Effect of solar radiation on radiosonde temperature sensors

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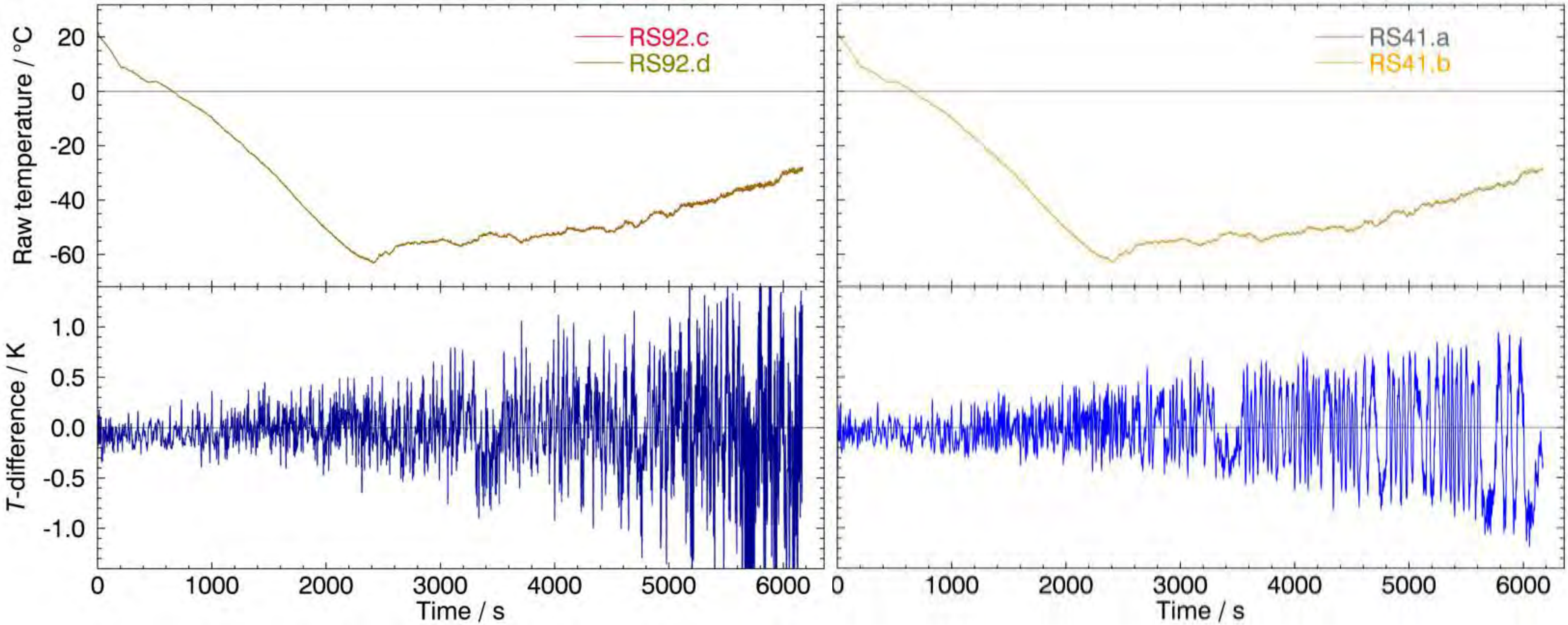
9th GRUAN Implementation and Coordination Meeting (ICM-9)
Helsinki, Finland
June 2017

Effect of direct irradiation, dual flight, 180°-setup, raw

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD



- T-difference (raw),
  oscillations by direct component of solar irradiation, orientation-dependent
- Amplitude depends on: irradiation, SEA, air density;
  angle of sensor boom, specific sensor properties (response)

Measurements, MOL radiation chamber

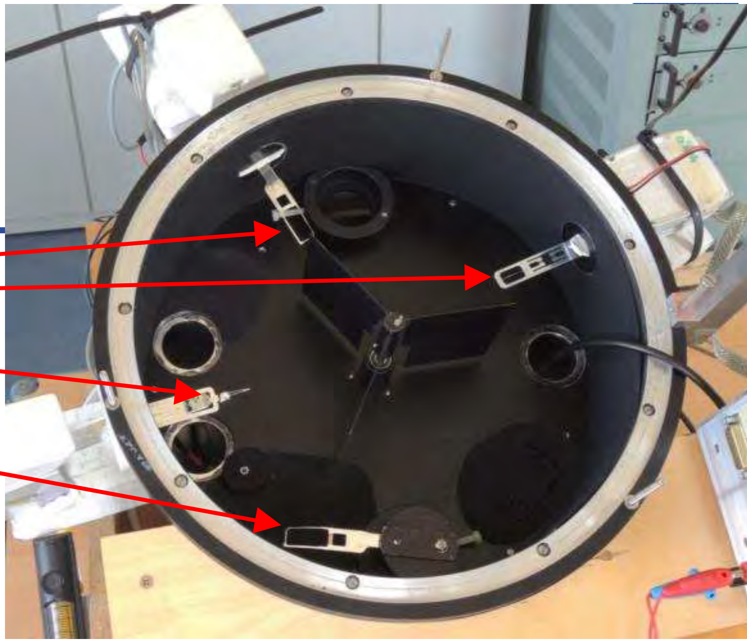
- Up to 3 test radiosondes
- Shadow reference sonde (p, T)
- Perpendicular irradiation of **sensor boom** with sunlight → maximum ΔT (thermal equilibrium)
- Controlled parameters:

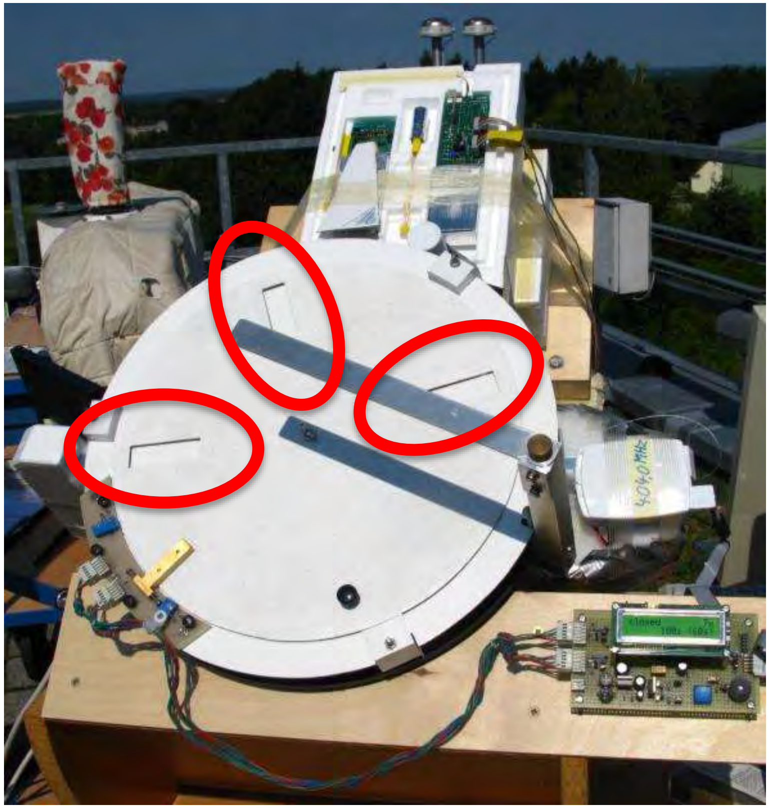
Irradiance I_a: (200–1000) W·m^{-2}, $u(I_a) = 2$ %

(direct sun and grey filters, pyrheliometer)

- Pressure p: (3–1020) hPa, $u(p) =$0.3 hPa
  (shadow sonde)
- Ventilation v: (0–10) m·s^{-1}, $u(v) < 1$ m·s^{-1}
  (related to fan voltage)

→ Evaluation of data 2012-2016 for several radiosonde models





Measurement data

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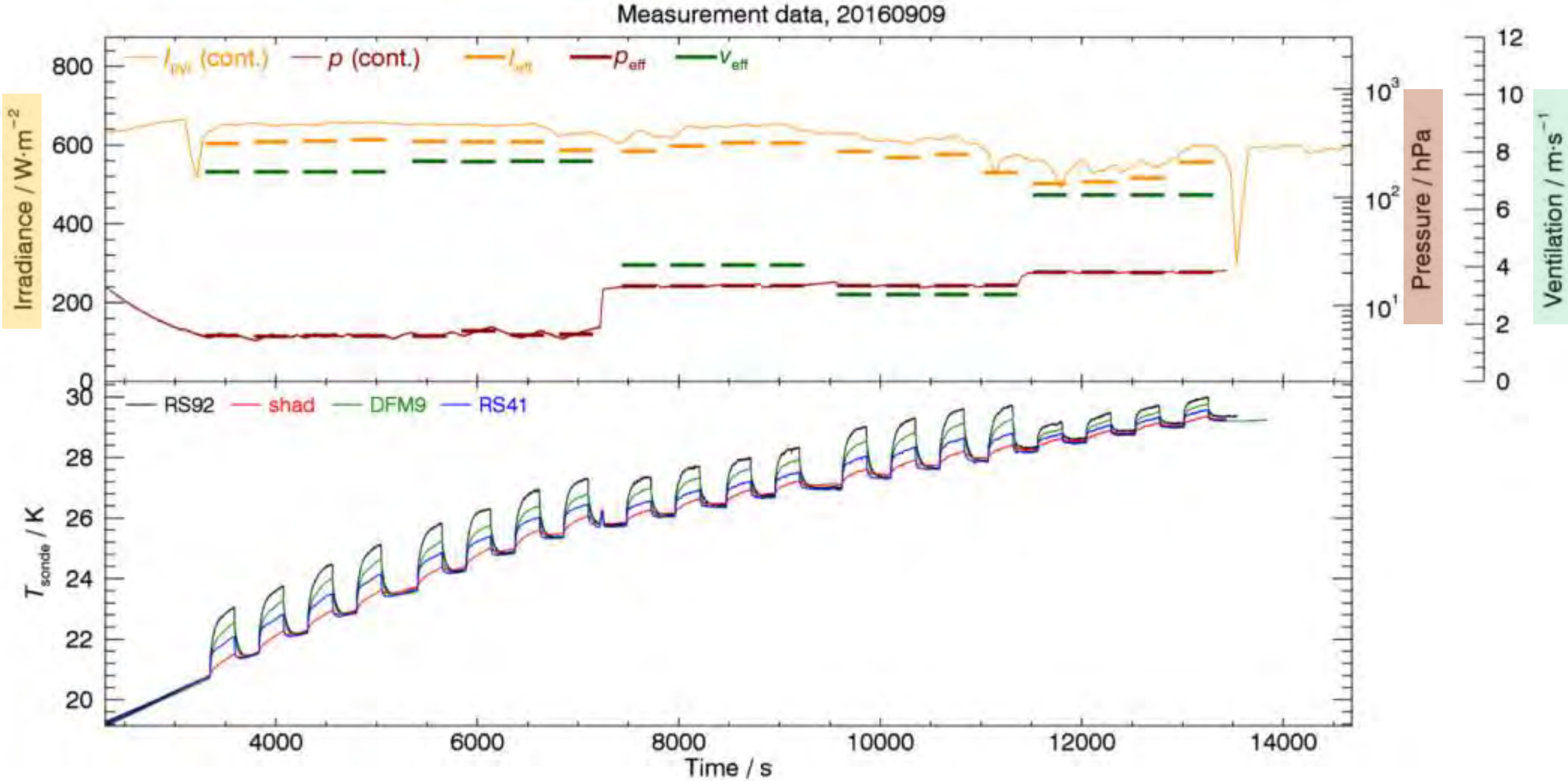

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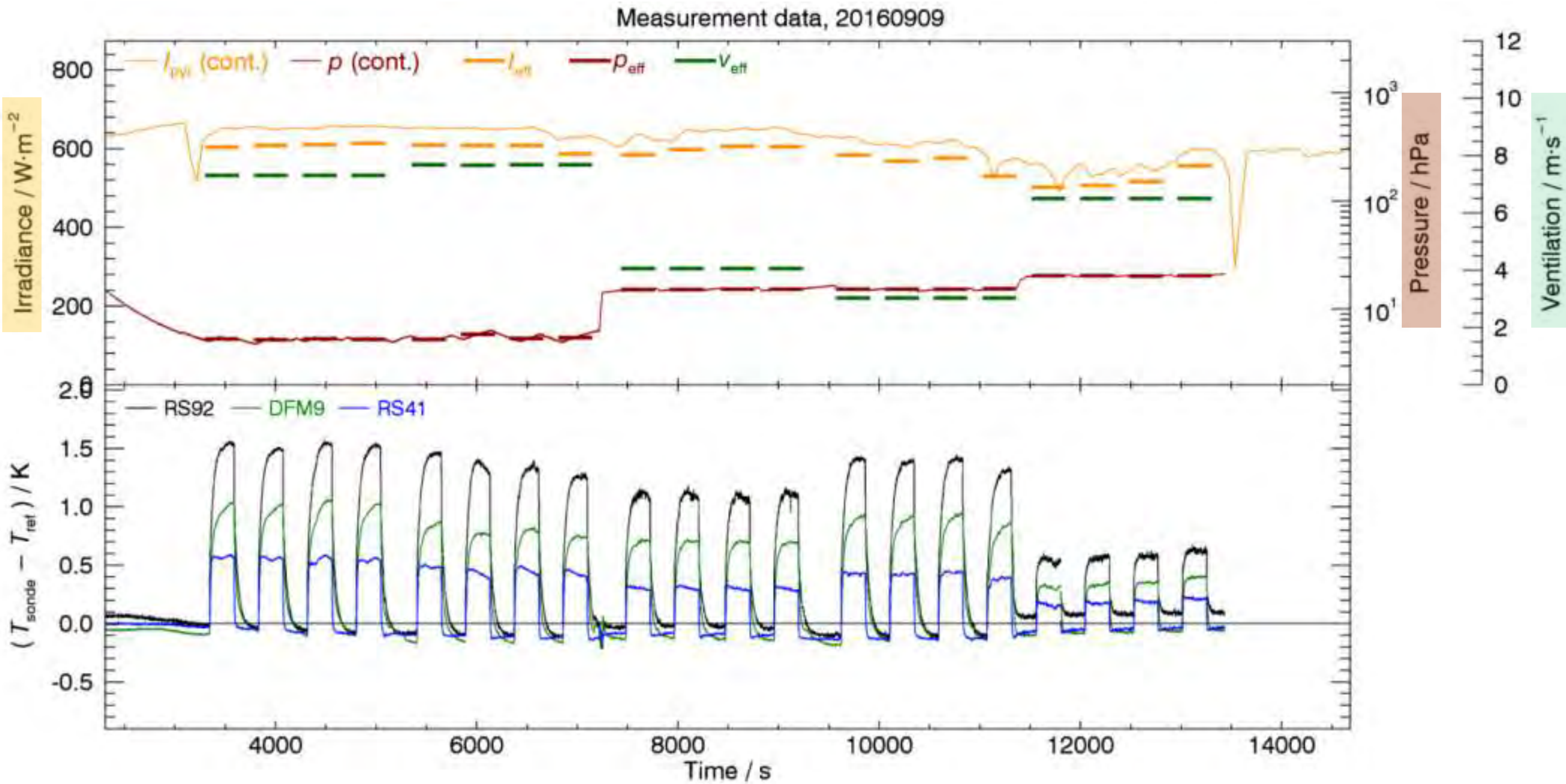

