in chamber not stabilized after initial cooling phase)
- Valve outside chamber; switched by hand



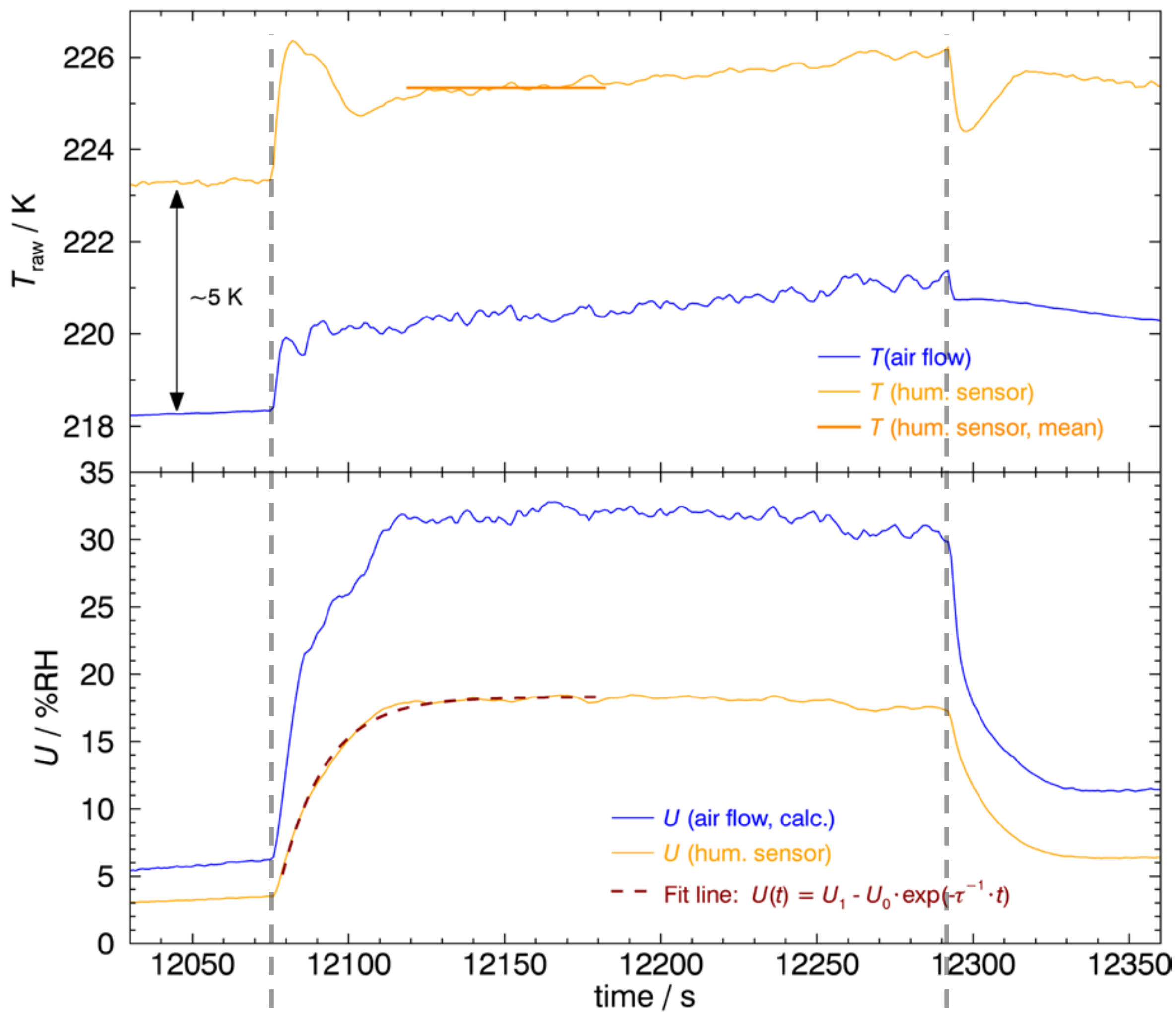
(II) RH Time lag RS41: Results

- U-sensor kept ~5 K above ambient air

→ τ derived for 'internal' U

→ τ related to 'internal' T (T of U-sensor)

- T at plateau taken as reference for U-response
- τ estimated from regression curve (fit parameter)



