Progress with response time measurements of radiosonde humidity sensors

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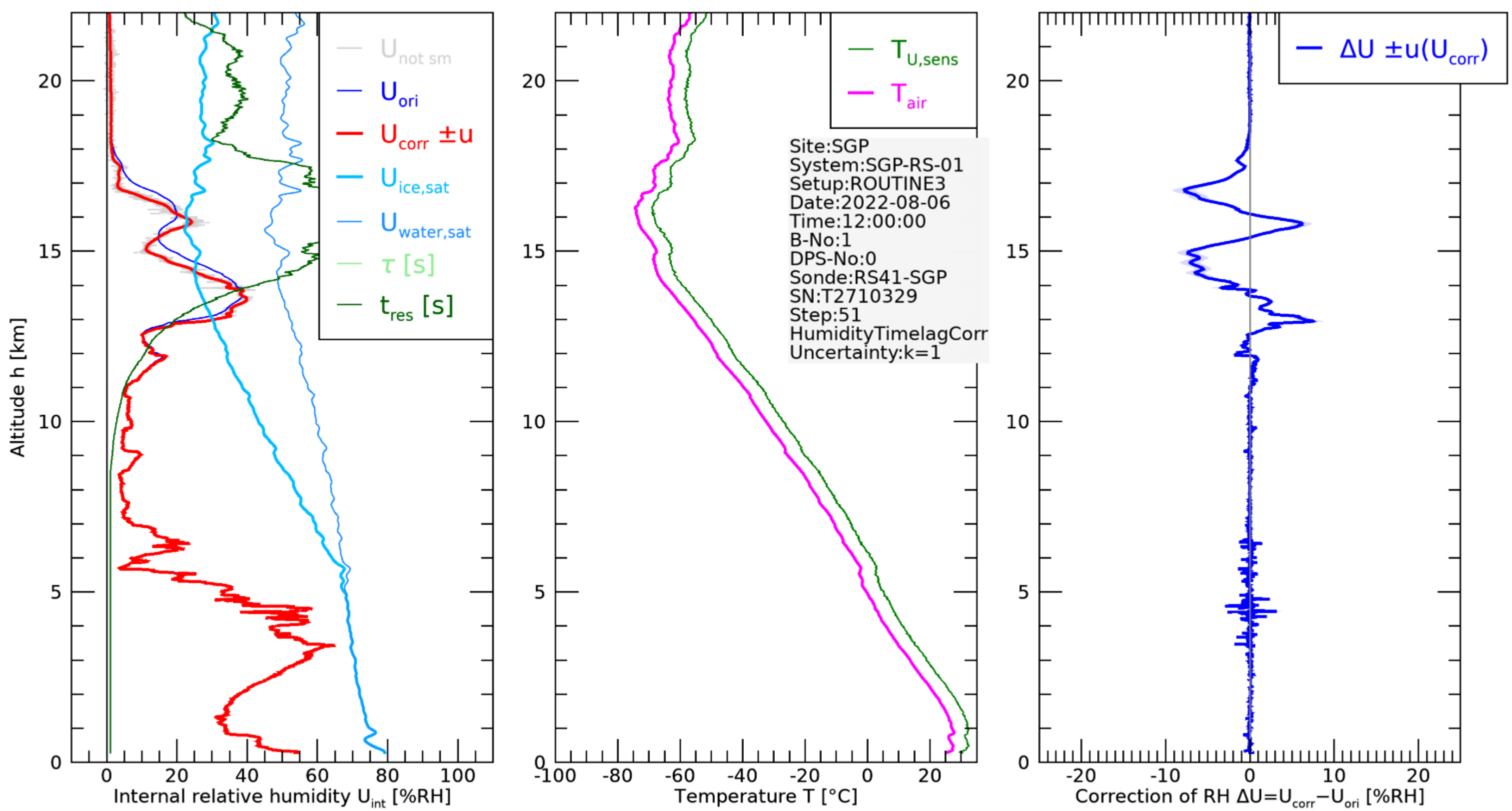
Motivation/Approach

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- Slow response time τ of humidity sensors causes smoothing and time lag of measured RH profile at low T
- T–dependence of diffusion of water vapor in pore space of sensor material and rate of adsorption/desorption processes
- Effect may produce significant RH biases



Motivation/Approach

- **Approach:**
  - Measure response at various T in laboratory setup:

    - Expose sensor to step-like changes of rel. humidity U

    - Evaluate response times τ (63.2%-times) assuming the sensor follows theoretical step response: $U(t) = U_\infty - \Delta U \cdot \exp\left(-\frac{(t-t_0)}{\tau}\right)$
  - Parameterise response time τ with T
  - Apply RH correction ('invert' the sensors filter effect) using $\tau(T)$ parameterisation

Assumptions/preconditions

- Sensor response can be fully described using **single parameter $\boldsymbol{\tau}$** (sensor follows theoretical step response function)
- Use of **RH raw data** (pure sensor signal, no corrections applied)
- RS **sampling rate** in general **1 s** → **lower limit** for measurement of $\boldsymbol{\tau}$
- $\boldsymbol{\tau}$ measured at surface pressure, but **representative** over **atmospheric $\boldsymbol{p}$-range**
- $\boldsymbol{\tau}$ is **calibration invariant** (*relative* RH changes at constant T)
- $\boldsymbol{\tau}$ should **not vary with RH step size**

Improved setup (2021/22)

Key setup specifications:

- T-range: −75 °C … +20 °C, atmospheric pressure
- Air exchange time in test cells $\approx$0.5 s (lower limit for τ)
- Two chambers: simultaneous tests of two RS

Recent improvements (2021/22):

- Pre-defined T-levels
- High T-stability during RH steps (<0.4 K)
- Enhanced efficiency of humidifier (large RH step size)
- Creation/evaluation of both directions of RH steps

Improved setup (2021/22)

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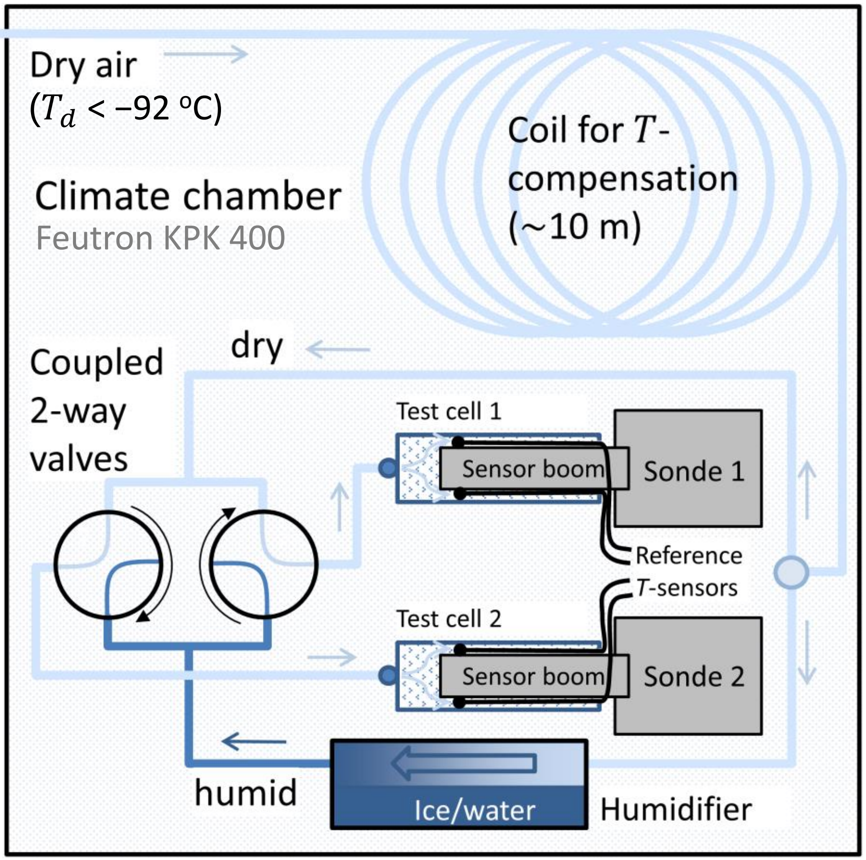