Step response

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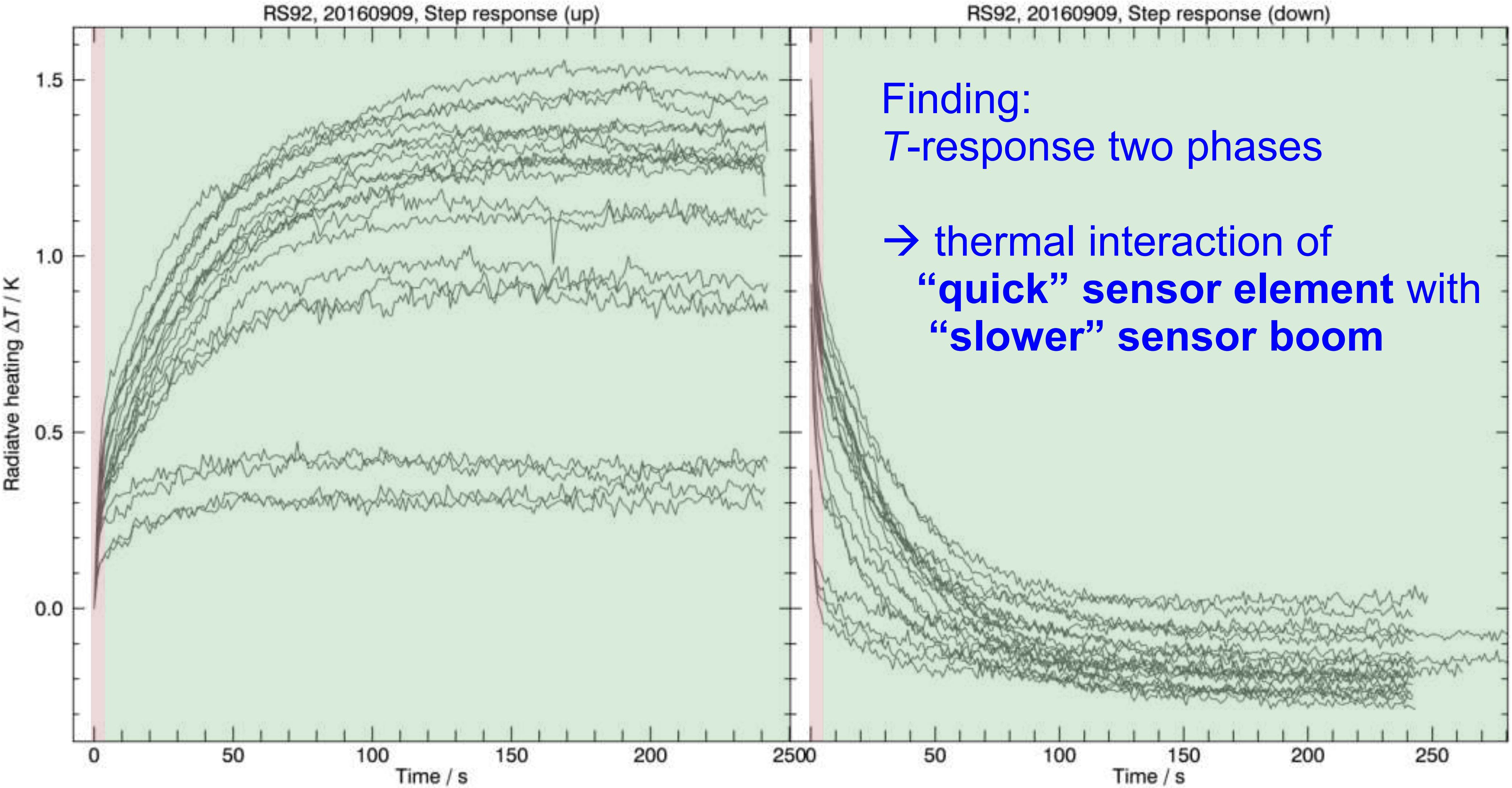

Finding:
T-response two phases

→ thermal interaction of **“quick” sensor element** with **“slower” sensor boom**

Estimating maximum T-response

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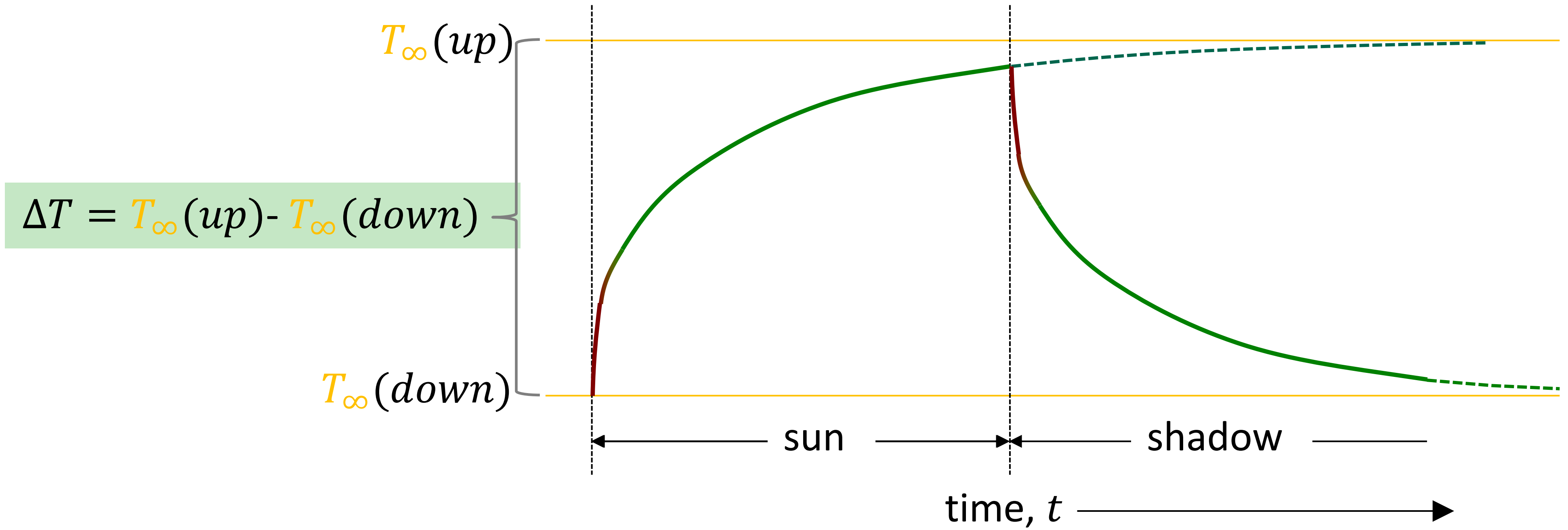
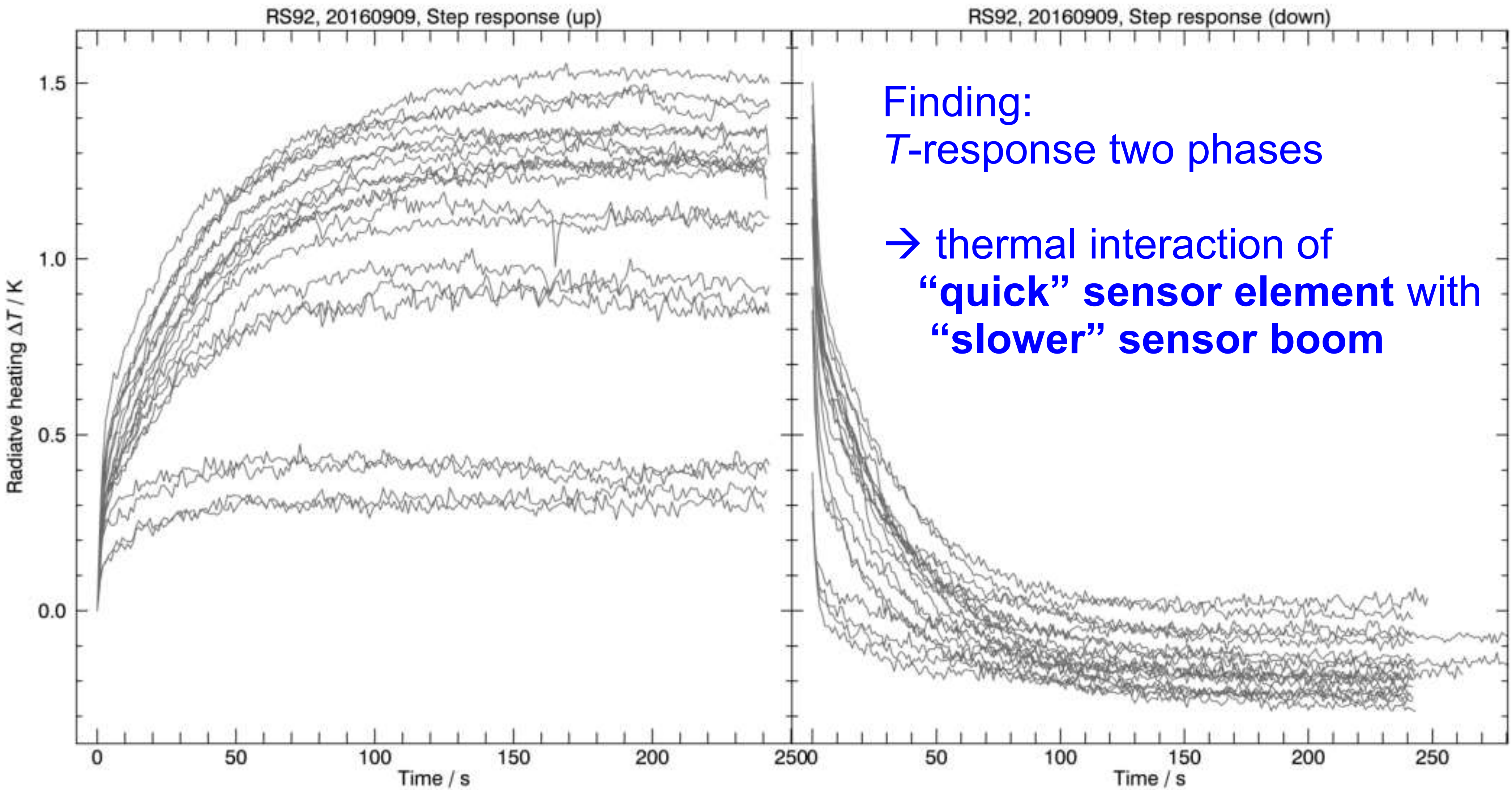
- ΔT as maximal effect in thermal equilibrium
- fit exp. data using 5 parameters: T_∞, T_a, τ_s, τ_l, r (τ_s fixed), separate for „up" and „down" parts

$$T(t) = T_\infty + T_a \cdot \left[(1-r) \cdot e^{-\frac{t}{\tau_s}} + r \cdot e^{-\frac{t}{\tau_l}}\right]$$



Estimating maximum *T*-response (Vaisala RS92)