Valve switch

Valve switch

(II) RH Time lag RS41: Results

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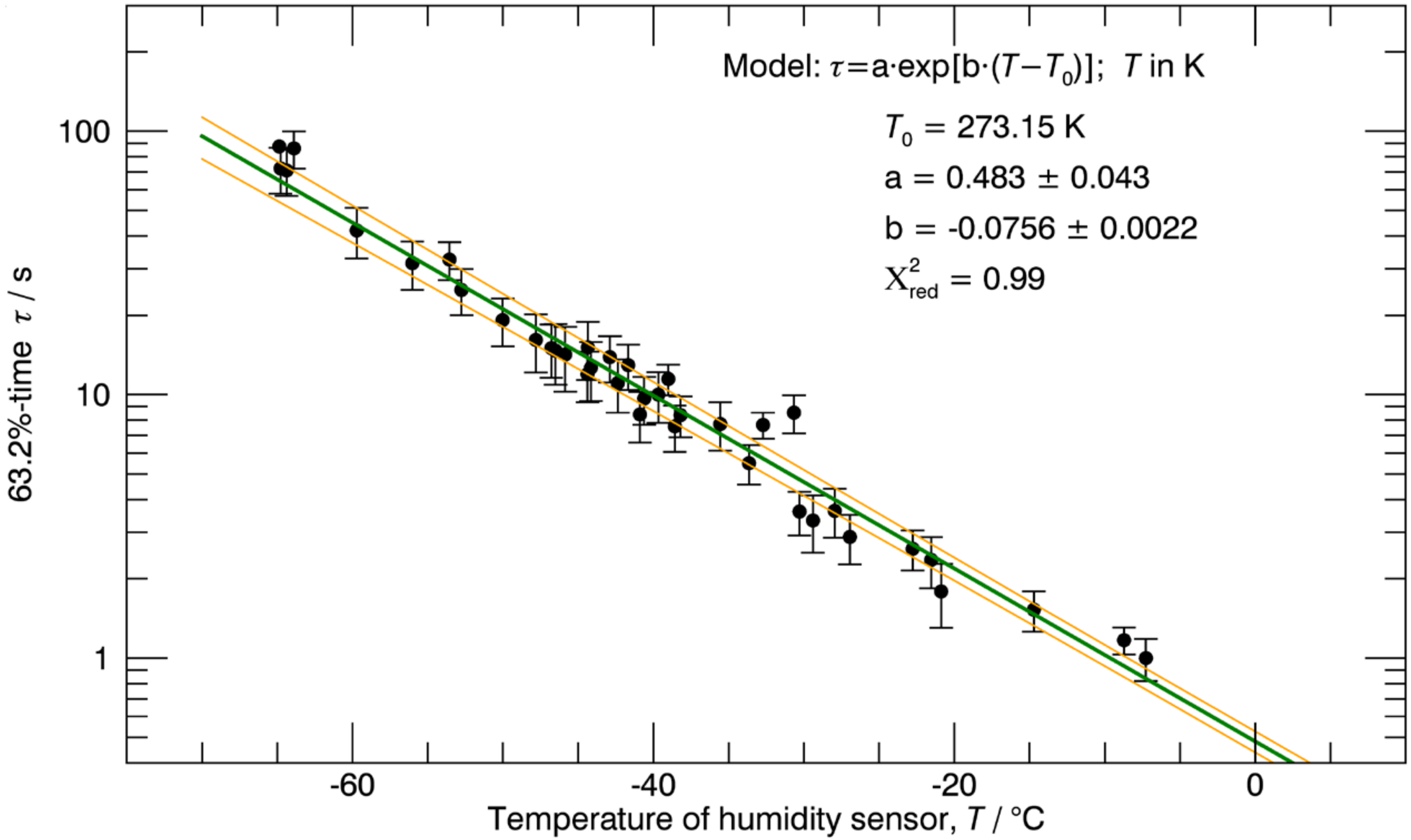
- Parameterization $\tau(T)$, T = temperature of humidity sensor



(II) RH Time lag RS41: Example (RS41-GDP-ALPHA.2)

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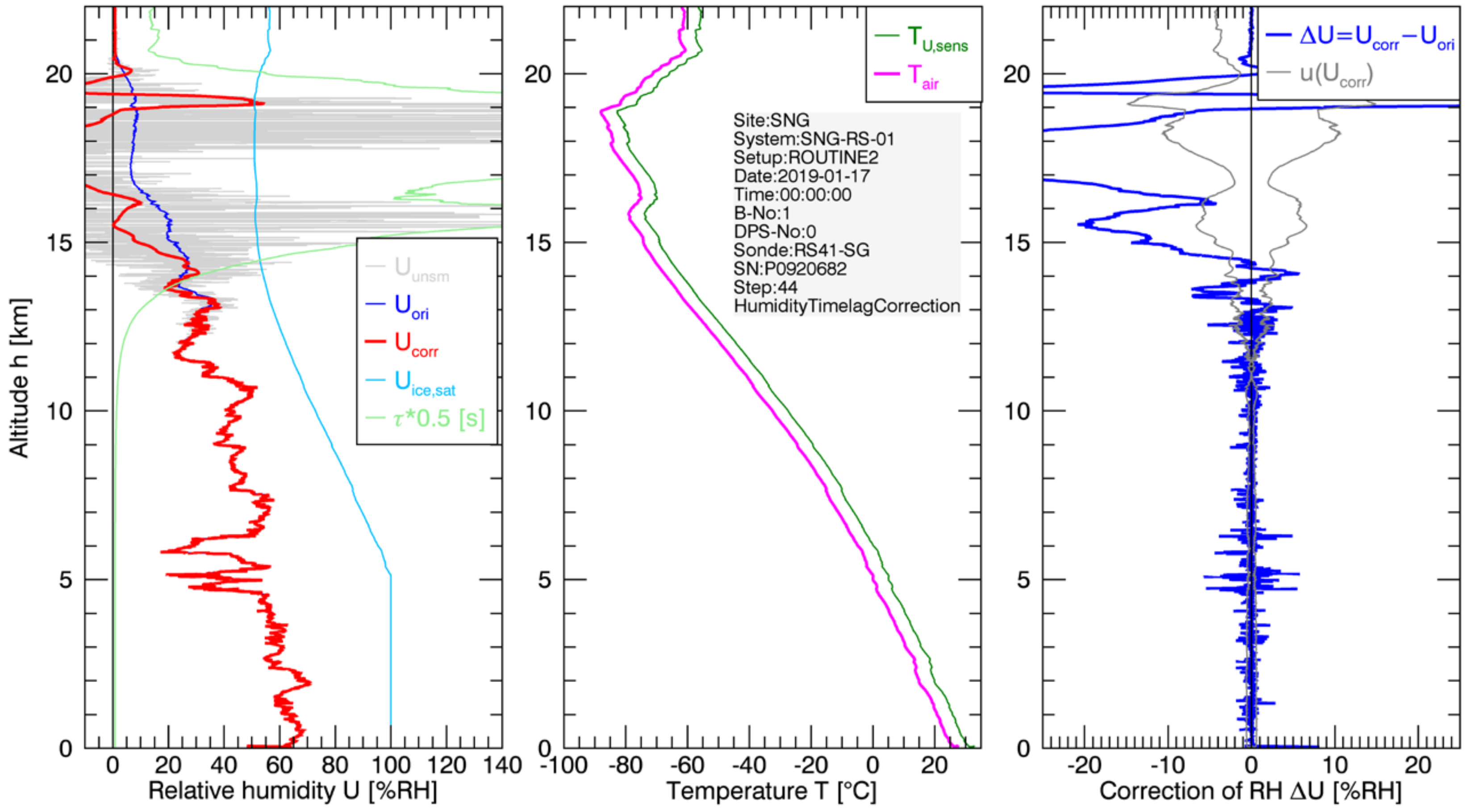
SNG, 2019-01-17, 00:00:00, 'internal' rel. humidity



(II) RH Time lag RS41: Example (RS41-GDP-BETA)