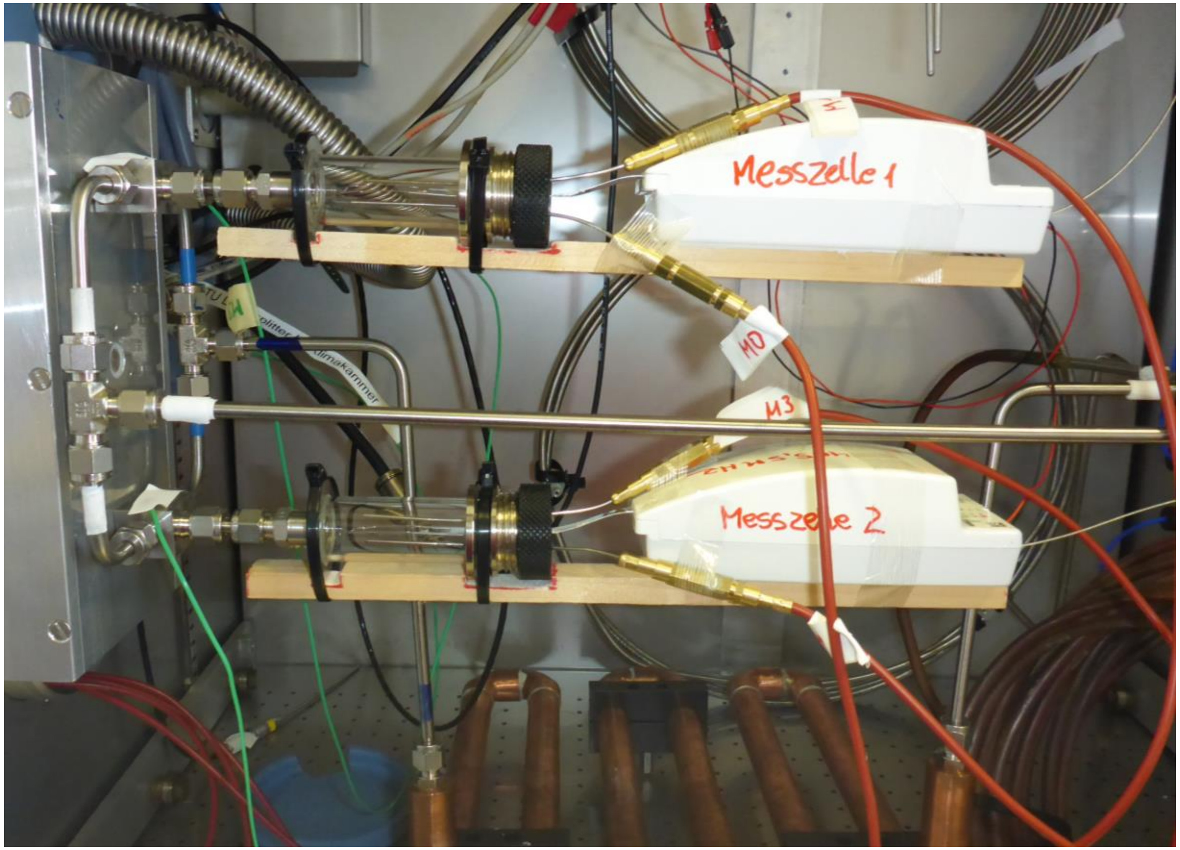

- Preparation time (installation of the RS and reference T-sensors in the test cells): ~1 h

Measurements

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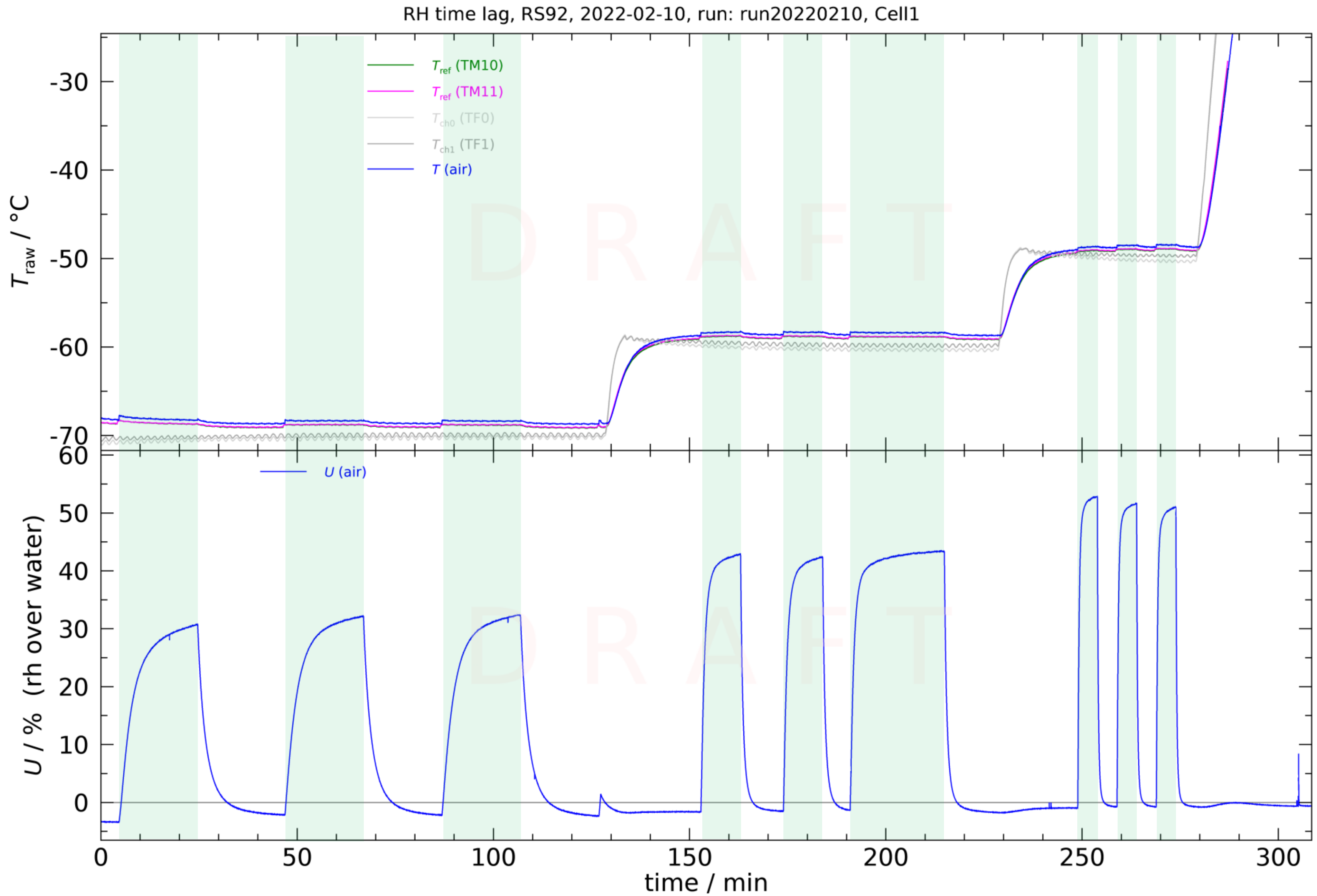
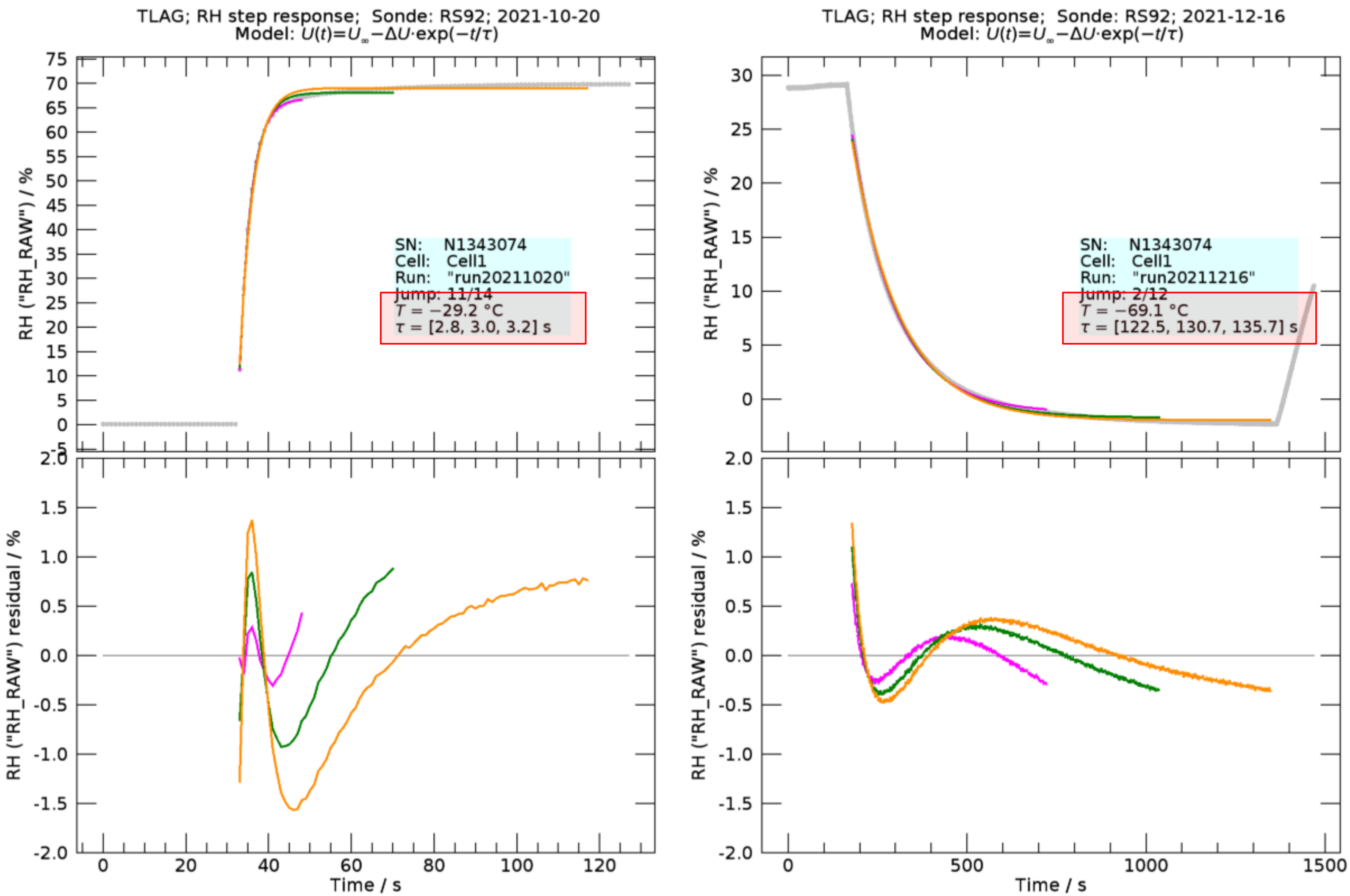