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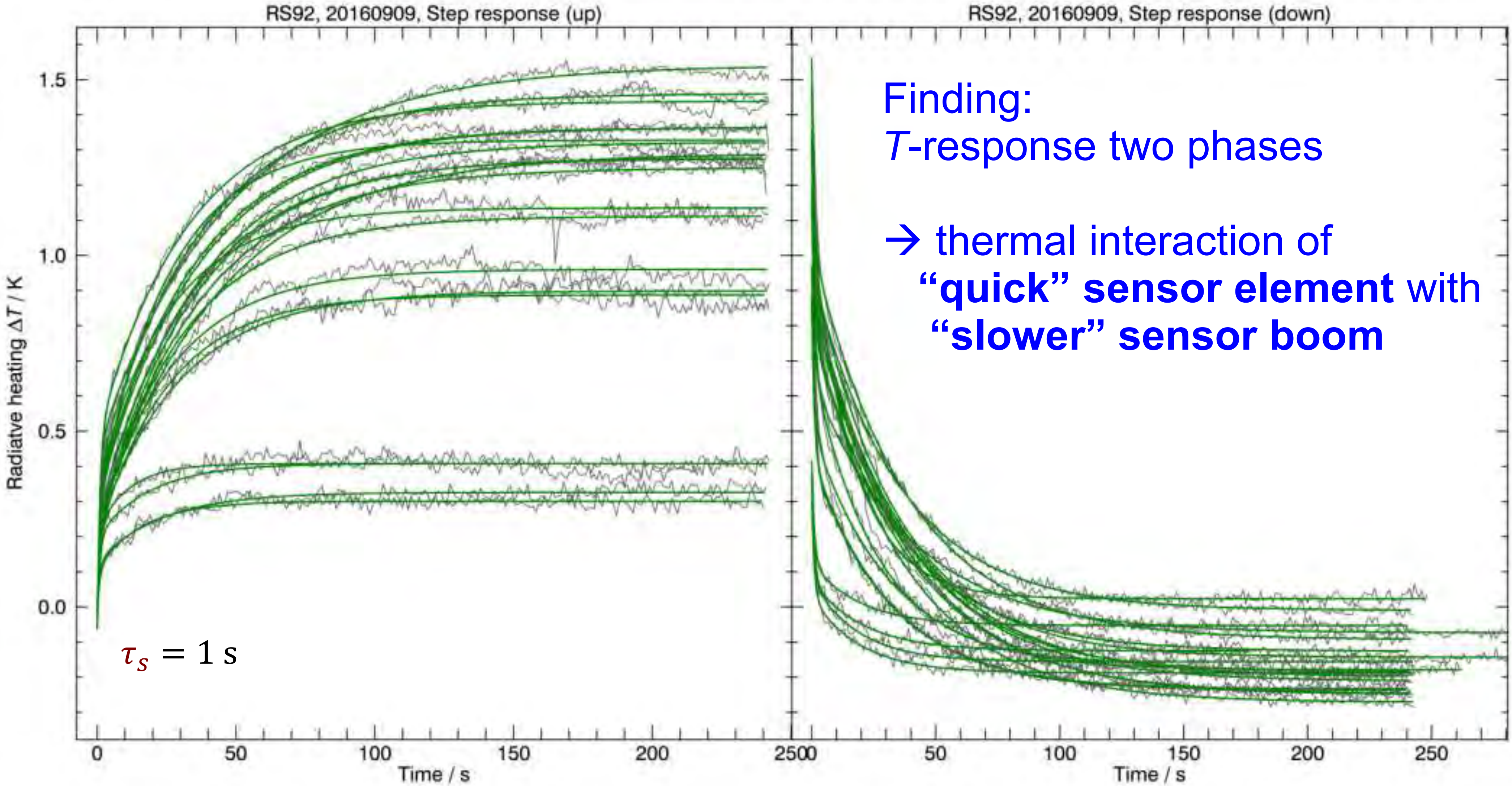

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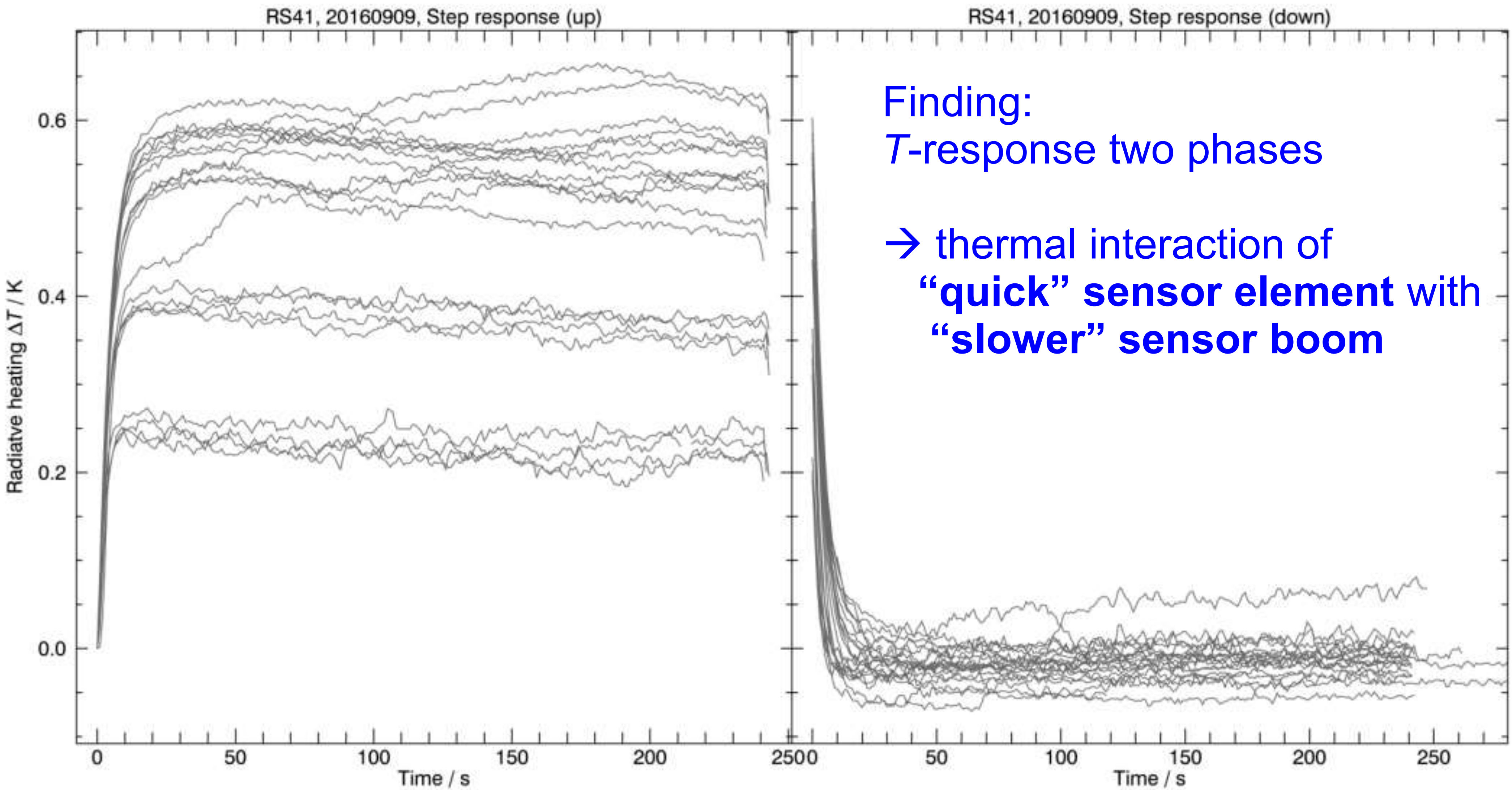

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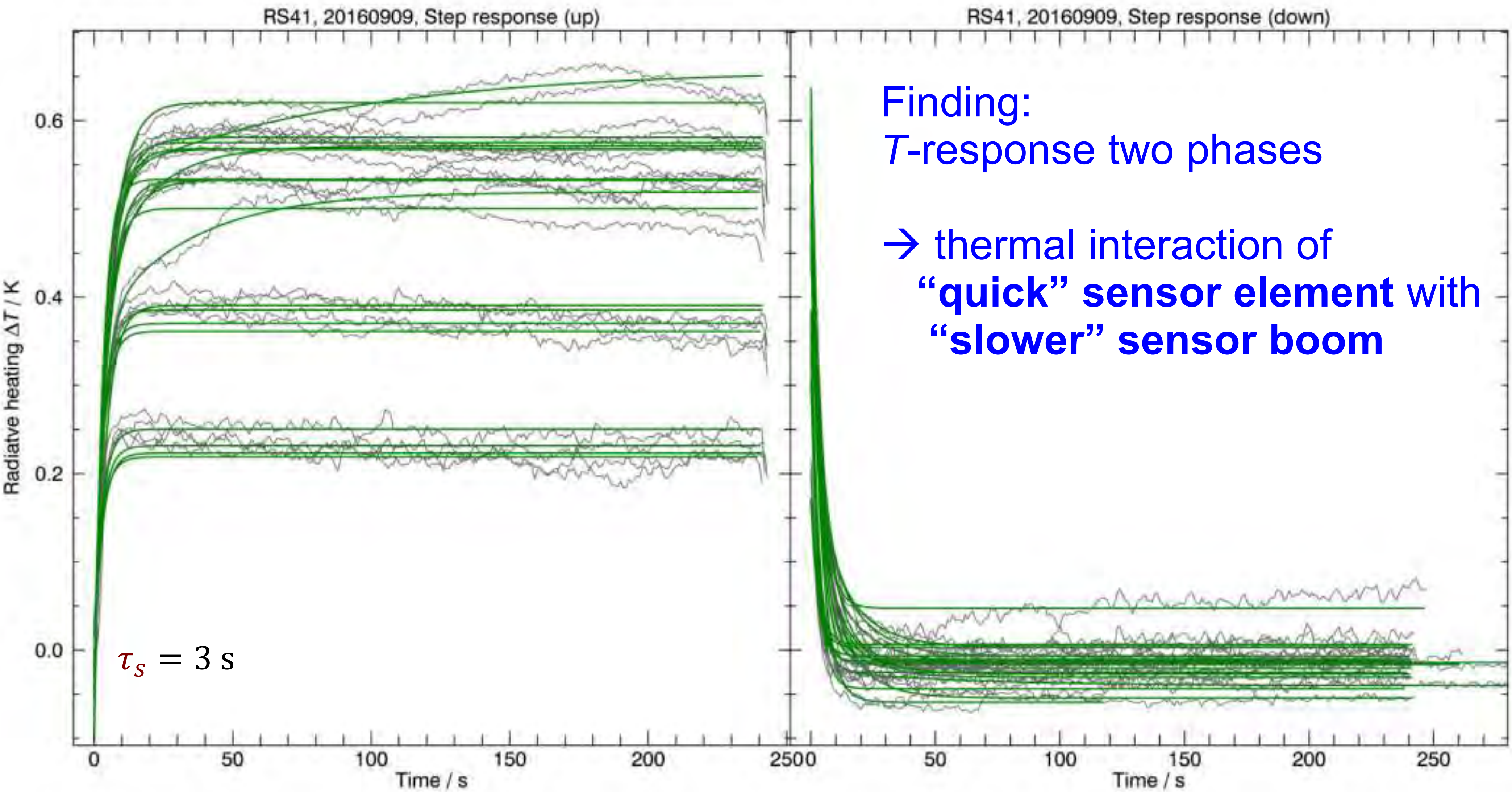

Finding:
T-response two phases

→ thermal interaction of **"quick" sensor element** with **"slower" sensor boom**

Effect of direct irradiation 180° setup - details

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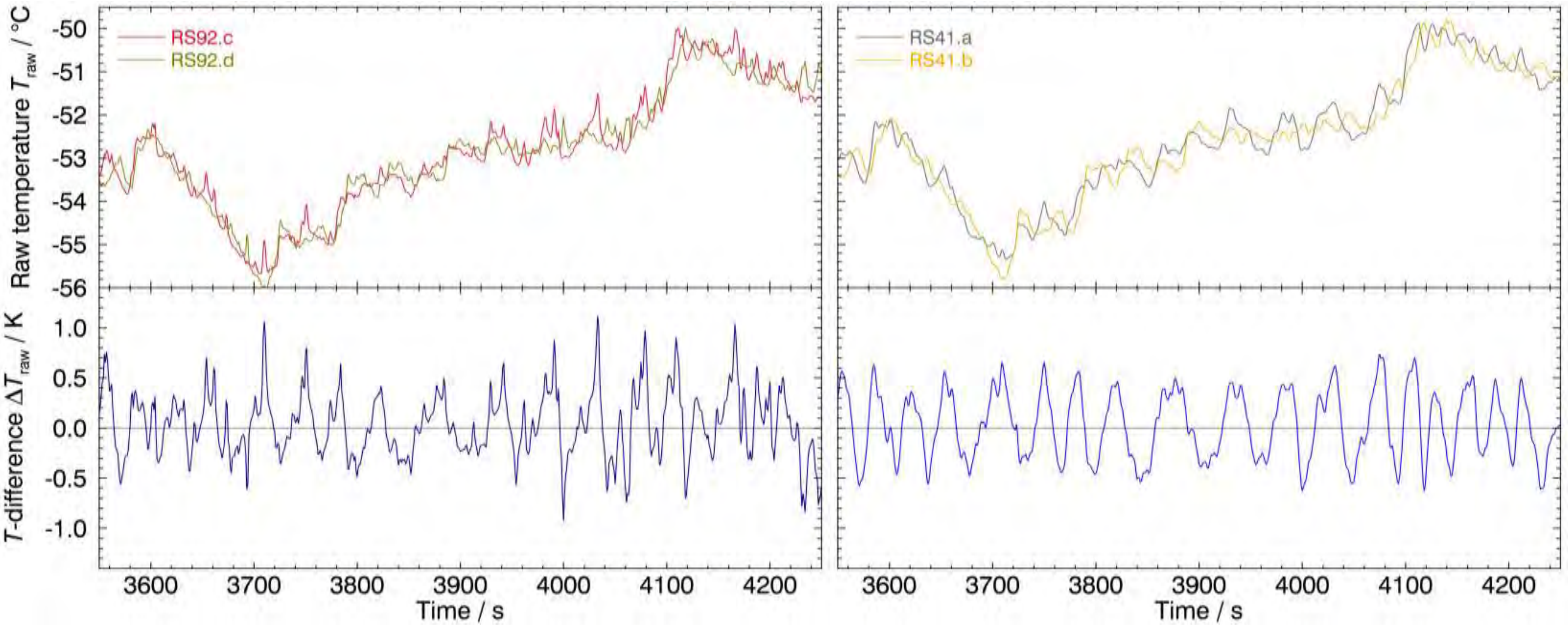