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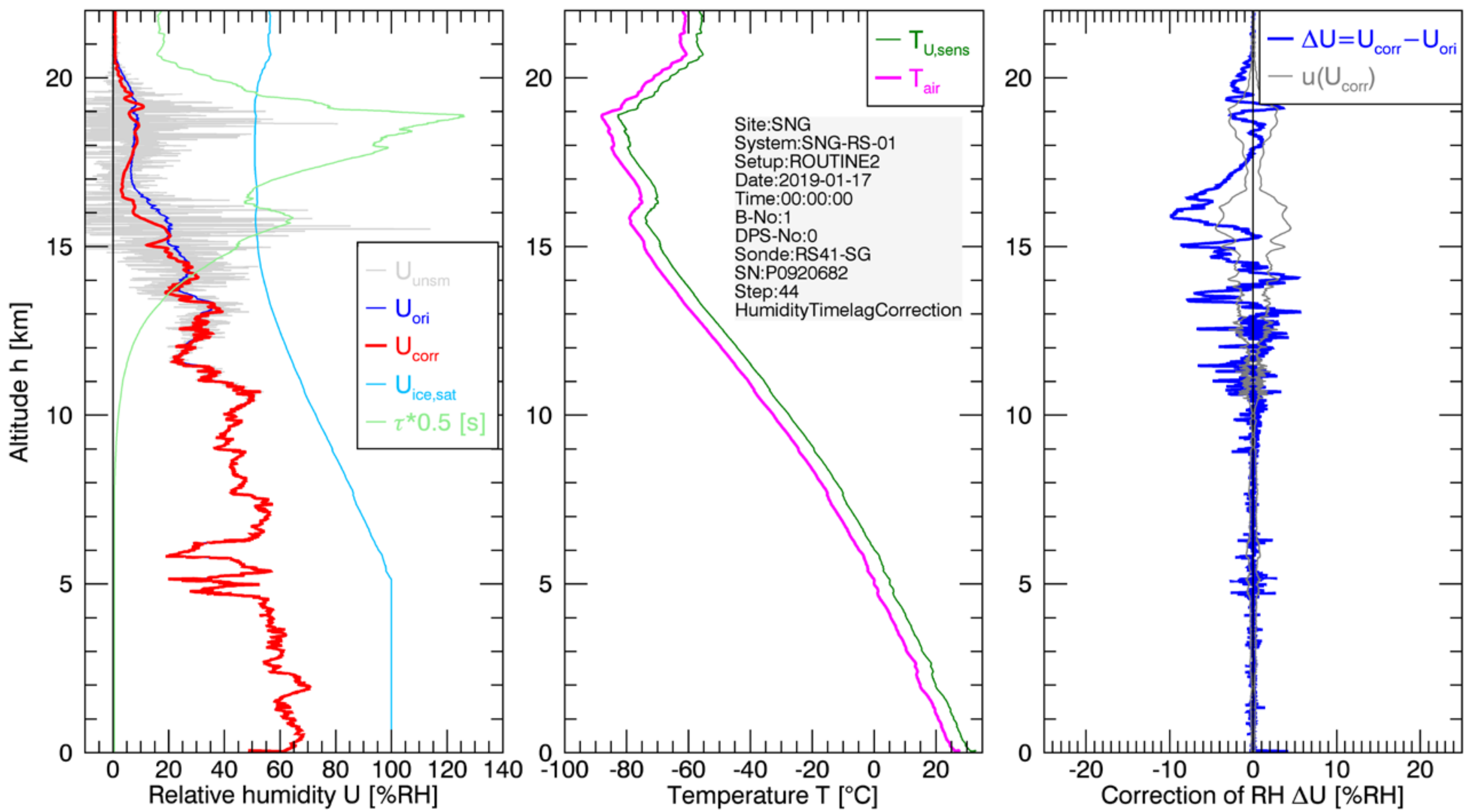
Wetter und Klima aus einer Hand

SNG, 2019-01-17, 00:00:00, ‘internal’ rel. humidity



Conclusions (II)

- Step response of RS41 humidity sensor measured at temperatures between 0 ºC and -70 ºC
- Re-analysis leads to more consistent time-lag correction for RS41
- Implementation in next version of RS41-GDP
- Measurements done at normal pressure:
  → transferrable to lower p of atmospheric profile?

Thank you.

Supplementary

(I) Radiation correction
New experimental setup: First results

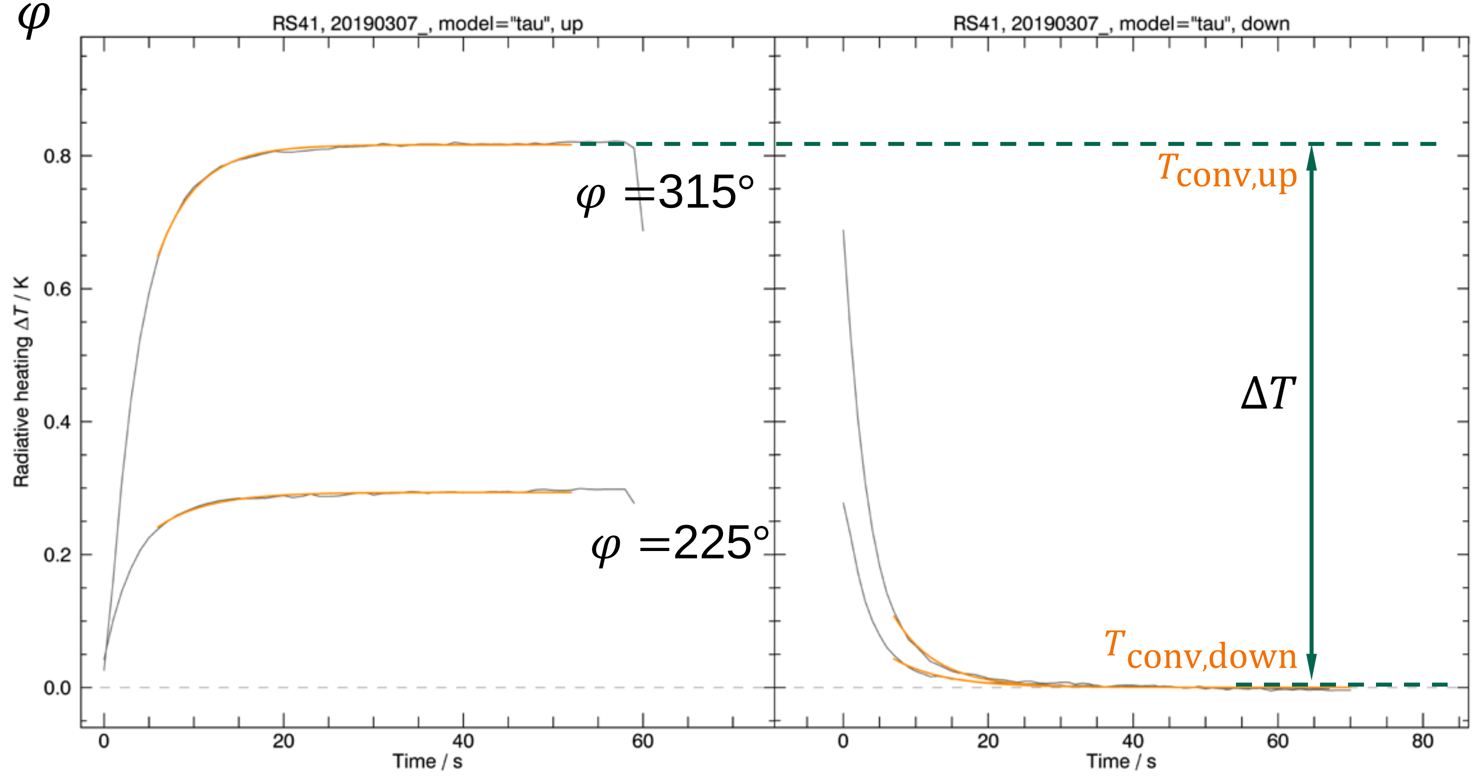
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- ‚Static' measurements:
  - No continuous sonde rotation
  - fixed 'azimuth' angles φ
  - thermal equilibrium