Measurements / Determination of τ

- Sequence of **2 to 4 RH steps** at each T-level (Repeatability)
- Simultaneous measurements **in two identical test chambers**; Repitition of measurement series with further copies of the sonde model (Reproducibility)
- Determination of τ by **fitting** theor. step **response curve** to sections of the data records; both directions (next slides)
- Fitting applied several times at each step, including data sections of varying lengths → assess τ-uncertainty (mean τ + SD) (next slides)

Determination of τ

Evaluation of response times τ



Results (RS92)

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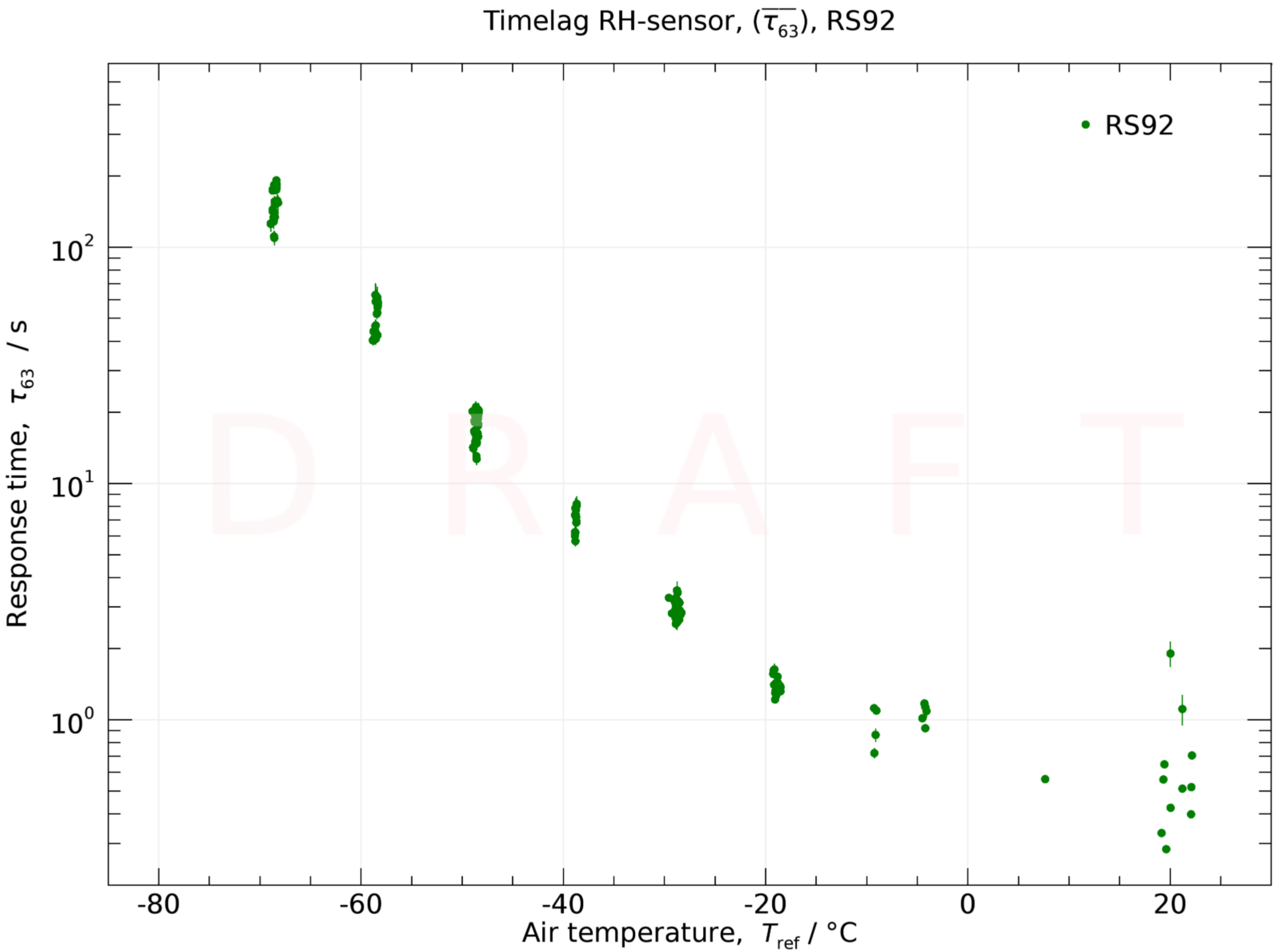

- Consistent overall picture

Results (RS92, RS41)

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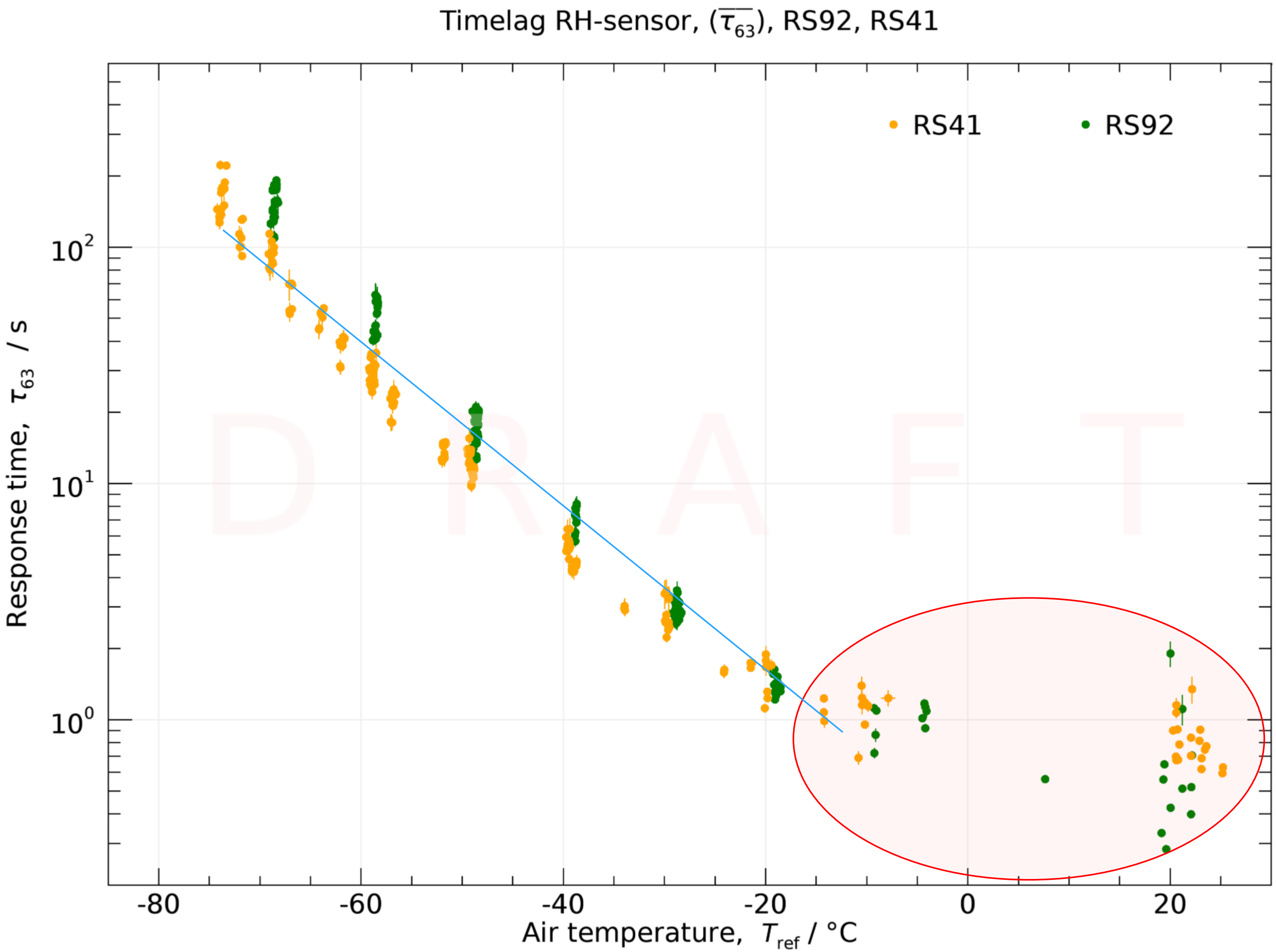

- Consistent overall picture
- Results reliable for τ>1s (T<−15 °C):
  - 1 s sampling rate
  - ≈0.5 s step duration
- Parameteris. $\tau(T)$: deviates from simple exponential relation (next slide)

Note: τ_{RS41} plotted vs. T_{air} (not T_{sensor})

Results (RS92, RS41)