- Lower frequency oscillations ("slow" part of radiation response → rotation?
  → similar in amplitude for both sondes
- Short peaks ("quick" part, τ_s) on top of slower osc. → pendulum motion?
  → more pronounced for RS92 (thinner sensor element)

Results: parameterization of maximal *T*-response (Δ*T*)

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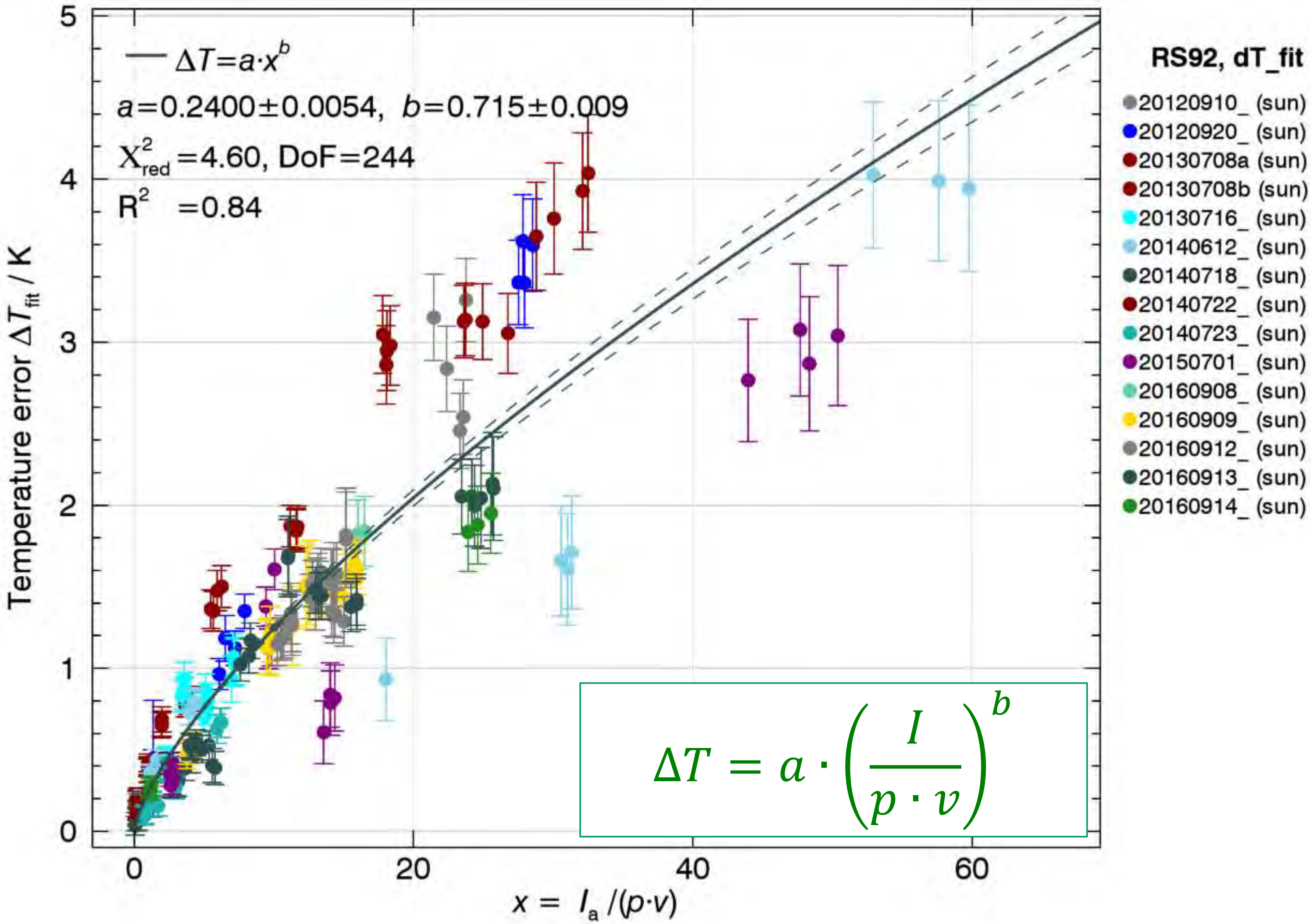

$$\Delta T = a \cdot \left(\frac{I}{p \cdot v}\right)^b$$

Results: parameterization of maximal *T*-response (ΔT)

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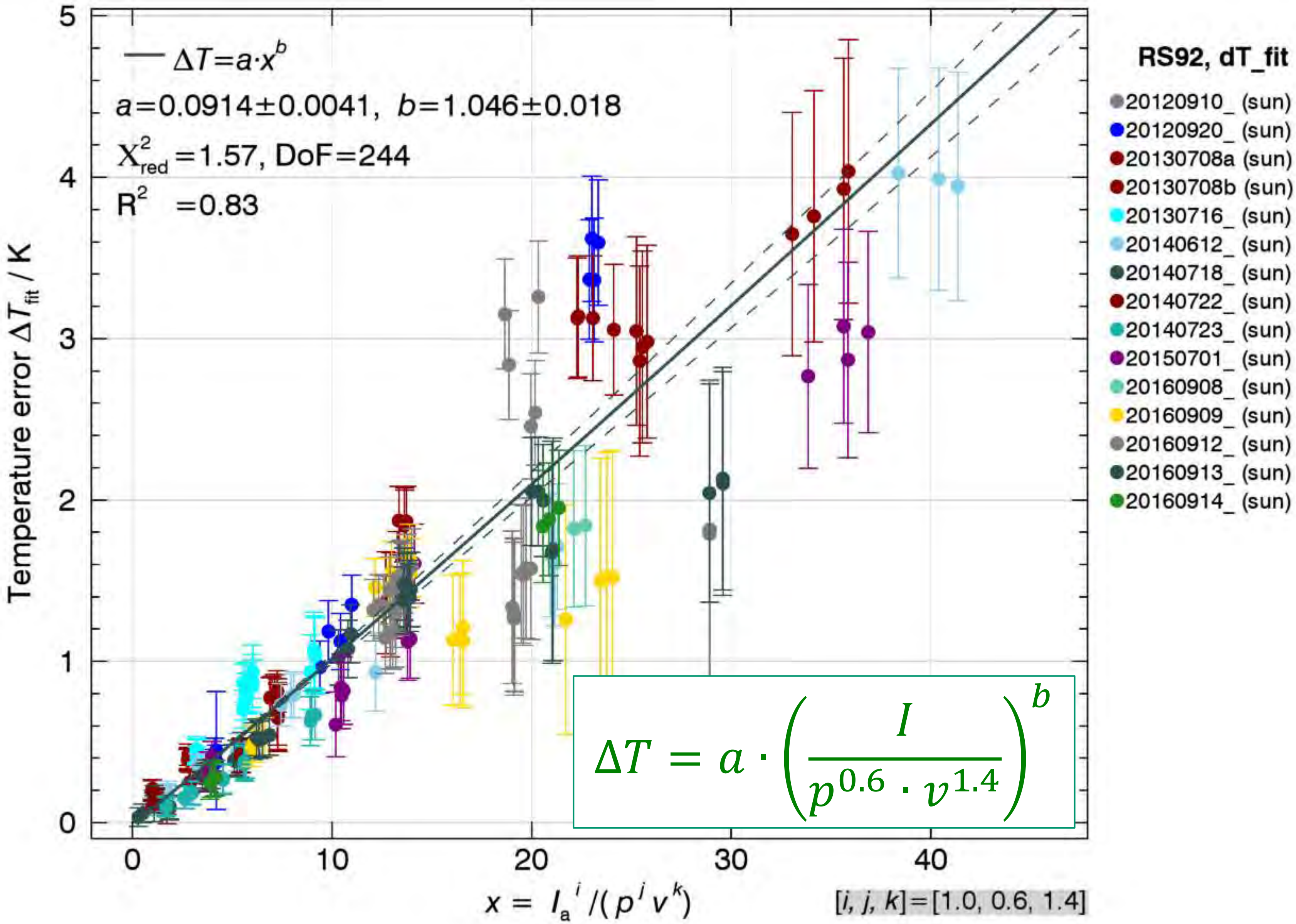

$$\Delta T = a \cdot \left(\frac{I}{p^{0.6} \cdot v^{1.4}} \right)^b$$

Results: parameterization of maximal *T*-response (ΔT)

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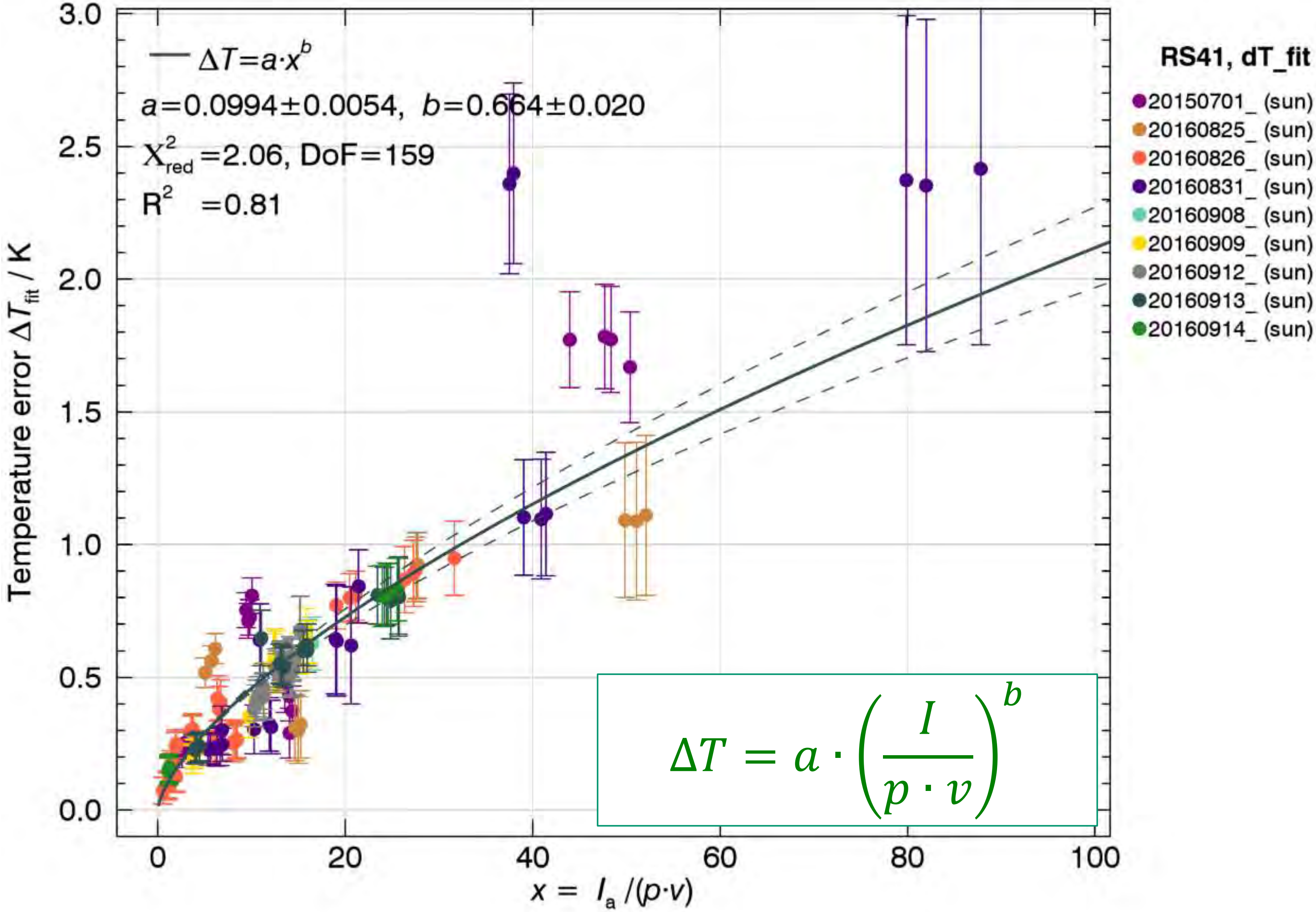
Wetter und Klima aus einer Hand