Fit function ('up' and 'down'):

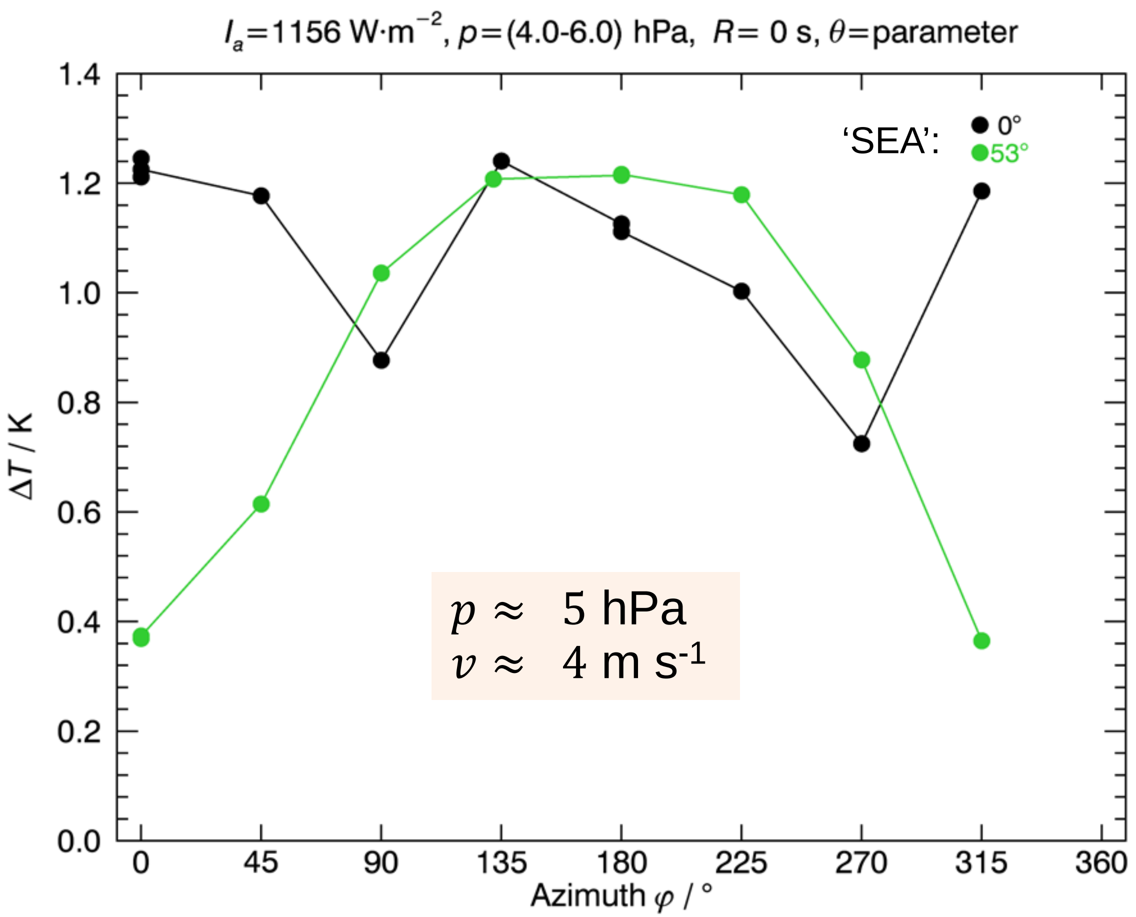
$\Delta T = T_{\mathrm{conv}} + c \cdot \exp\left(\frac{t}{\tau}\right)$

p =10 hPa, v =4.3 m·s^{-1}, θ =53°



(I) Radiation correction
New experimental setup: First results

- ‚Static' measurements:
  - No continuous sonde rotation
  - fixed 'azimuth' angles φ
  - thermal equilibrium