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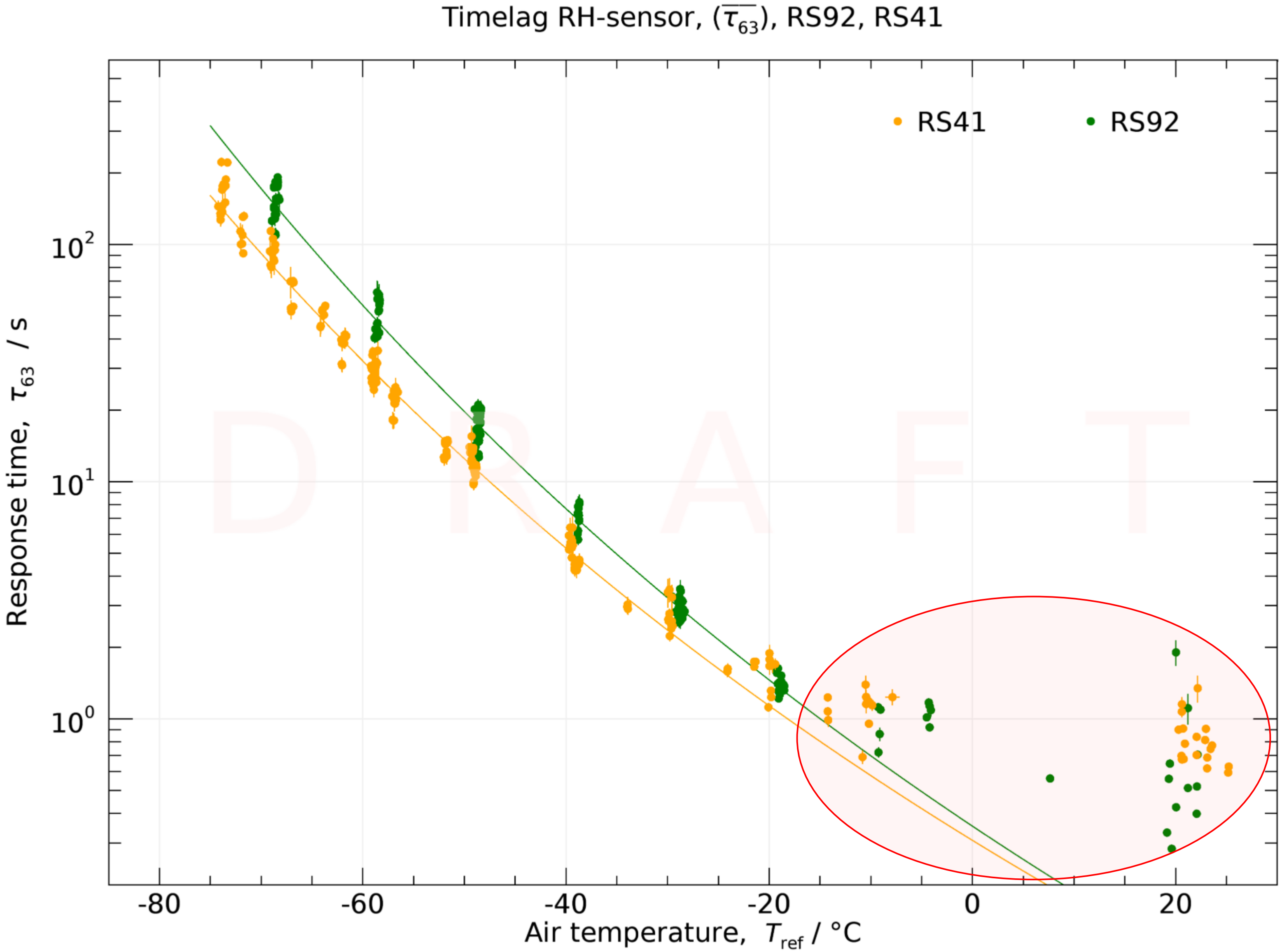
Wetter und Klima aus einer Hand



- Consistent overall picture
- Results reliable for τ>1s (T<−15 °C):
  - 1 s sampling rate
  - ≈0.5 s step duration
- Parameteris. $\tau(T)$:

E.g. Arrhenius-curve:

$$\tau(T) = \tau_0 e^{-\left(\frac{E_a}{R(T_0+T)}\right)}$$

Results (RS92, RS41)

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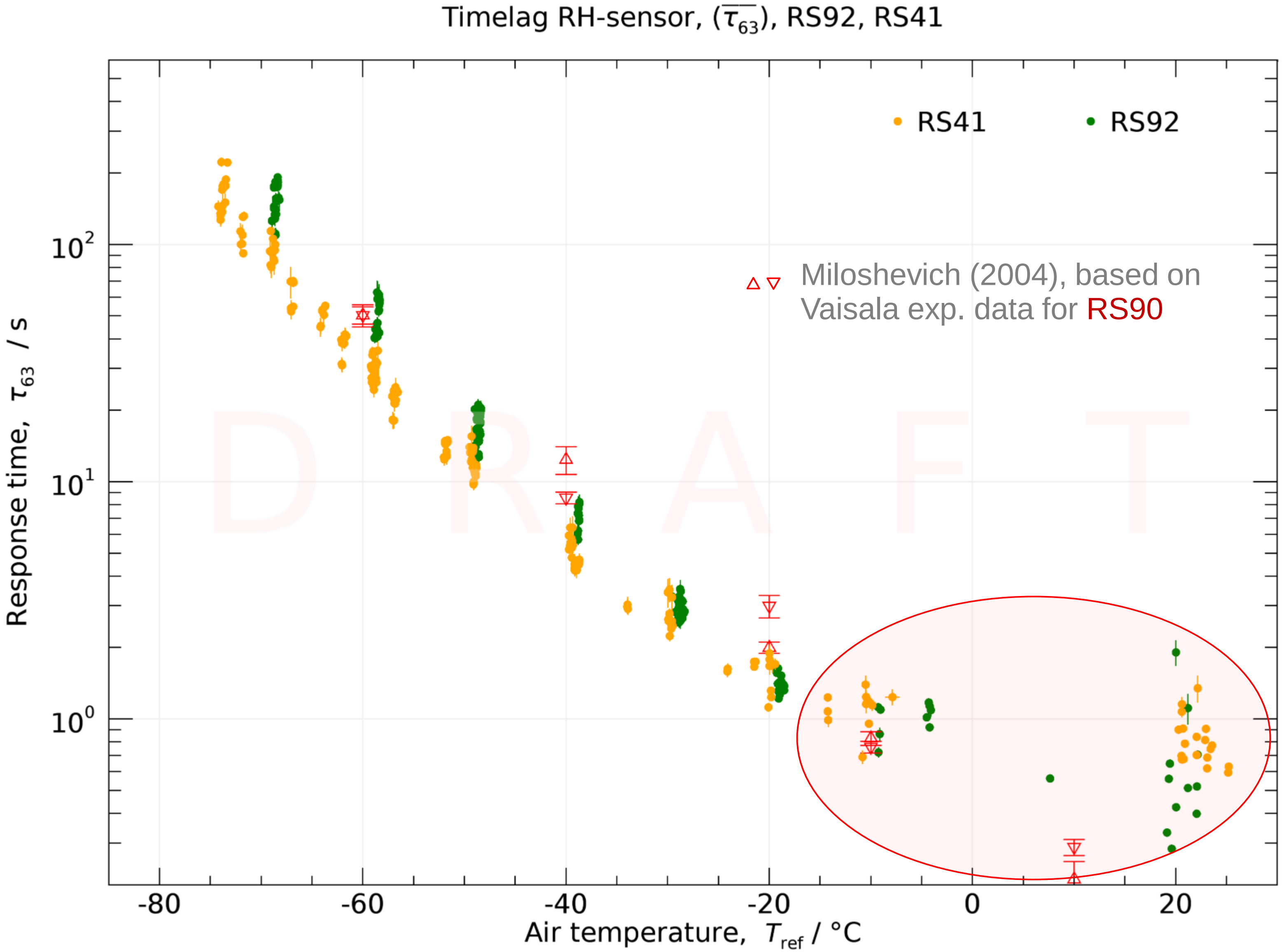

- Comparison with previous data (RS92)

Results (RS92, RS41)