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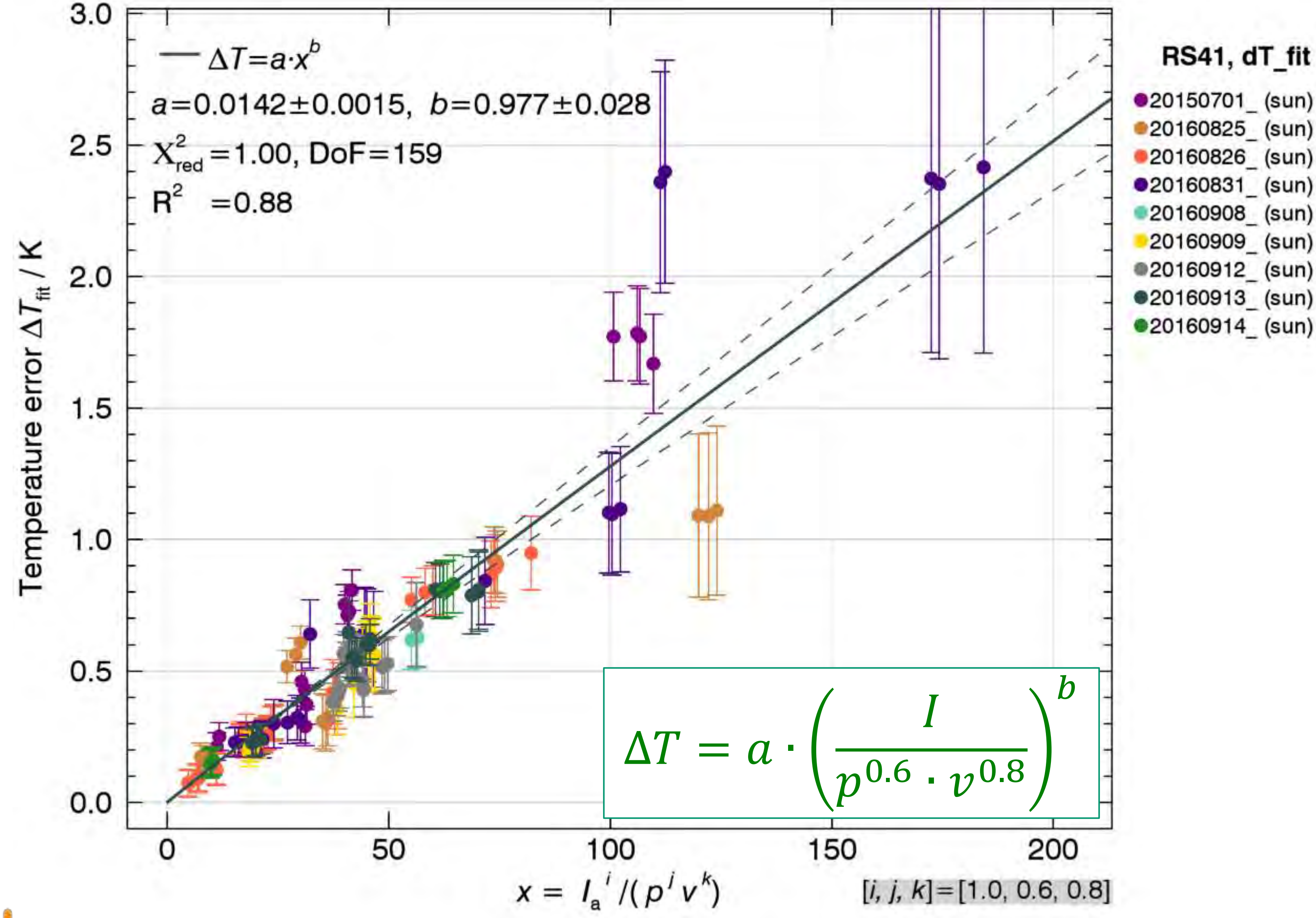

$$\Delta T = a \cdot \left(\frac{I}{p^{0.6} \cdot v^{0.8}} \right)^b$$

Results: parameterization of maximal *T*-response (ΔT)

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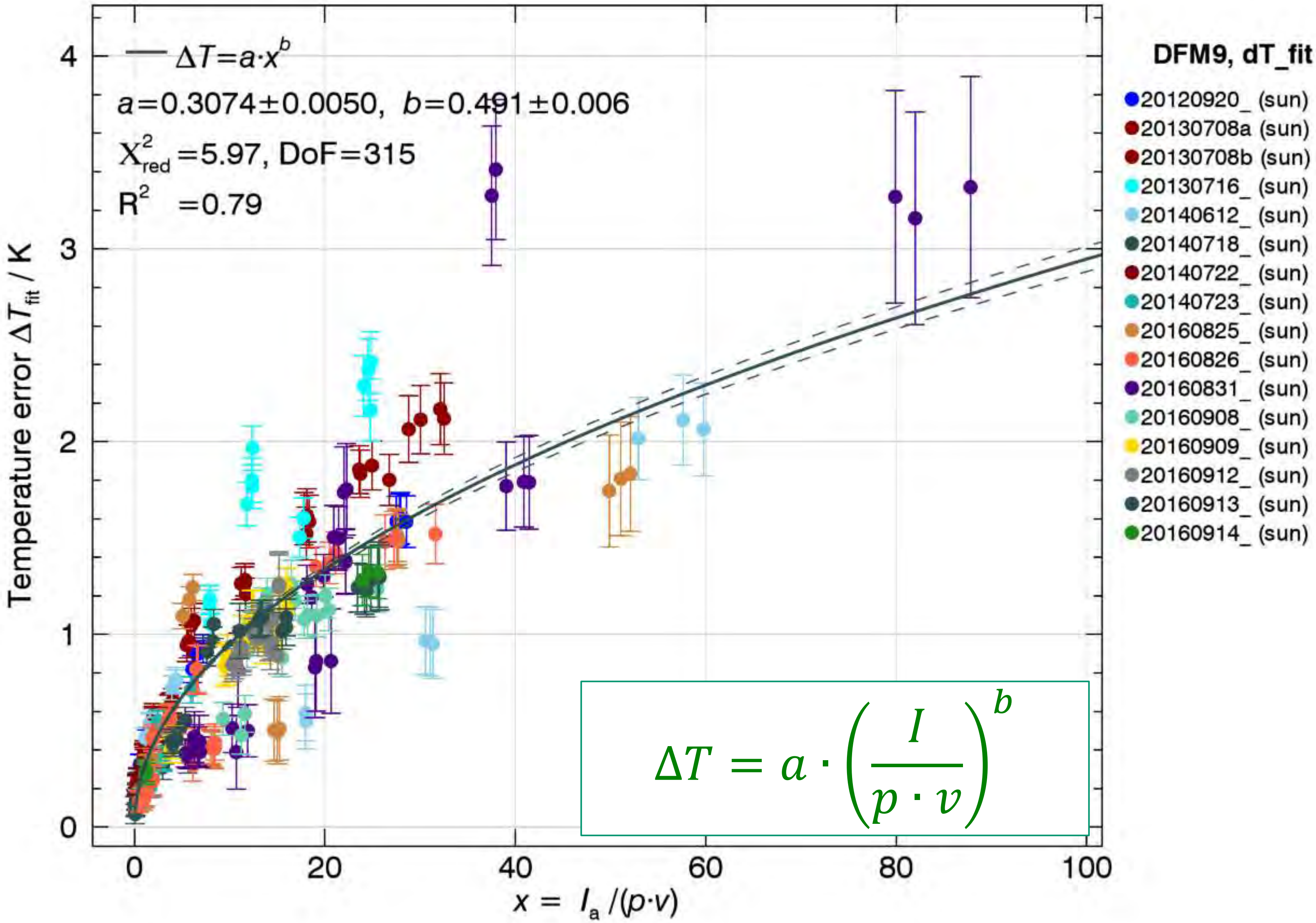

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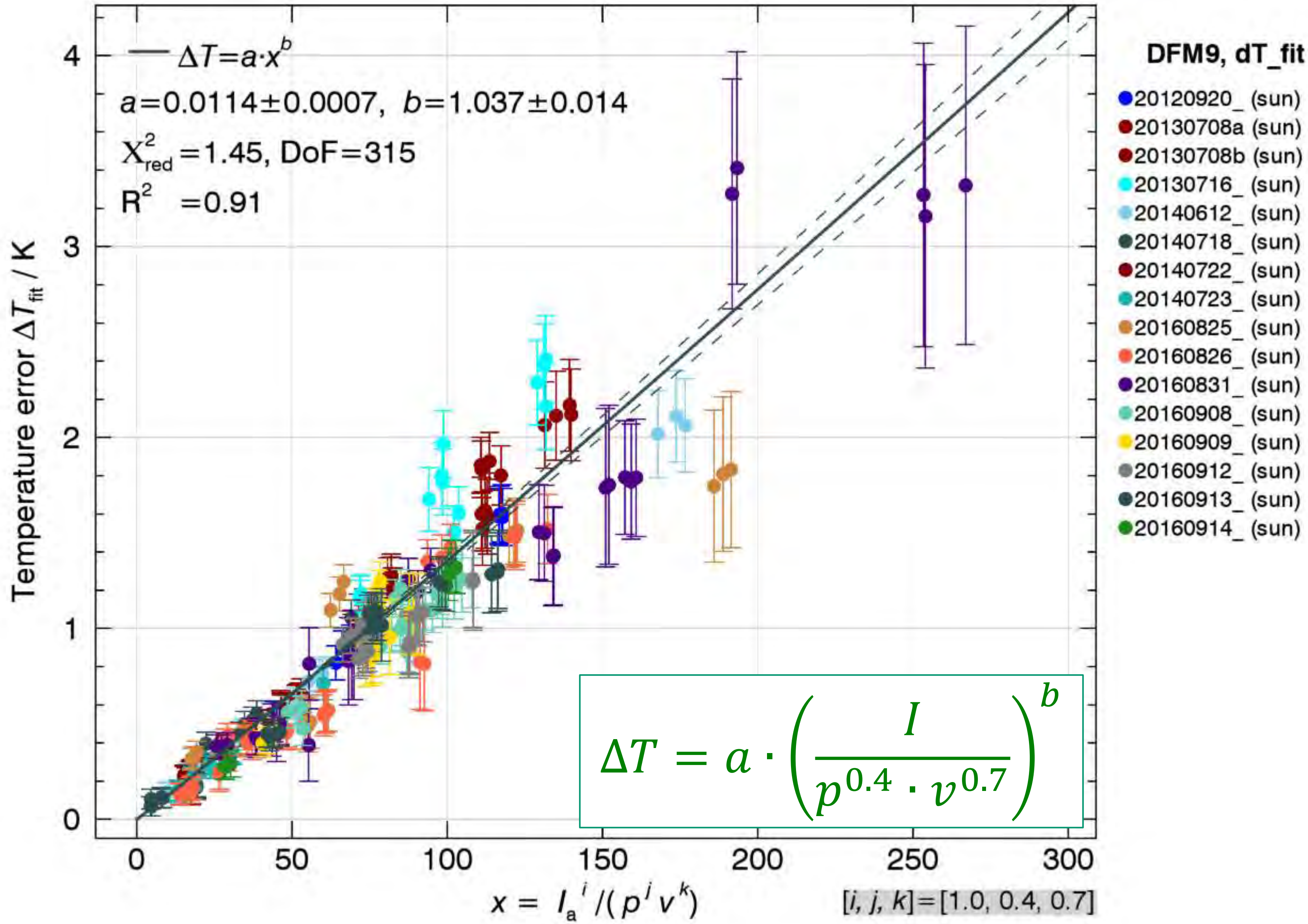

$$\Delta T = a \cdot \left(\frac{I}{p^{0.4} \cdot v^{0.7}} \right)^b$$

Results: parameterization of maximal *T*-response (ΔT)

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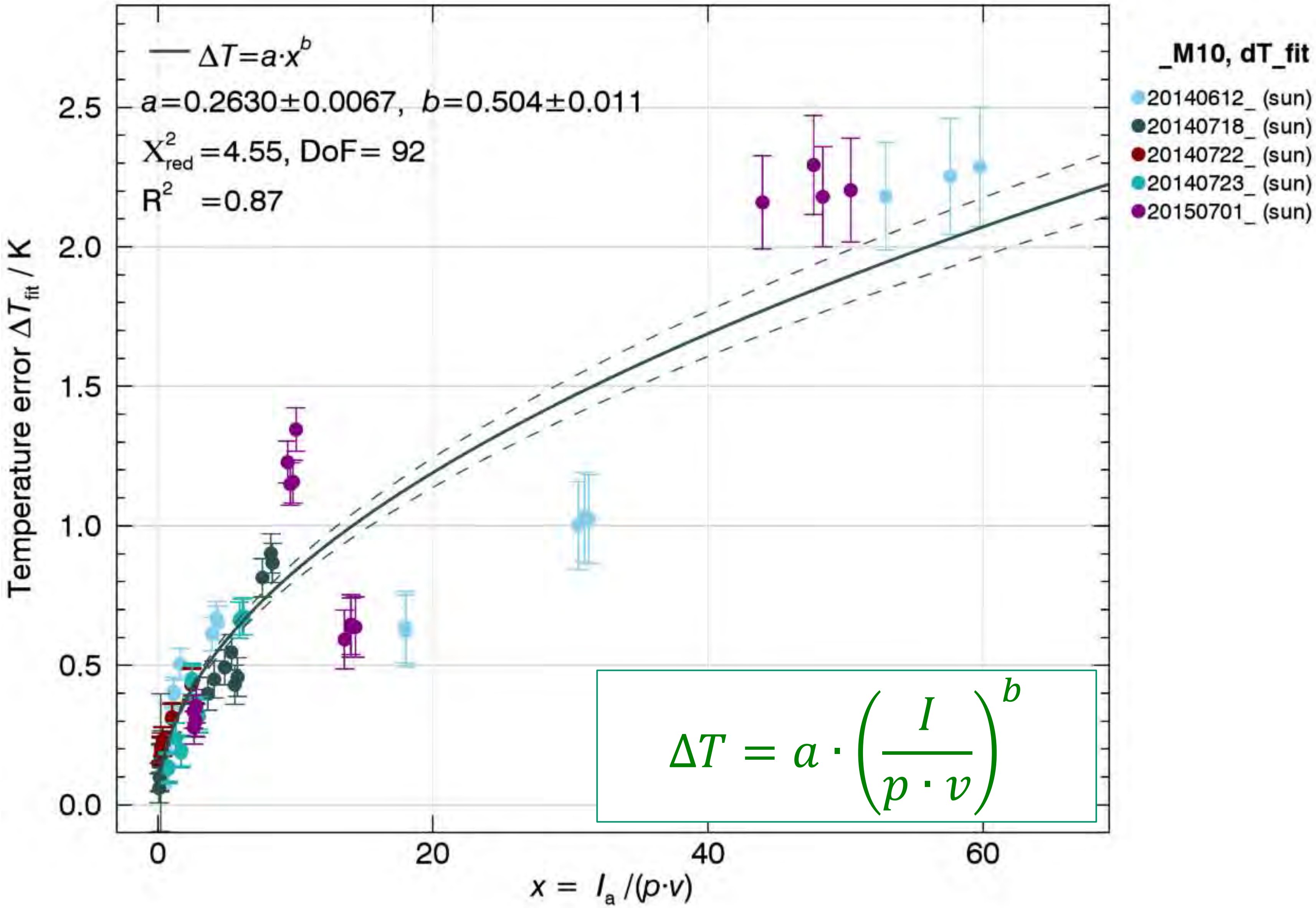