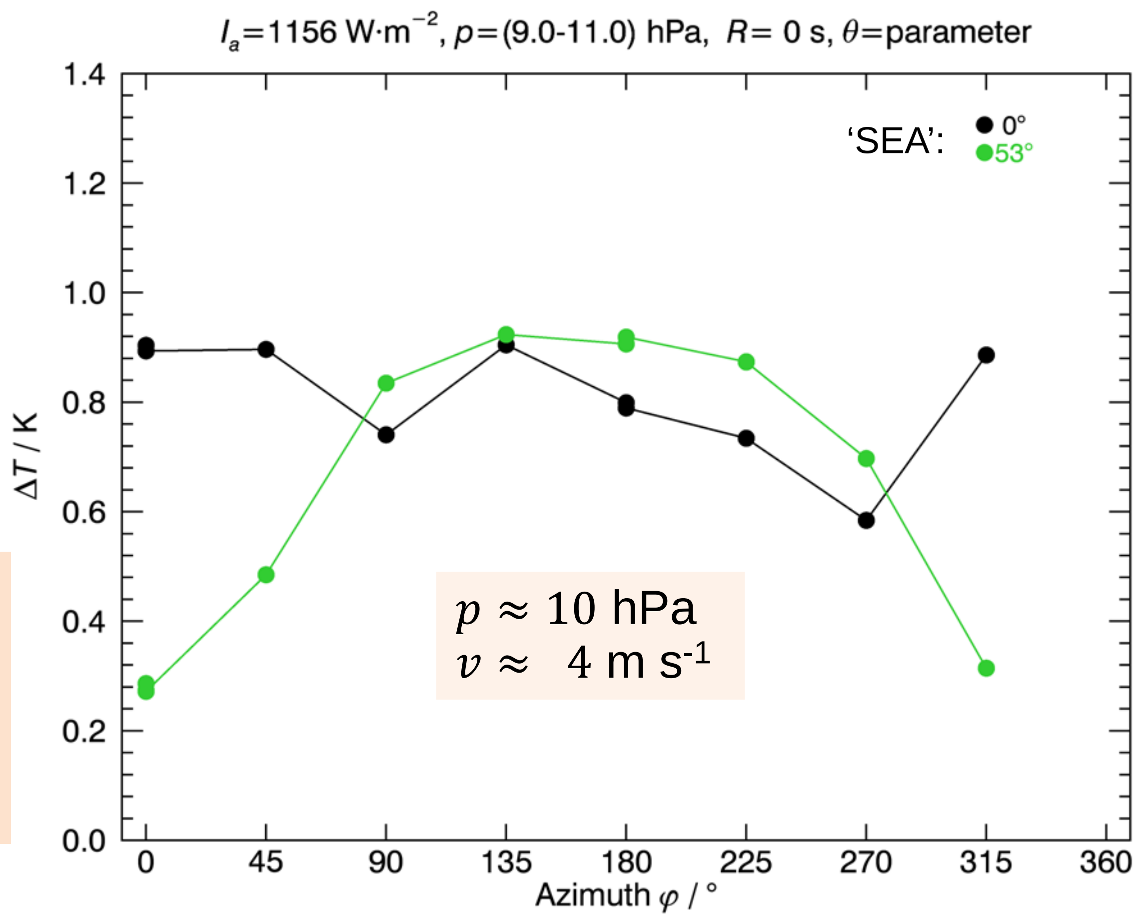


New experimental setup: First results

- ‚Static‘ measurements:
  - No continuous sonde rotation
  - fixed 'azimuth' angles φ
  - thermal equilibrium

→ Direction of incident radiation determines ΔT

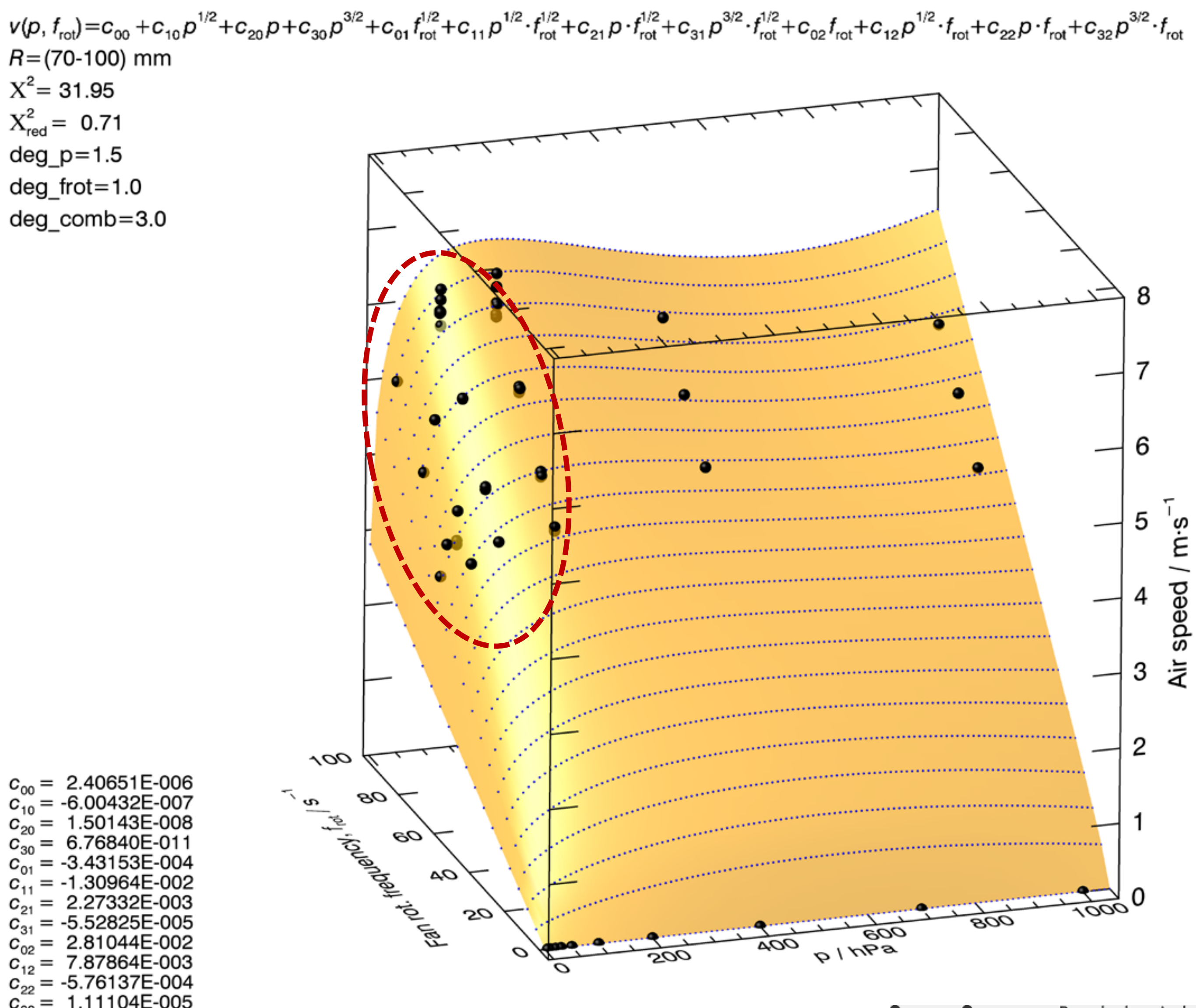
→ Considerable proportion of ΔT from sensor boom