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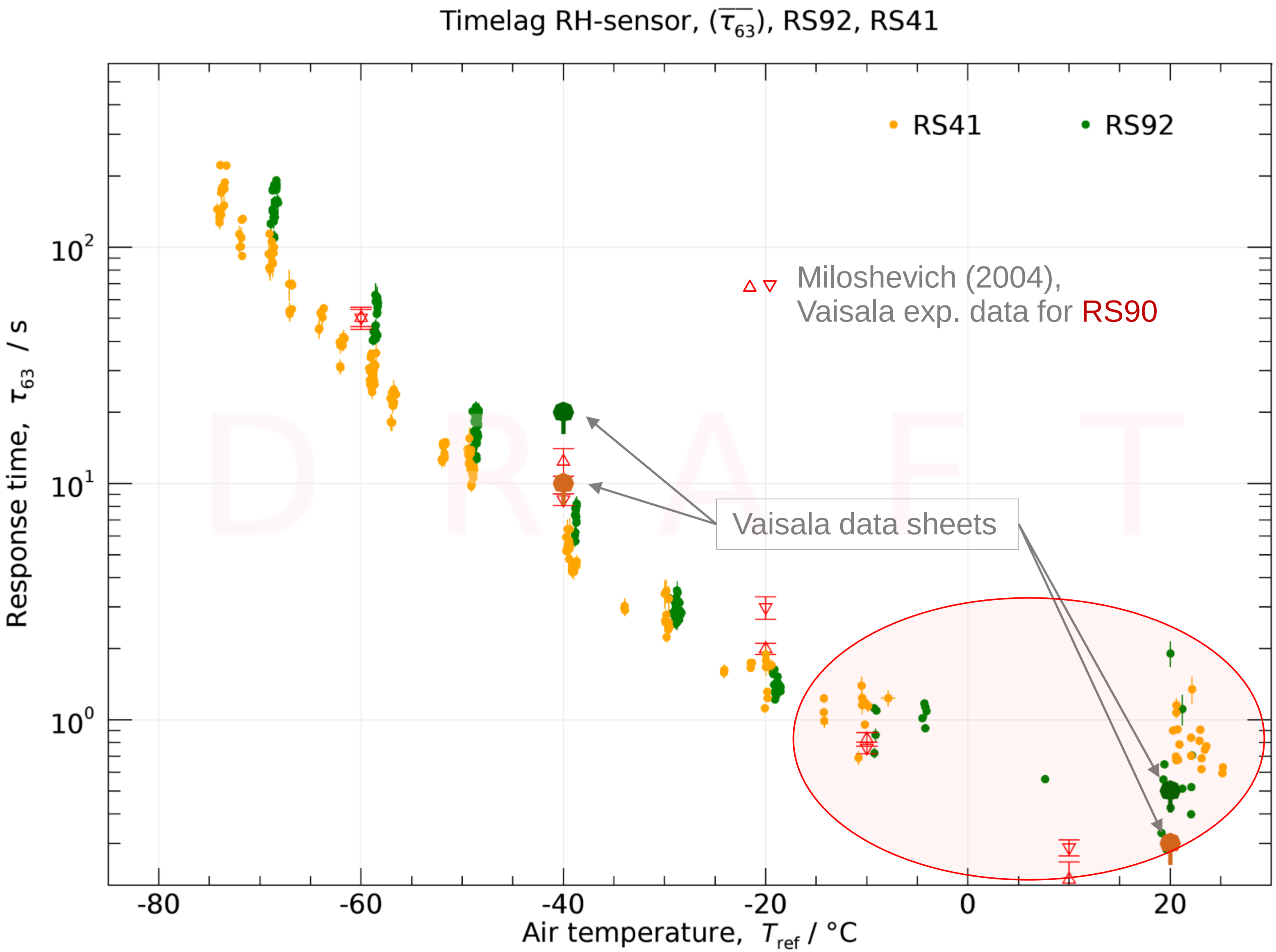
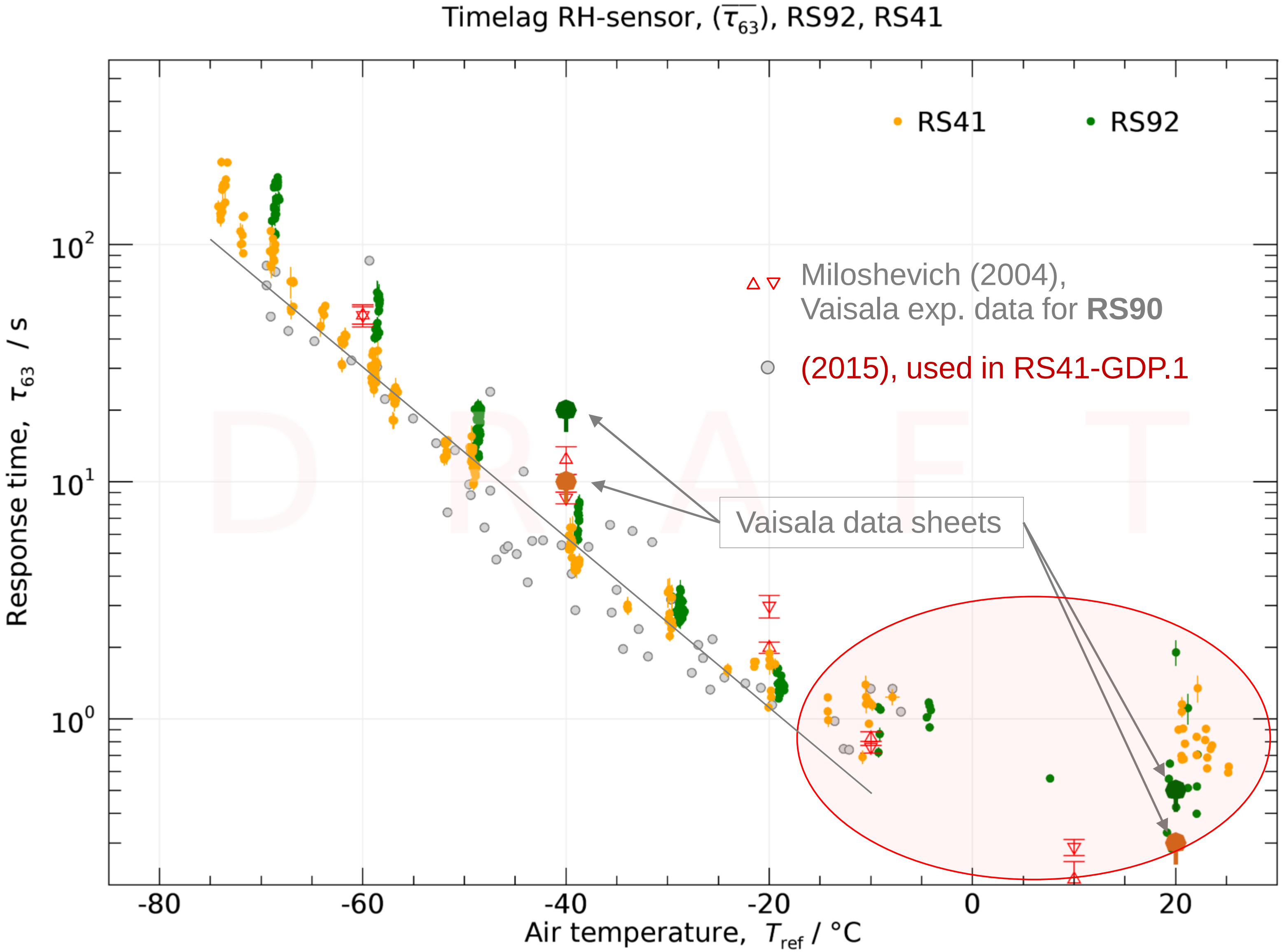


- Comparison with previous data

Results (RS92, RS41)



- Comparison with previous data

Issues now solved:

- No constant T-levels)
- T not stable at RH steps (several K)
- Small RH step size (low efficiency of humidifier)
- No humid-to-dry steps evaluated (contamination issues)
- Large scatter

Results (RS92, RS41), up/down steps

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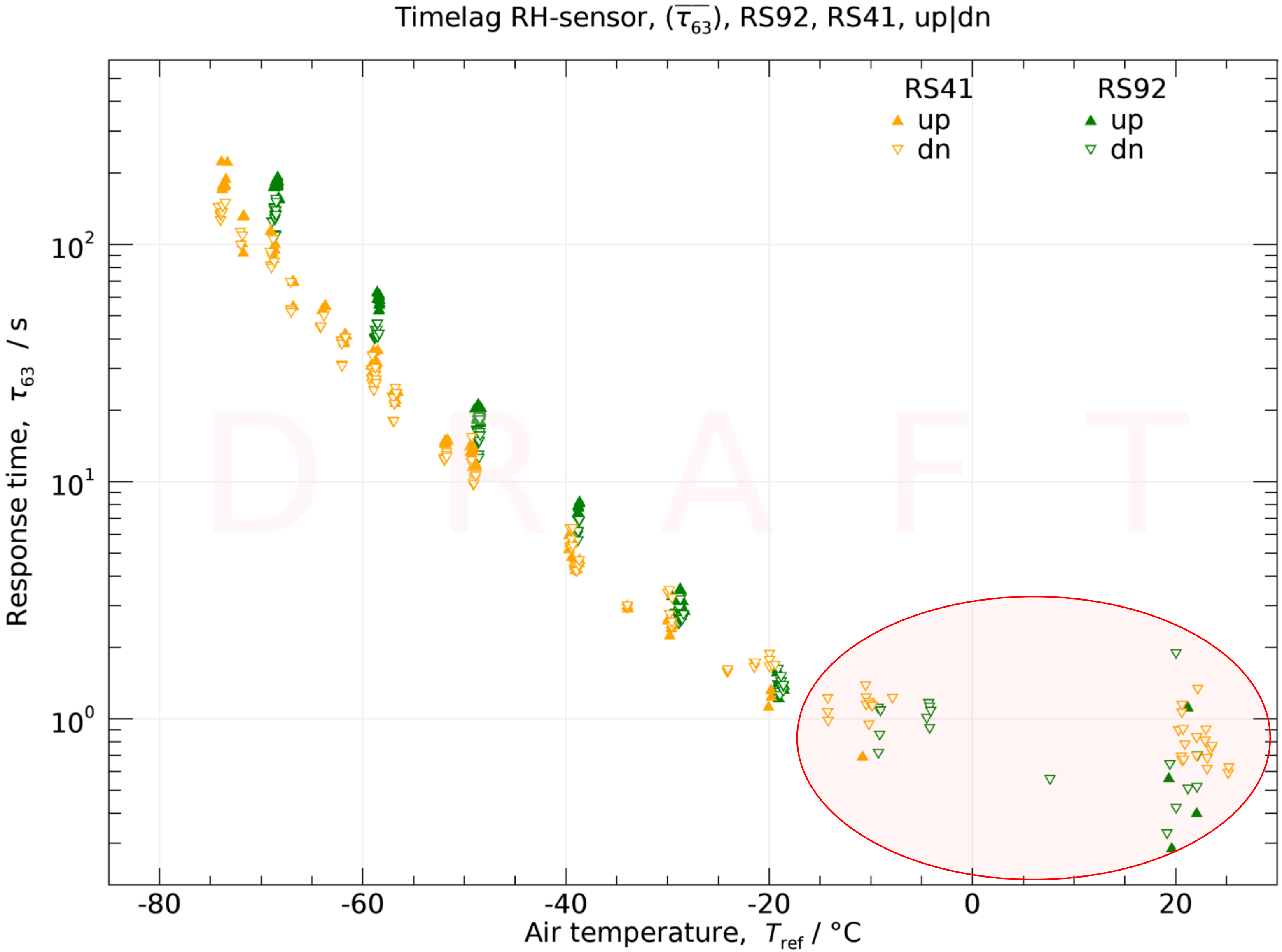