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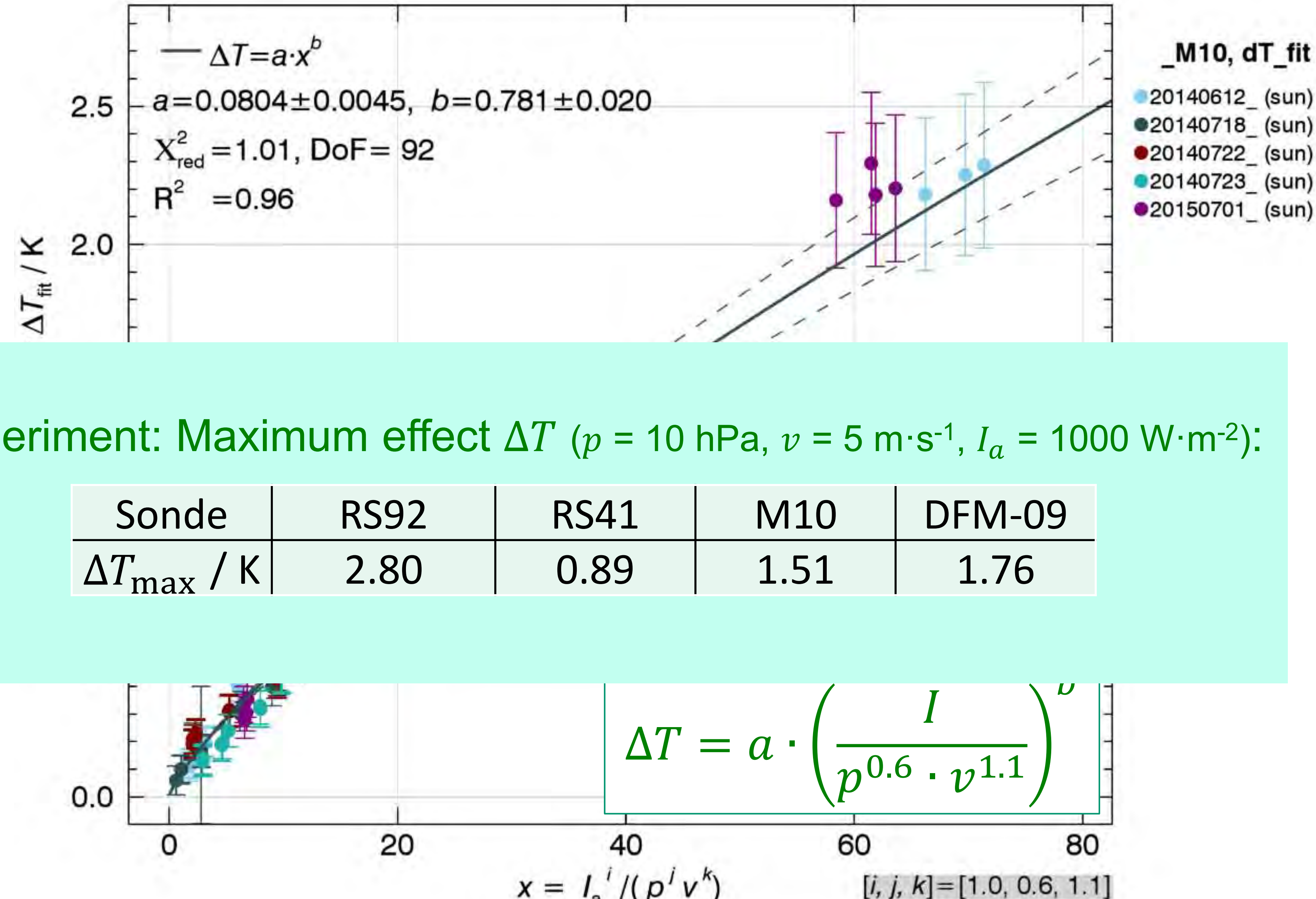

- Experiment: Maximum effect ΔT (p = 10 hPa, v = 5 m·s^{-1}, I_a = 1000 W·m^{-2}):

Sonde	RS92	RS41	M10	DFM-09
ΔT_{max} / K	2.80	0.89	1.51	1.76

$$\Delta T = a \cdot \left(\frac{I}{p^{0.6} \cdot v^{1.1}}\right)^b$$

Experimental data → radiation correction

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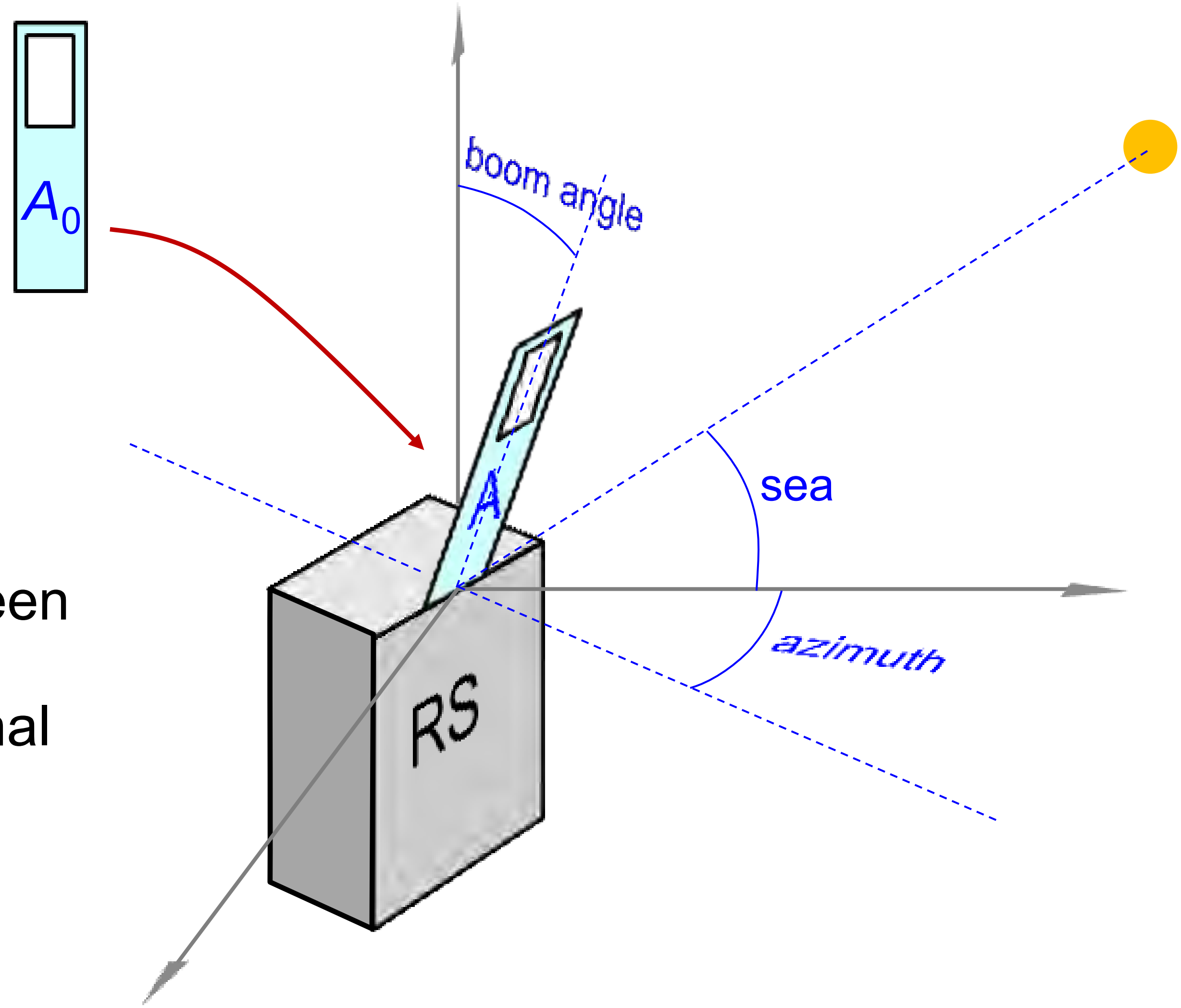
- Approach for T-correction:
  1) Calculate average „geometry"-factor f_{geo}(SEA, boom angle) *(next slide)*
  2) Reduce **direct** component of solar radiation I (from rad. model) by f_{geo}:
     $$I = I_{\mathrm{diffuse}} + f_{\mathrm{geo}} \cdot I_{\mathrm{direct}}$$
  3) Calculate radiation correction:
     $$\Delta T = a \cdot \left(\frac{I}{p^j \cdot v^k}\right)^b$$

Assumptions:
- same response characteristic for diffuse or direct radiation
- heating by **diffuse** radiation independent of orientation
- same behavior for **upper and lower side** of sensor boom
- **longwave** radiation effects **not considered**

Sensor boom orientation

- assume sensor boom as thin flat object with surface A_0

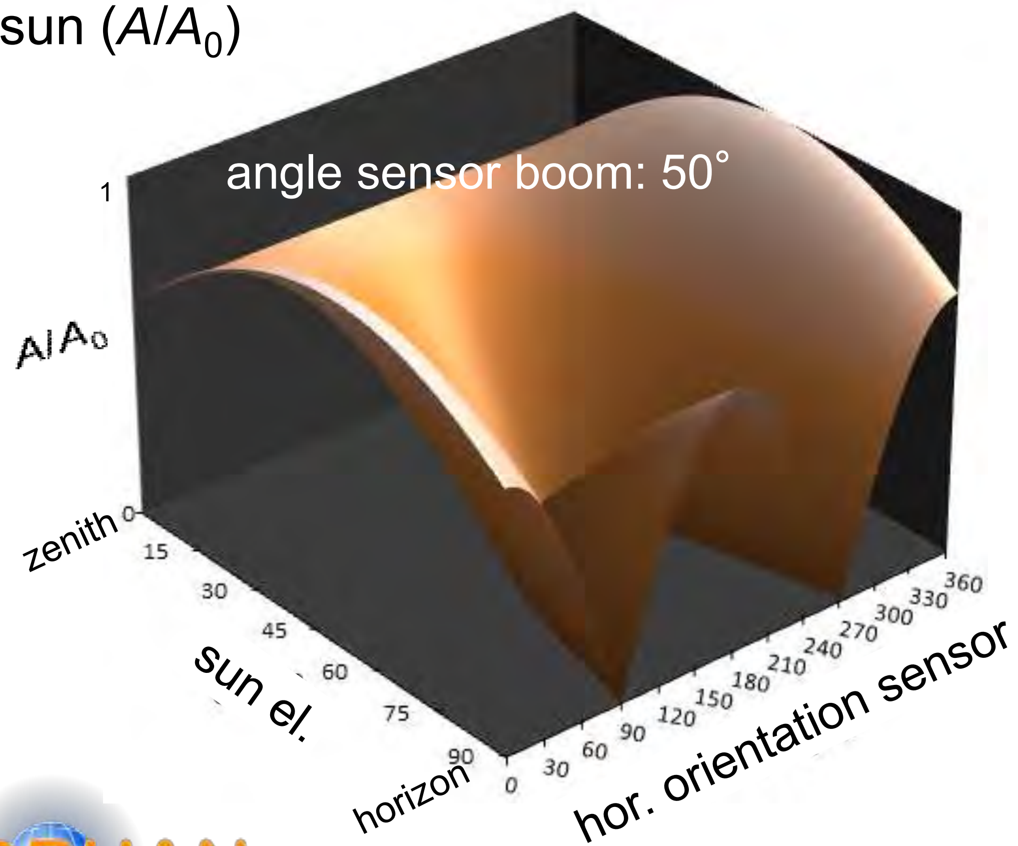


- „reduced“ boom surface *A* seen by sun dependent on boom angle, current sonde azimuthal and sun elevation angles