(I) Radiation correction
Setup: Ventilation

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- Air speed measured as cross-sectional profiles using Laser-Doppler-Anemometry (LDA)
- Derivation of expression for $v(p, f_{rot})$ for central axis of quartz cylinder at position in front of sensor boom (cylinder symmetry assumed)



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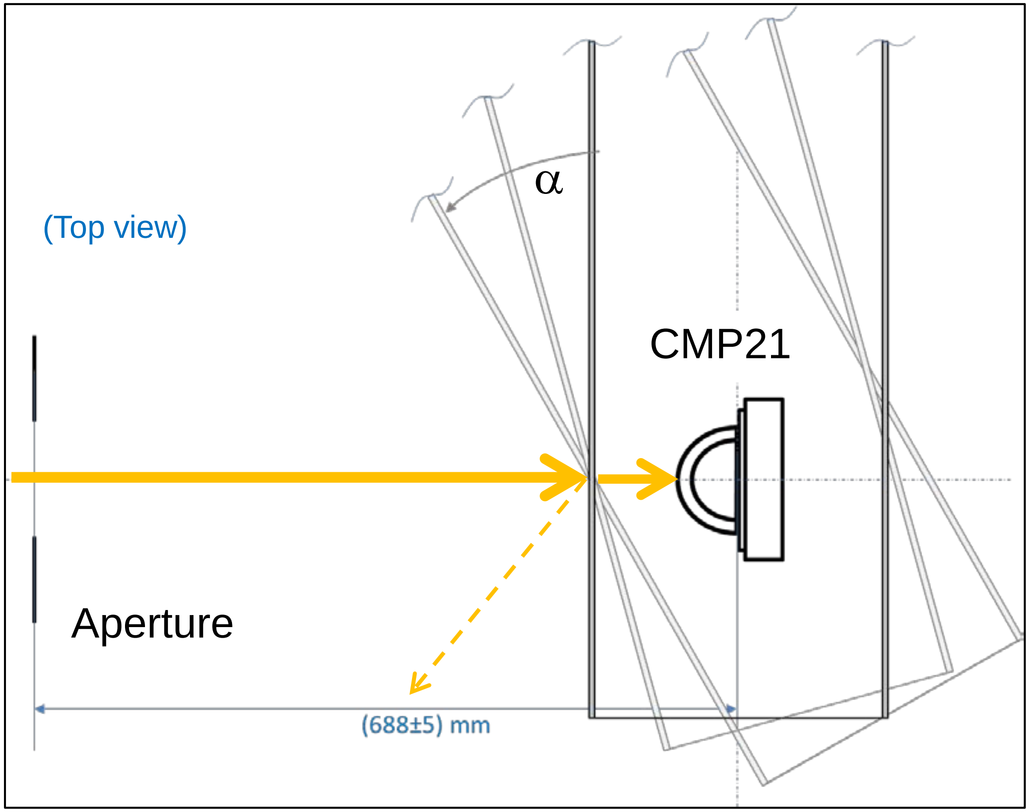
(I) Radiation correction
Setup: Transmission Quartz Cylinder

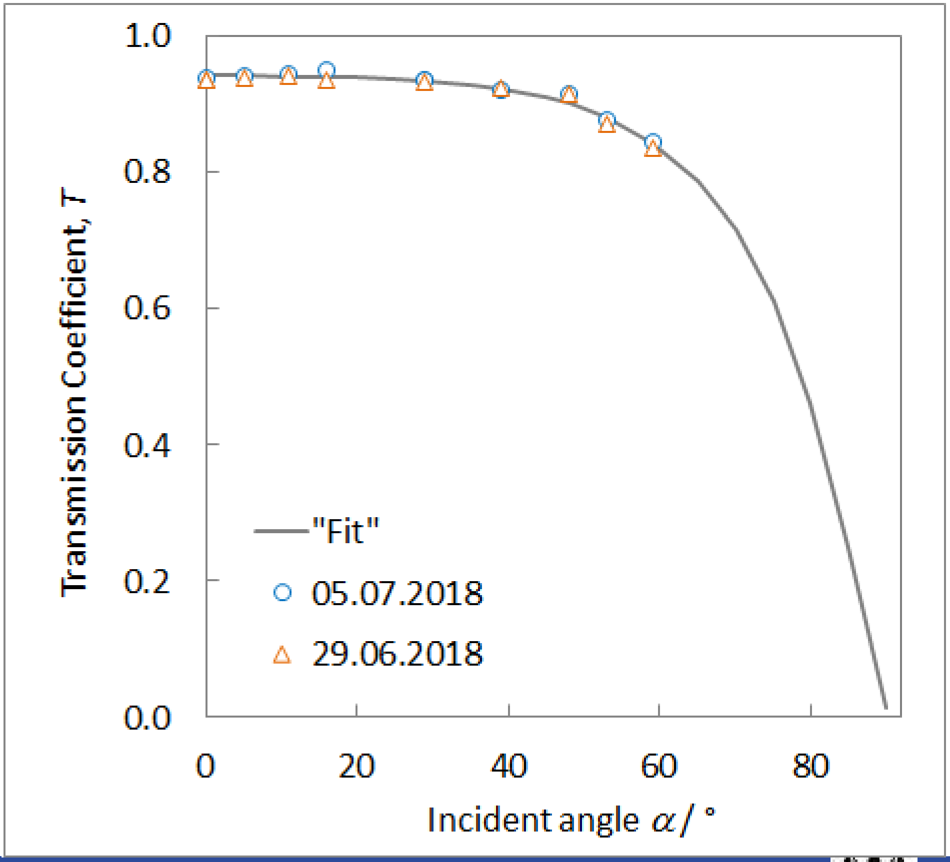
- Effective light transmission T measured by comparing irradiance inside and outside cylinder at different ‚sun elevation' angles