- Seperate eval. for up/dn step direction:

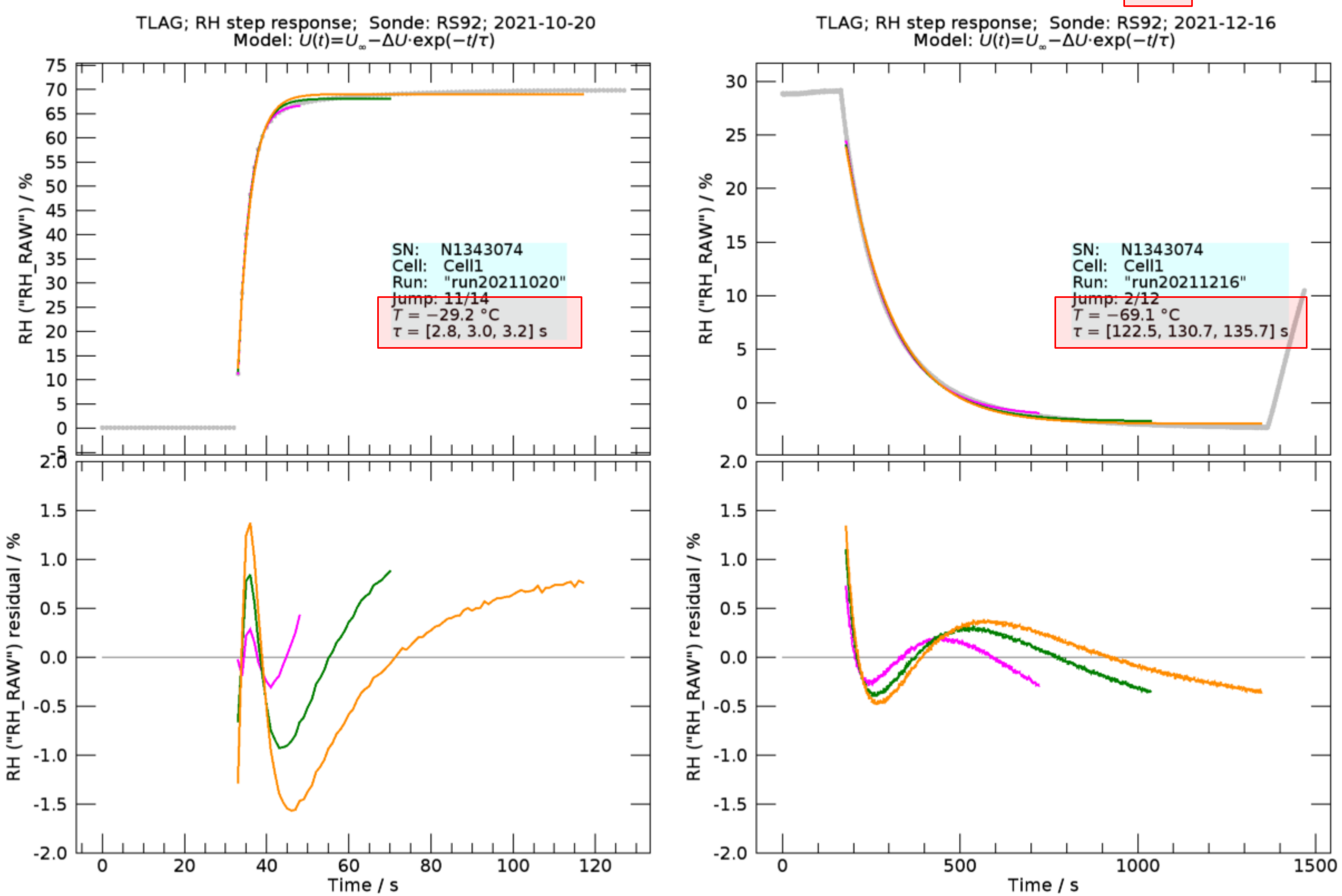
  RS92: Systematic τ-offset at $T < -30$ °C, 'up' $\sim 1.5 \times$ *slower* than 'down'

  RS41: less clear

- → Hysteresis?

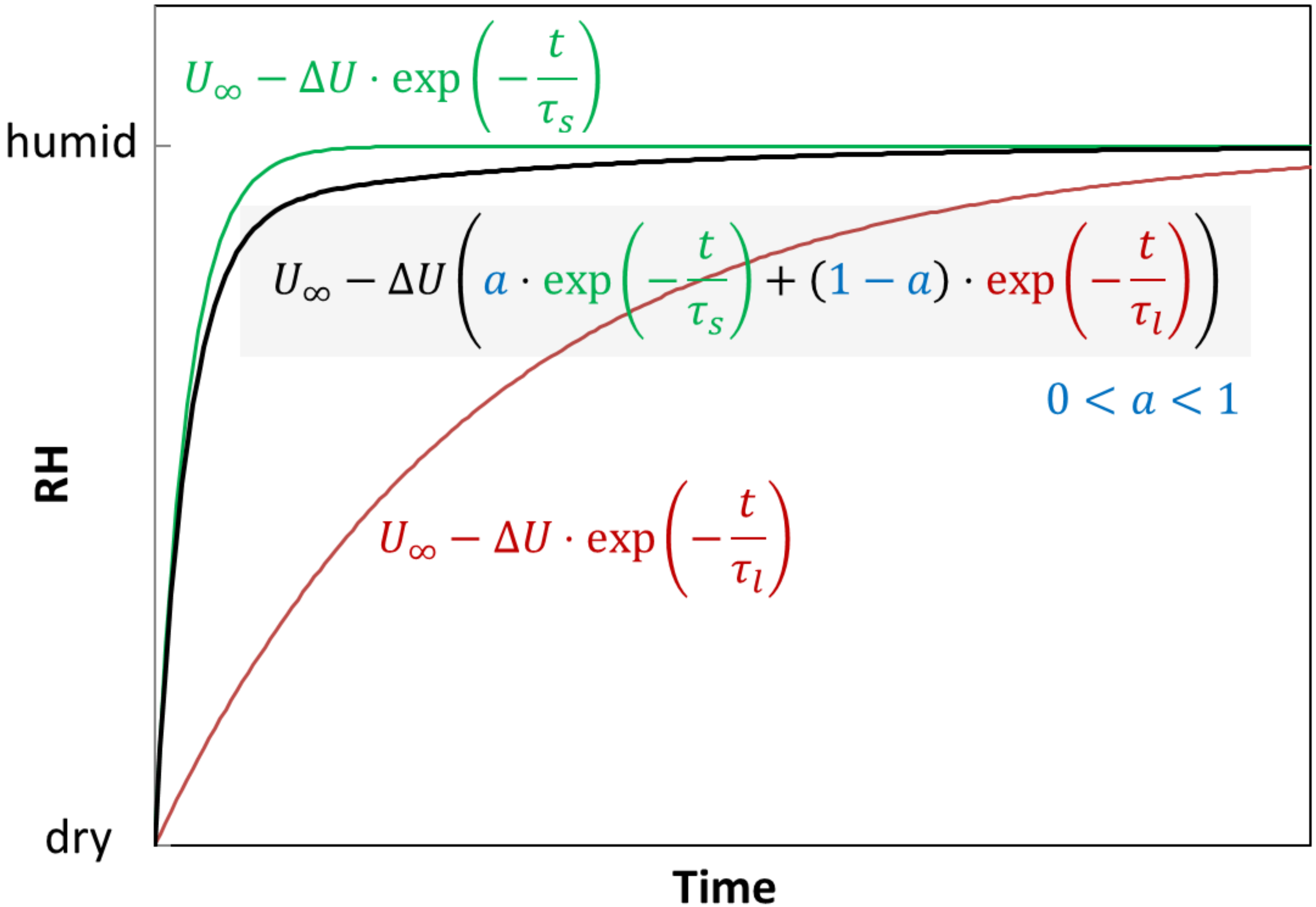
Data analysis, closer look

Evaluation of response times τ: Fit $U(t) = U_\infty - \Delta U \cdot \exp\left(-\frac{(t-t_0)}{\boxed{\tau}}\right)$