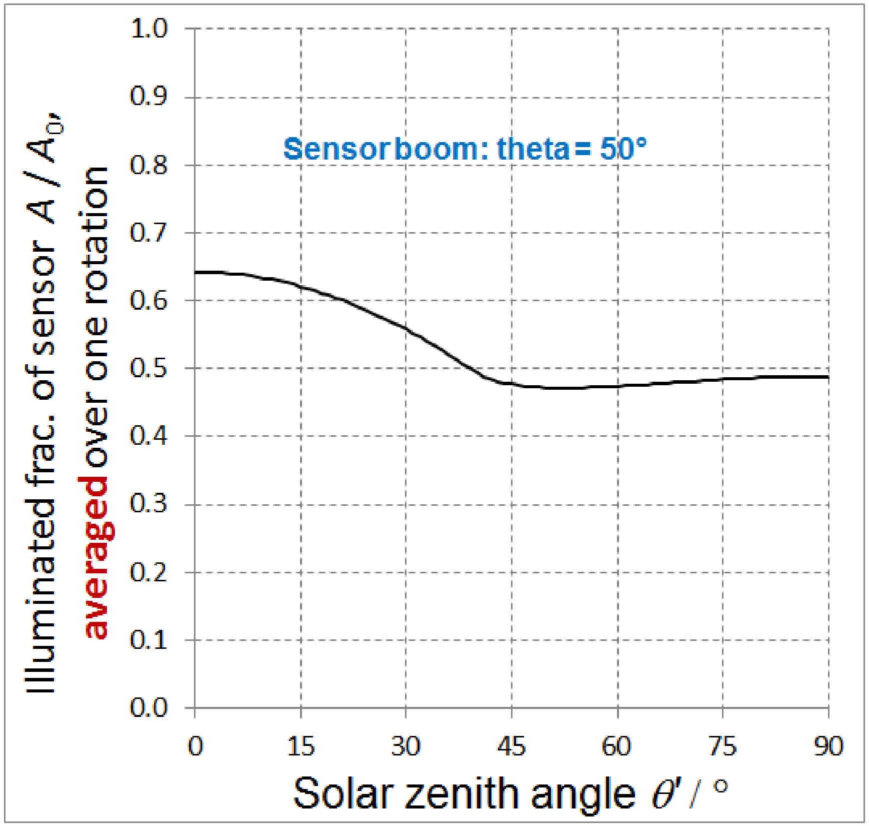
Average orientation of sensor boom

- Correction of direct component of irradiance ("geometry" factor, f_{geo})

Direct irradiation **reduced** according to relative sensor boom surface as seen by sun (A/A_0)



$f_{geo} = A/A_0$ **averaged** over one sonde rotation

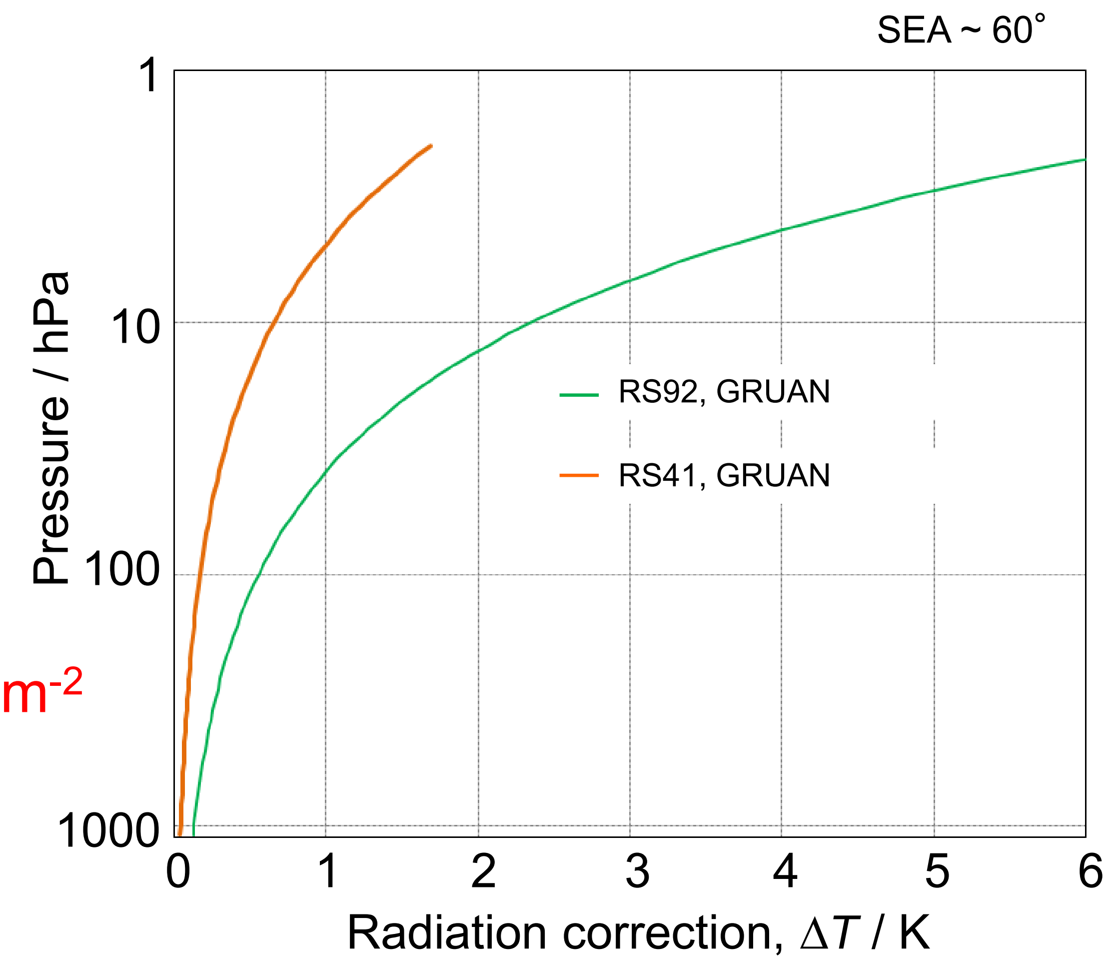


Results daytime radiation correction

Example:

	RS92	RS41
v	5 m·s^{-1}	6 m·s^{-1}
boom angle	50°	63°
f_{geo}	0.47	0.51

- SEA = 60°
- I_{dir} = 1300 W·m^{-2}, I_{diff} = 300 W·m^{-2}



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boom angle	50°	63°
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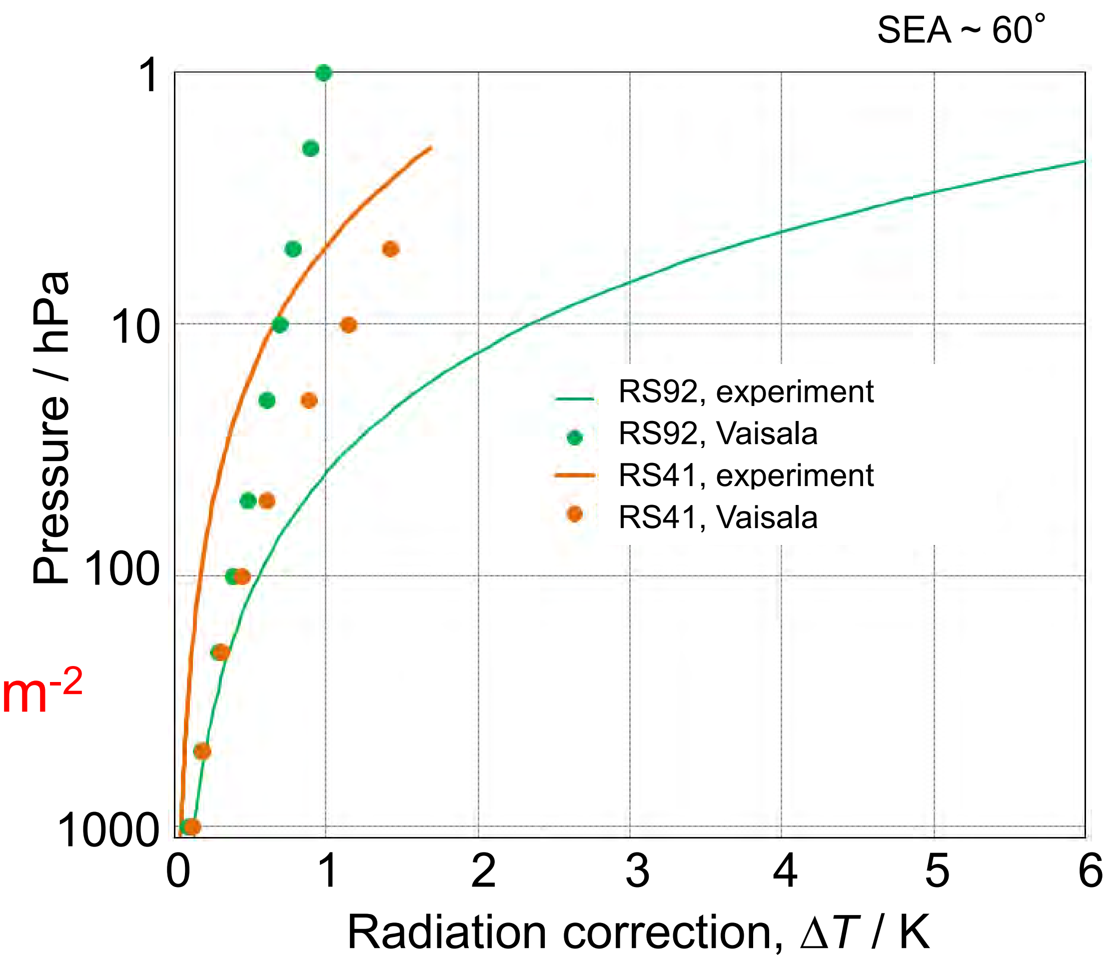
- SEA = 60°
- I_{dir} = 1300 W·m^{-2}, I_{diff} = 300 W·m^{-2}
- Comp. to Vaisala tables
  (B211356EN-A (White Paper), RSN2010)



Comparison *T* –difference RS41-RS92, raw data

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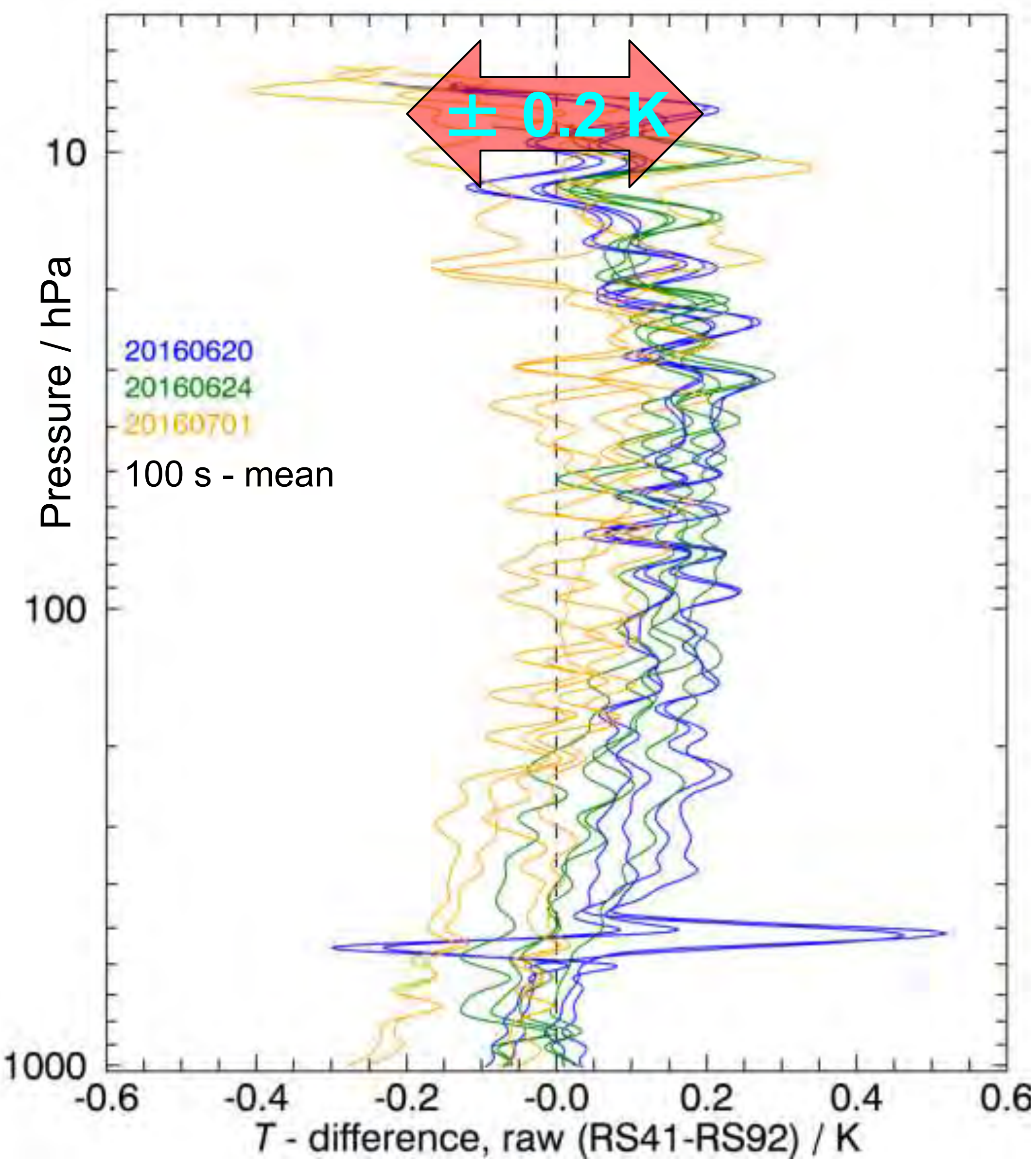
- 2 x RS41, 2 x RS92, 3 flights, booms pointing in the same direct.
- Difference *T*(RS41) - *T*(RS92) → different sensitivity to radiation
- Measured raw *T* -diff. << difference of corrections from experiments

→ inconsistency of experiment-based Corrections (?)



Conclusions / Outlook

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- Resilient experimental data sets for ΔT for several sonde models
- Extended empirical parameterization for better fit model

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

- Results for maximum effect, thermal equilibrium:
  (p = 10 hPa, v = 5 m·s^{-1}, I_a = 1000 W·m^{-2})

Sonde	RS92	RS41	M10	DFM-09
ΔT_{max} / K	2.80	0.89	1.51	1.76

- Correction model:
  Use experimental parameterization $\Delta T(I, p, v)$, reduced by "geometry" factor f_{geo} for direct component of solar irradiation

Conclusions / Outlook

- RS41: correction comparable to Vaisala
- RS92: correction comparable to Vaisala for p > 100 hPa;
  for p < 100 hPa overestimation (?)
- How to explain:
  - large exp. T-response → large RS92-correction
  - RS92-RS41 mismatch (?)
- Further deficiencies / disregarded effects with experimental setup (?)