- Empirical fit to data, based on Fresnel formula:

$$T = c_0 \cdot \frac{\tan(c_1 \cdot \alpha)}{\tan(c_3 \cdot \beta)} \cdot \left[\frac{2\cos(c_2 \cdot \alpha)}{n_2 \cos(c_2 \cdot \alpha) + \cos(c_3 \cdot \beta)}\right]^2$$

with $\beta = \sin^{-1}\left(\frac{\sin(c_1 \cdot \alpha)}{n_2}\right)$



(I) Radiation correction
New experimental setup: First results

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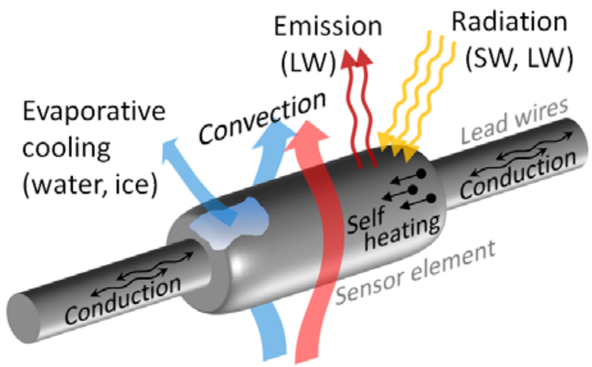
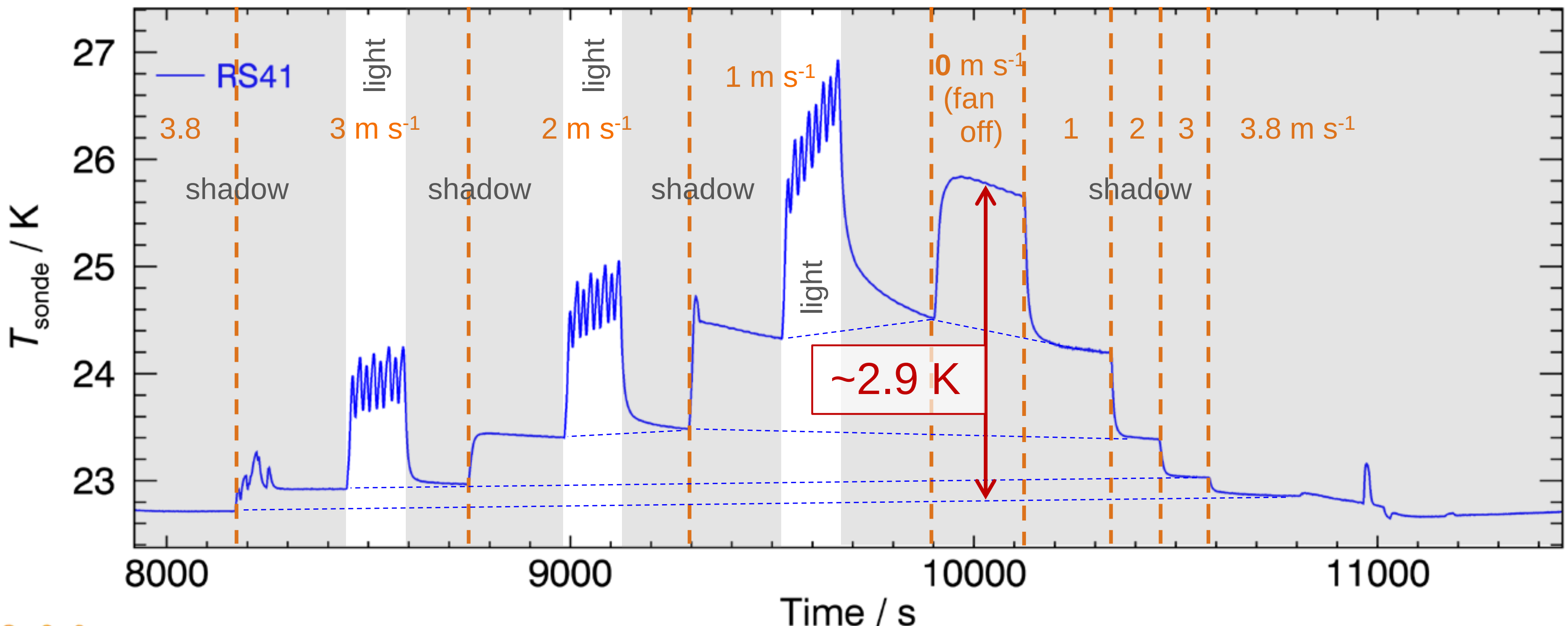
- ‚Contamination' from permanently heated (~5 K) humidity sensor

→ T sensitive to v at low ventilation (<4 m s^{-1})

… Extra investigation/correction needed, independent of radiative heating?



p = 6 hPa, SEA = 53º, I_a= 1156 W·m², v variable



(II) RH Time lag RS41:
Example (RS41-GDP-ALPHA.3)