Evaluation of response times:

Assume that sensor response can be described as **superposition of a 'short-term'** (τ_s) **and 'long-term'** (τ_l) **response**, scaled with complementing factors a and $1 - a$



Data analysis, closer look

Deutscher Wetterdienst
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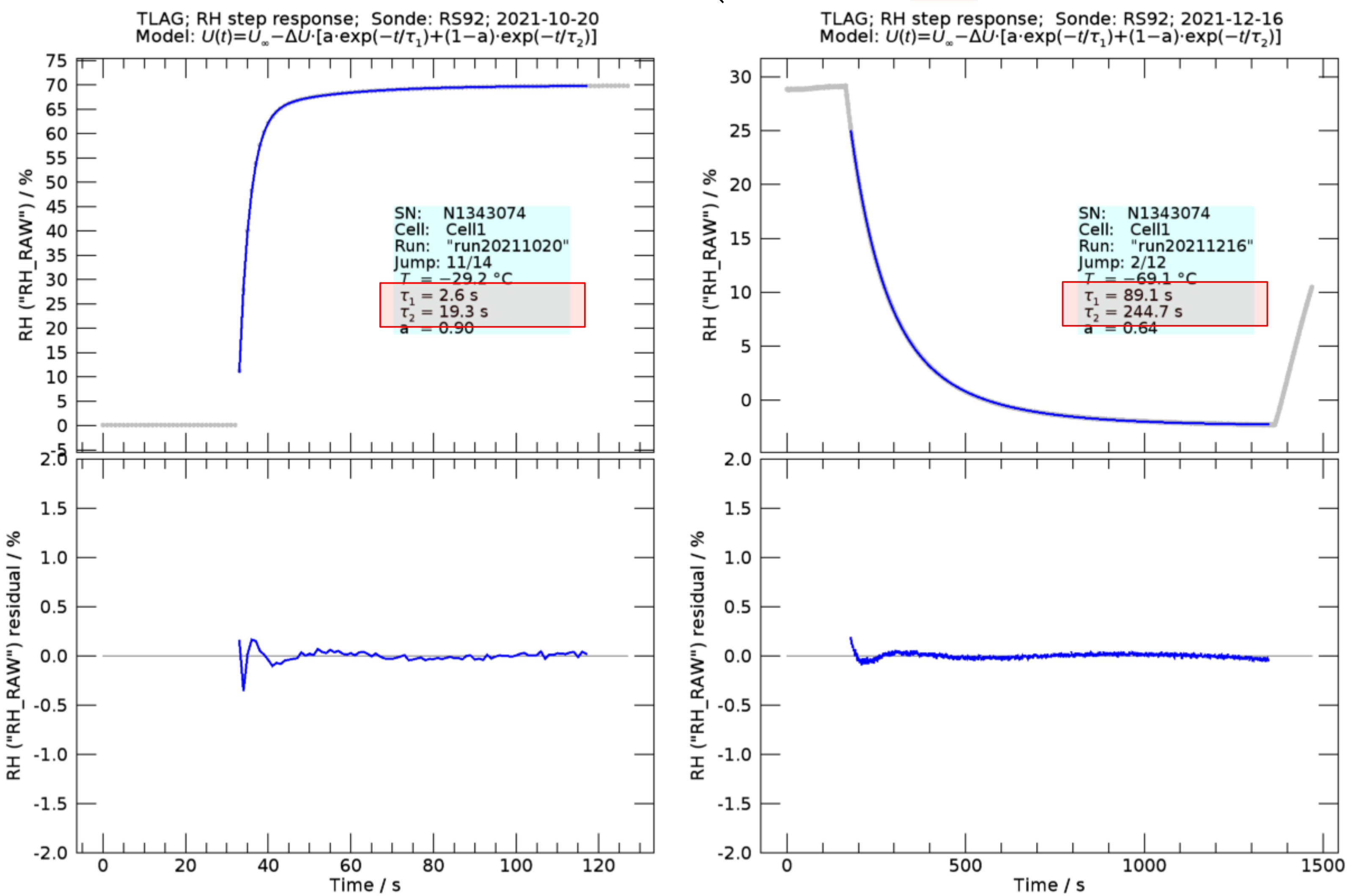
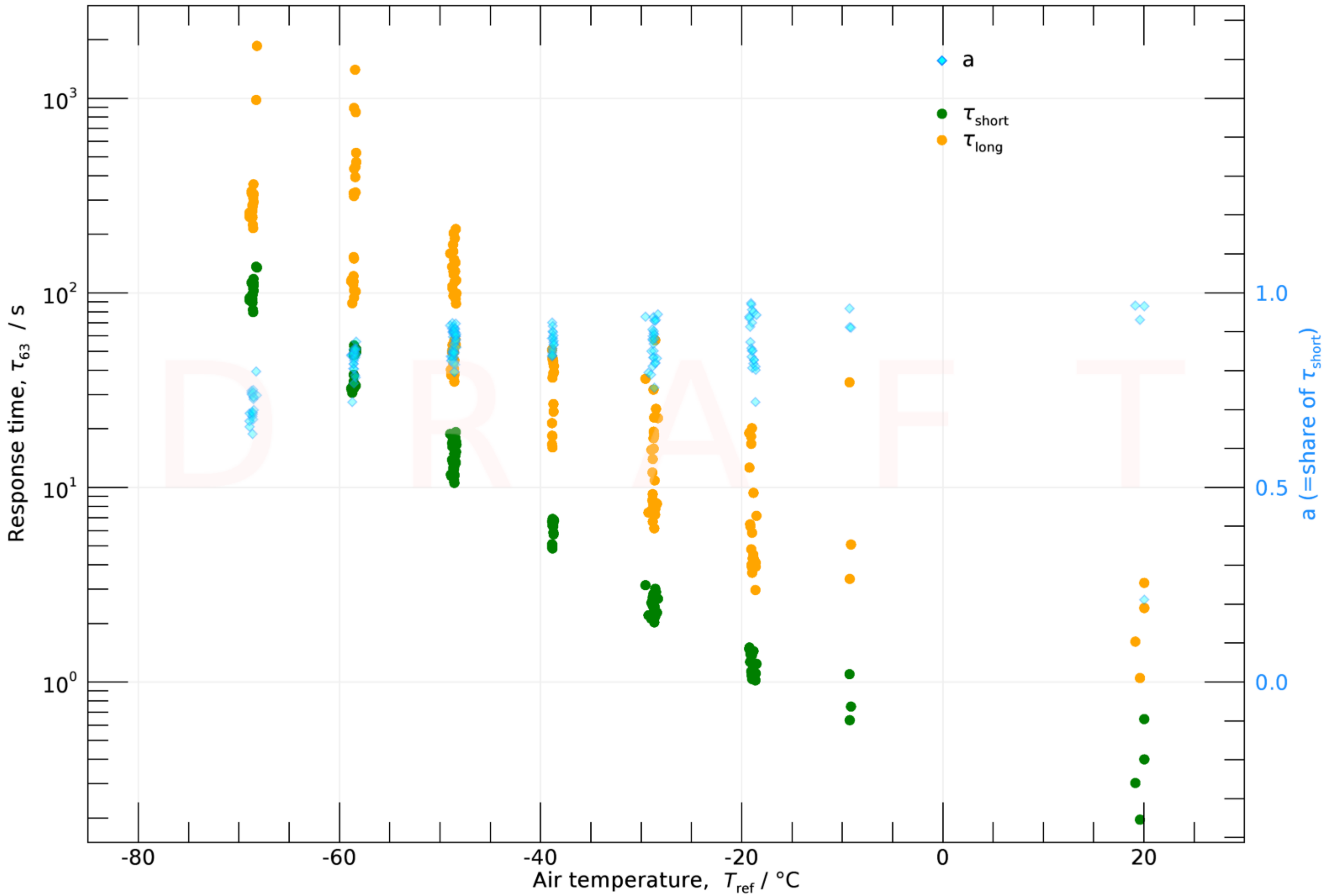
Evaluation of response times: $U(t) = U_\infty - \Delta U \left(\boxed{\mathrm{a}} \cdot \exp\left(-\frac{(t-t_0)}{\boxed{\tau_s}}\right) + \boxed{(1-\mathrm{a})} \cdot \exp\left(-\frac{(t-t_0)}{\boxed{\tau_l}}\right) \right)$



Data analysis, closer look (RS92)

Evaluation of response times: $U(t) = U_\infty - \Delta U \left(\boxed{a} \cdot \exp\left(-\frac{(t-t_0)}{\boxed{\tau_s}}\right) + \boxed{(1-a)} \cdot \exp\left(-\frac{(t-t_0)}{\boxed{\tau_l}}\right)\right)$

- 'τ_l-τ_s' model fits the sensor response better than single τ
- Works over entire response time range
- Ratio ($\tau_l/\tau_s \gtrsim 3$) and parameter a weakly T-dependent
- → Interpretation?
  → 'Slow regime' correction for M10 (Dupont, 2020)