→ Check validity of "geometry" factor f_{geo} by measuring T- effect in chamber as function of sensor orientation

→ Statistical analyses: consistency of radiation correction from
daytime - nighttime comparisons
dual soundings with different sondes

→ More measurements at low p and high I

Thanks for your attention

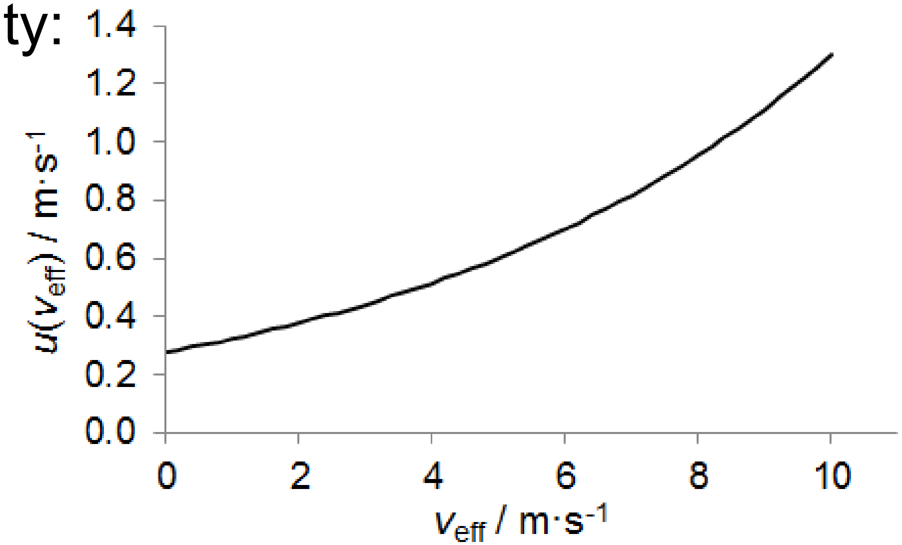
Measurements: Ventilation v

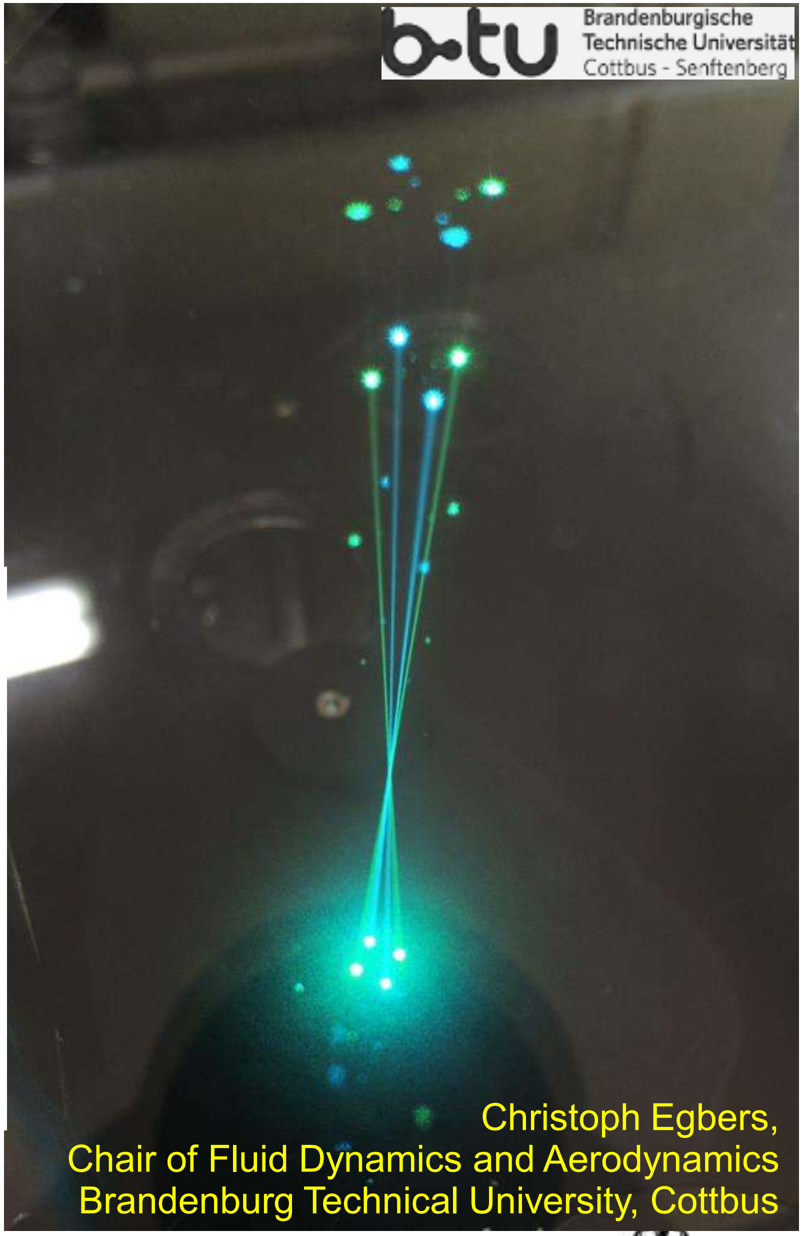
– Measurement of chamber air velocity field using LDA (Laser Doppler Anemometry)

– Parameterization with p and fan voltage U_{fan}:

$$v = f(p) \cdot U_{\mathrm{fan}}$$

– Uncertainty:





Results: parameterization of maximal T-response (ΔT)

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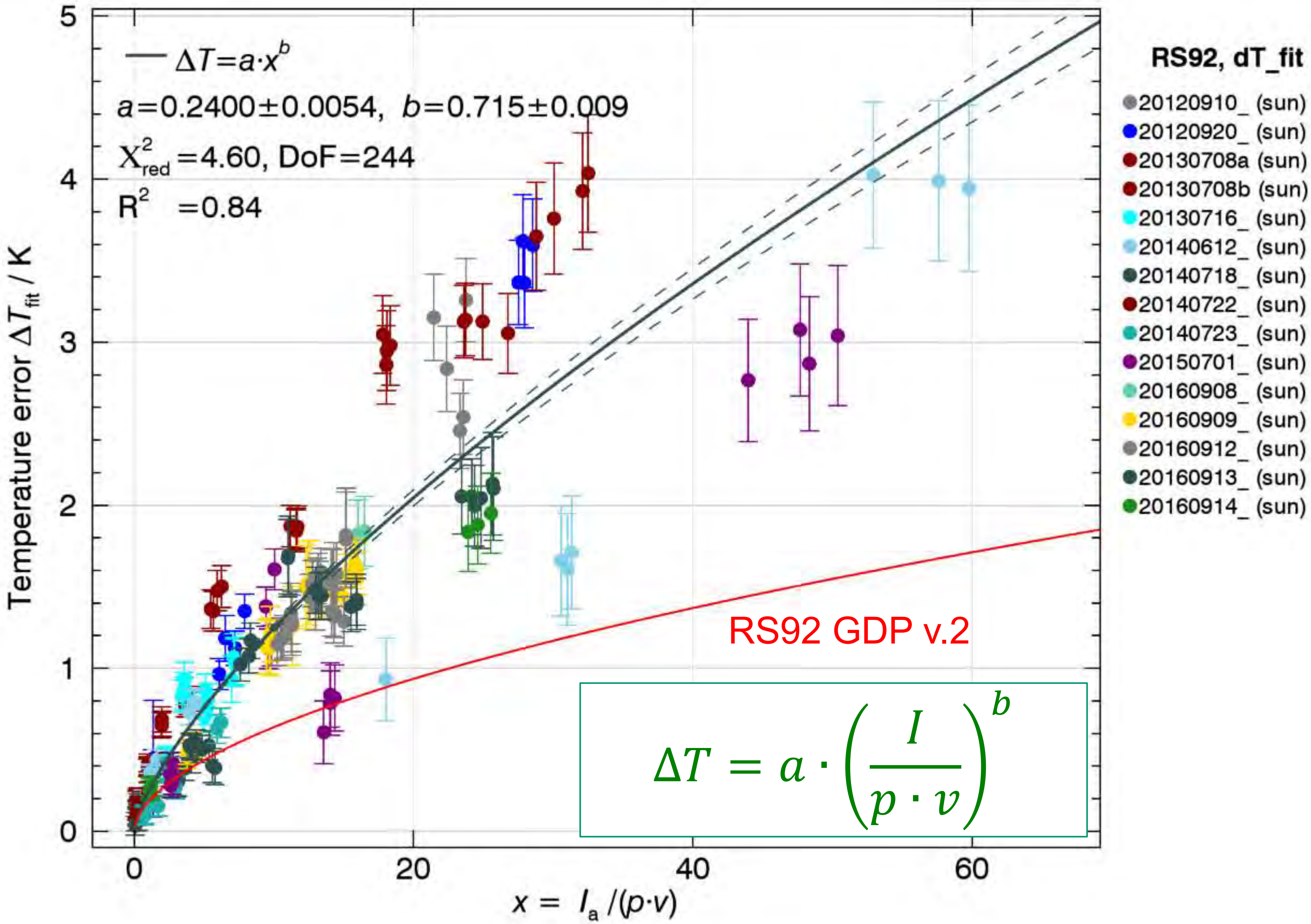
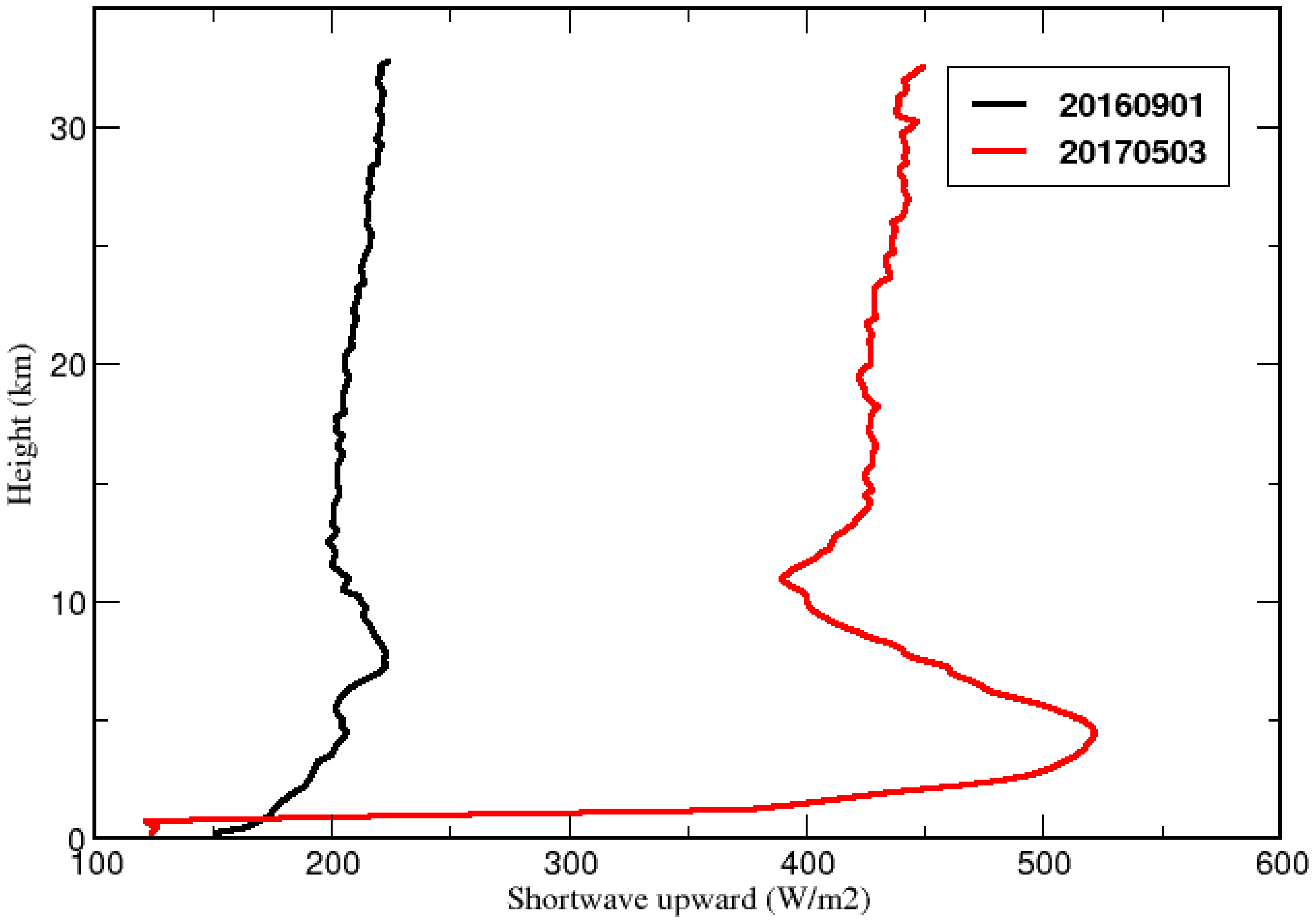


$$\Delta T = a \cdot \left(\frac{I}{p \cdot v}\right)^{b}$$

ISOLDE Lindenberg/DWD



Fri Jun 9 10:12:11 2017

Ralf Becker, MOL-RAO Lindenberg