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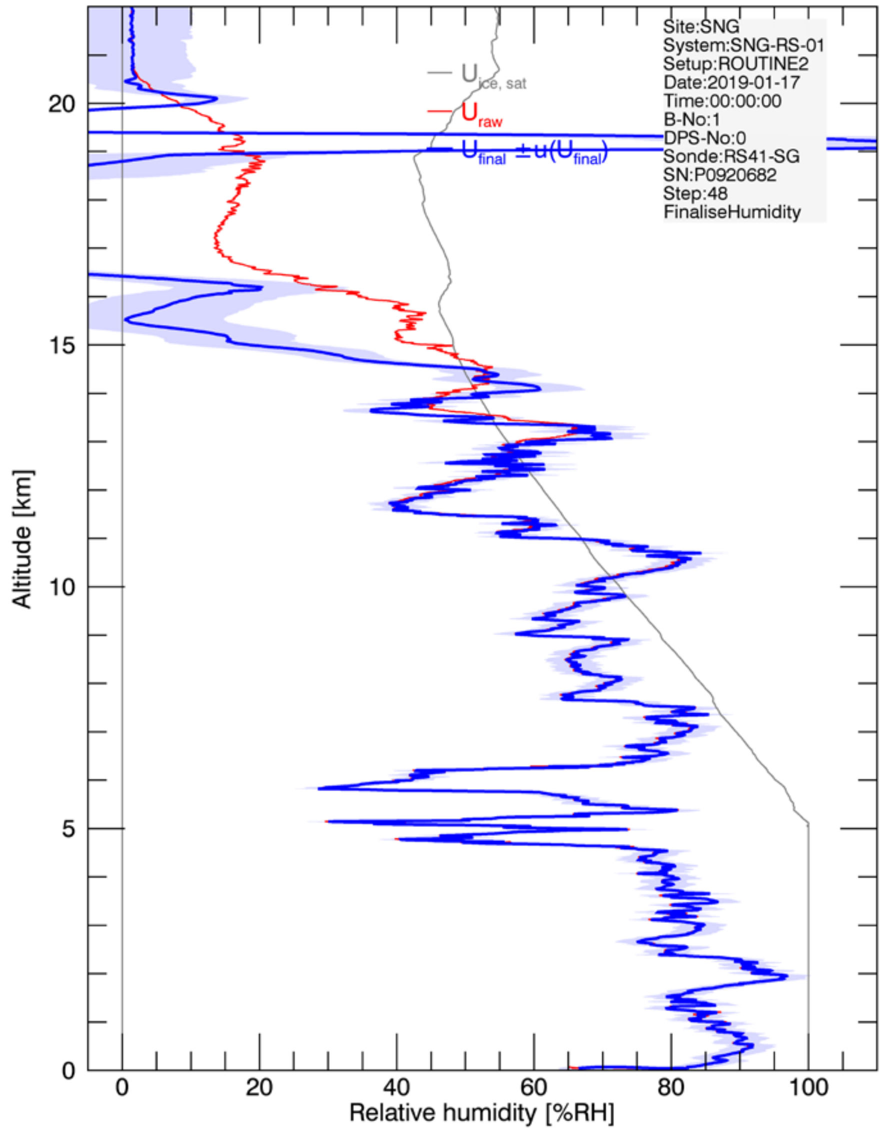
Wetter und Klima aus einer Hand

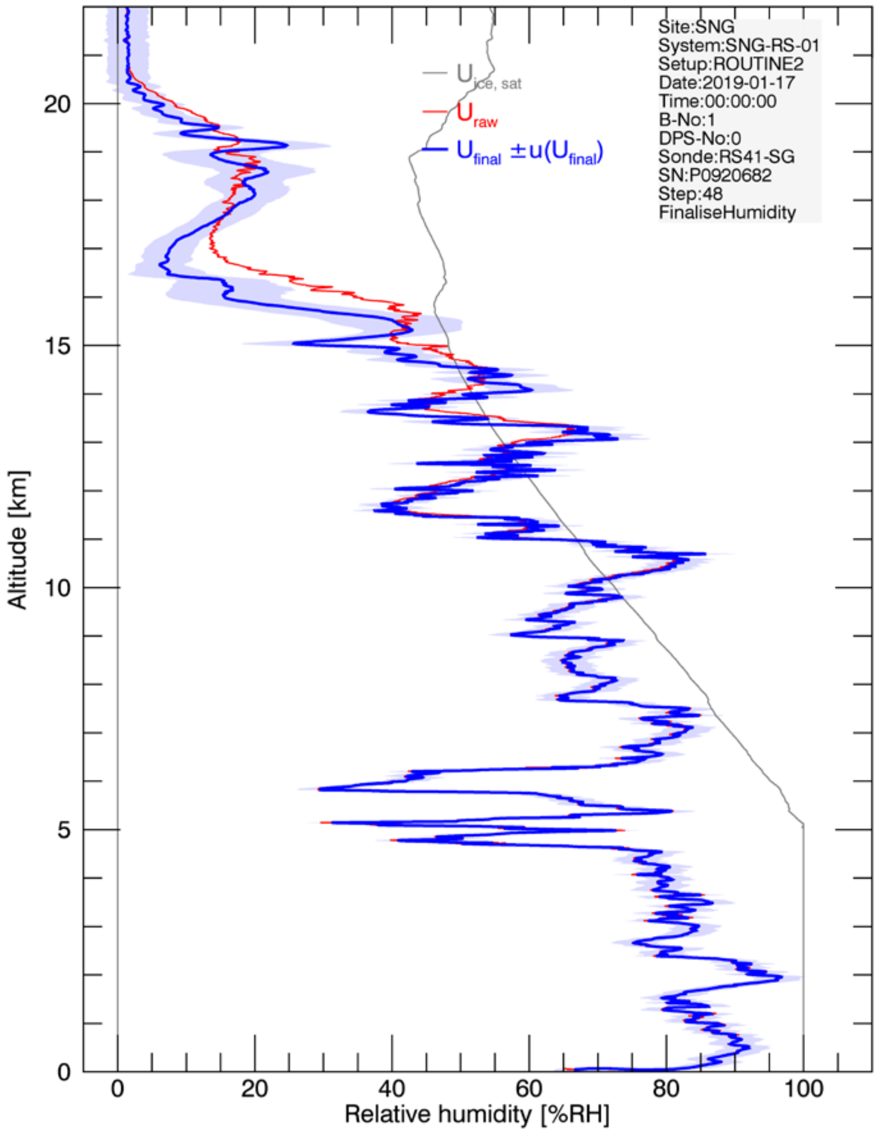
SNG, 2019-01-17, 00:00:00, Rel. Humidity (after conversion to air temperature



(II) RH Time lag RS41:
Example (RS41 GDP v. ALPHA.3)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

SNG, 2019-01-17, 00:00:00, Rel. humidity



(II) RH Time lag RS41: Results

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- U-sensor kept ~5 K above ambient air

→ τ derived for 'internal' U

→ τ related to 'internal' T (T of U-sensor)

- U-steps accompanied by (undesired) T-steps