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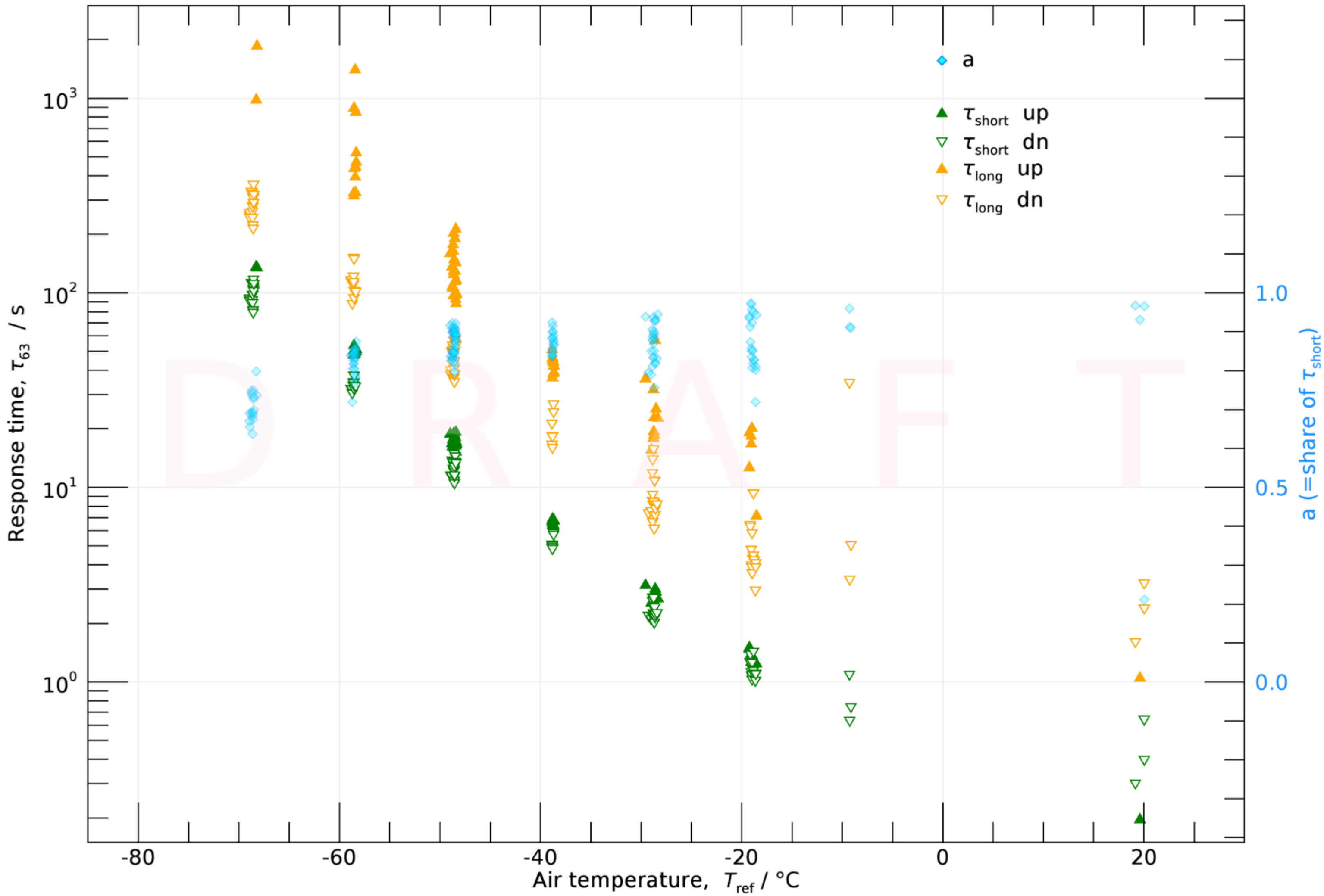

Data analysis, closer look (RS41)

Evaluation of response times: $U(t) = U_\infty - \Delta U \left(\boxed{\mathrm{a}} \cdot \exp\left(-\frac{(t-t_0)}{\boxed{\tau_s}}\right) + \boxed{(1-\mathrm{a})} \cdot \exp\left(-\frac{(t-t_0)}{\boxed{\tau_l}}\right)\right)$

- 'τ_l-τ_s' model fits the sensor response better than single τ
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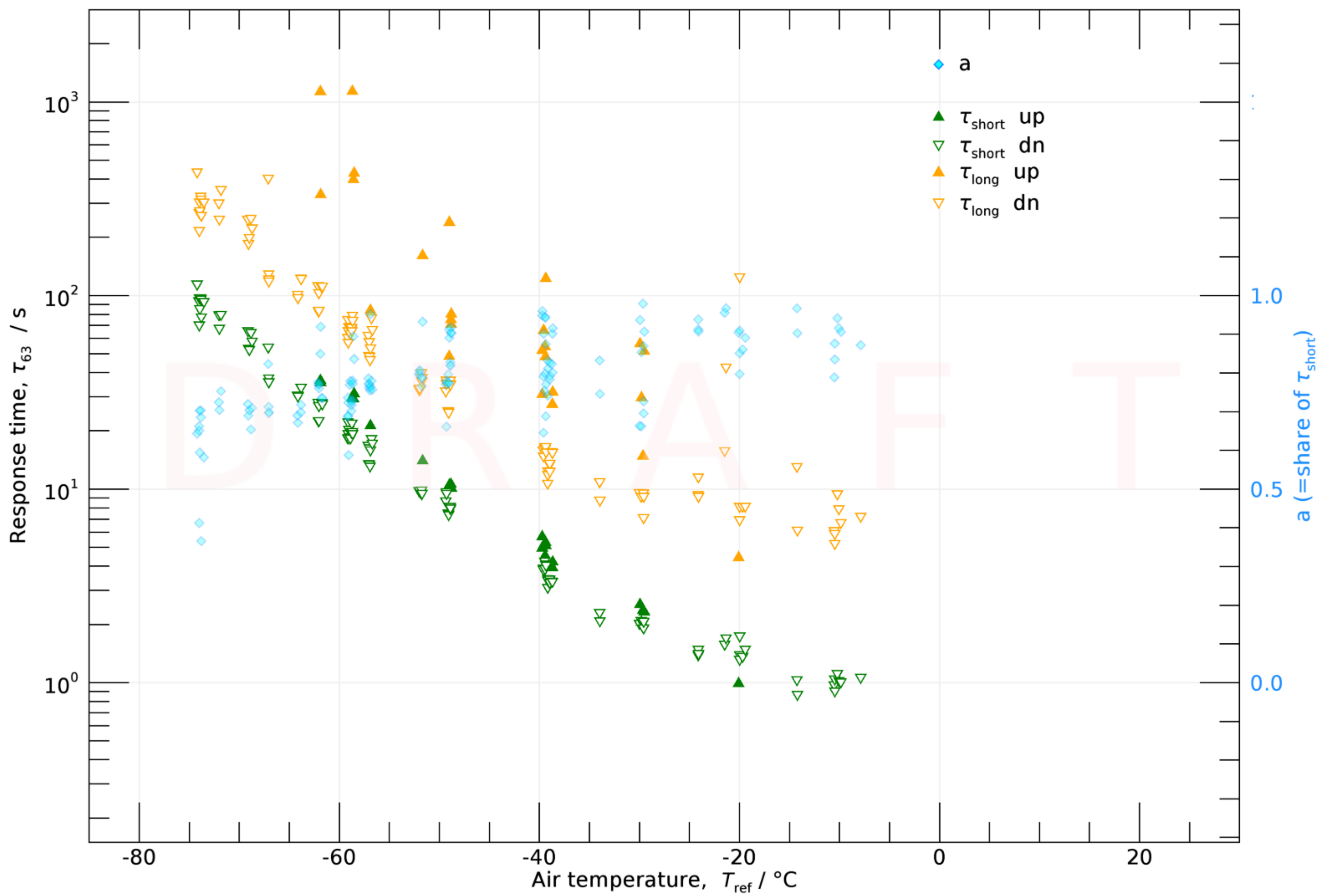
- → Interpretation?
  → 'Slow regime' correction for M10 (Dupont, 2020)
- Separation up/down: τ_l syst. larger for 'up' steps
- RS41: more scatter (cont. sensor heating ?)



Outlook

- Parameterisation τ with T for use in GDP time-lag correction: find an appropriate model

  E.g.: Arrhenius-like fit: $\tau(T) = \tau_0 \cdot \exp\left(-\frac{E_a}{RT}\right)$

  (accounts for curvature in semi-log representation)
- Evaluation ongoing with respect to:
  - Deviation in τ for up/down steps (to be taken into account in correction?)
  - Uncertainty estimates
- 'τ_l-τ_s' response model:
  - Interpretation?
  - Significance for time lag correction?
- Experiments at various air flow rates

Conclusions

- 2021/22: substantial technical improvements,
  Setup **ready for routine experiments**
- **New measurements with RS41/92**;
  Implementation of updated time-lag corrections based on 2021/22 measurements for RS41 and RS92 in follow-up GDP versions (RS41-GDP.2 and RS92-GDP.3)
- Setup extensively used in laboratory part of WMO inter-comparison campaign (UAII-2022): Standardised time-lag tests of 10 radiosonde models; evaluation ongoing