Effect of solar radiation on radiosonde temperature sensors

Christoph von Rohden
GRUAN Lead Centre, DWD

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

- $T$-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 \(\rightarrow\) maximum \(\Delta T\) (thermal equilibrium)
- Controlled parameters:
  - Irradiance \(I_a\): \((200–1000)\) \(W\cdot m^{-2}\), \(u(I_a) = 2\) % (direct sun and grey filters, pyrheliometer)
  - Pressure \(p\): \((3–1020)\) hPa, \(u(p) = 0.3\) hPa (shadow sonde)
  - Ventilation \(v\): \((0–10)\) \(m\cdot s^{-1}\), \(u(v) < 1 \) m\cdot s^{-1}\) (related to fan voltage)

\(\rightarrow\) Evaluation of data 2012-2016 for several radiosonde models
Measurement data
Measurement data

![Graph showing measurement data](image-url)
Step response

Finding:
$T$-response two phases

→ thermal interaction of "quick" sensor element with "slower" sensor boom
Estimating maximum $T$-response

- $\Delta T$ as maximal effect in thermal equilibrium
- fit exp. data using 5 parameters: $T_\infty$, $T_a$, $\tau_s$, $\tau_l$, $r$ ($\tau_s$ fixed), separate for "up" and "down" parts

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

$\Delta T = T_\infty(\text{up}) - T_\infty(\text{down})$

$T_\infty(\text{up})$  $T_\infty(\text{down})$

sun  shadow

time, $t$
Estimating maximum $T$-response (Vaisala RS92)

Finding:
$T$-response two phases

→ thermal interaction of “quick” sensor element with “slower” sensor boom
Estimating maximum $T$-response (Vaisala RS92)

Finding:

$T$-response two phases

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

$\tau_s = 1 \, \text{s}$
Estimating maximum $T$-response (Vaisala RS92)

Finding:
$T$-response two phases

→ thermal interaction of “quick” sensor element with “slower” sensor boom
Estimating maximum $T$-response (Vaisala RS92)

Finding:
$T$-response two phases

$\tau_s = 3 \text{ s}$
Effect of direct irradiation

180° setup - details

- Lower frequency oscillations ("slow" part of radiation response \( \rightarrow \) rotation?)
  \( \rightarrow \) similar in amplitude for both sondes
- Short peaks ("quick" part, \( \tau_s \)) on top of slower osc. \( \rightarrow \) pendulum motion?
  \( \rightarrow \) more pronounced for RS92 (thinner sensor element)
Results: parameterization of maximal $T$-response ($\Delta T$)

$$\Delta T = a \cdot x^b$$

$a = 0.2400 \pm 0.0054$, $b = 0.715 \pm 0.009$

$X_{\text{red}}^2 = 4.60$, DoF = 244

$R^2 = 0.84$
Results: parameterization of maximal $T$-response ($\Delta T$)

$$\Delta T = a \cdot x^b$$

$a = 0.0914 \pm 0.0041, \ b = 1.046 \pm 0.018$

$X_{\text{red}}^2 = 1.57, \ DoF = 244$

$R^2 = 0.83$

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

$x = \frac{I}{(p^i \cdot v^k)}$ 

$[i, j, k] = [1.0, 0.6, 1.4]$
Results: parameterization of maximal $T$-response ($\Delta T$)

$$\Delta T = a \cdot x^b$$

$a = 0.0994 \pm 0.0054$, $b = 0.664 \pm 0.020$

$X_{\text{red}}^2 = 2.06$, DoF = 159

$R^2 = 0.81$

$$\Delta T = a \cdot \left( \frac{I}{p \cdot v} \right)^b$$
Results: parameterization of maximal \( T \)-response (\( \Delta T \))

\[ \Delta T = a \cdot x^b \]

\( a = 0.0142 \pm 0.0015, \ b = 0.977 \pm 0.028 \)

\( X_{\text{red}}^2 = 1.00, \text{DoF} = 159 \)

\( R^2 = 0.88 \)
Results: parameterization of maximal $T$-response ($\Delta T$)

$$\Delta T = a \cdot x^b$$

$a = 0.3074 \pm 0.0050$, $b = 0.491 \pm 0.006$

$X_{\text{red}}^2 = 5.97$, DoF = 315

$R^2 = 0.79$
Results: parameterization of maximal $T$-response ($\Delta T$)

$$\Delta T = a \cdot x^b$$

$a = 0.0114 \pm 0.0007$, $b = 1.037 \pm 0.014$

$X_{\text{red}} = 1.45$, DoF = 315

$R^2 = 0.91$
Results: parameterization of maximal $T$-response ($\Delta T$)

\[ \Delta T = a \cdot x^b \]

$a = 0.2630 \pm 0.0067$, $b = 0.504 \pm 0.011$

$X_{\text{red}}^2 = 4.55$, DoF = 92

$R^2 = 0.87$
Results: parameterization of maximal $T$-response ($\Delta T$)

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

<table>
<thead>
<tr>
<th>Sonde</th>
<th>RS92</th>
<th>RS41</th>
<th>M10</th>
<th>DFM-09</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta T_{\text{max}} / K$</td>
<td>2.80</td>
<td>0.89</td>
<td>1.51</td>
<td>1.76</td>
</tr>
</tbody>
</table>

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

\[ x = \frac{I_a}{(p \cdot v)^k} \]

\[ [i, j, k] = [1.0, 0.6, 1.1] \]
Experimental data \[ \rightarrow \text{radiation correction} \]

- **Approach for } T\text{-correction:**
  
  1) Calculate average "geometry“-factor \( f_{\text{geo}} \) (SEA, boom angle) *(next slide)*
  
  2) Reduce **direct** component of solar radiation \( I \) (from rad. model) by \( f_{\text{geo}} \):

  \[
  I = I_{\text{diffuse}} + f_{\text{geo}} \cdot I_{\text{direct}}
  \]

  3) Calculate radiation correction:

  \[
  \Delta T = a \cdot \left( \frac{I}{p_{i\cdot v^k}} \right)^b
  \]

**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
• 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
Correction of direct component of irradiance ("geometry" factor, $f_{\text{geo}}$)

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

$$f_{\text{geo}} = \frac{A}{A_0} \text{ averaged over one sonde rotation}$$
Results daytime radiation correction

Example:

<table>
<thead>
<tr>
<th>$v$ (m·s$^{-1}$)</th>
<th>RS92</th>
<th>RS41</th>
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<td>boom angle</td>
<td>50°</td>
<td>63°</td>
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<td>$f_{\text{geo}}$</td>
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- SEA = 60°
- $I_{\text{dir}} = 1300$ W·m$^{-2}$, $I_{\text{diff}} = 300$ W·m$^{-2}$
Results daytime radiation correction

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- SEA = 60°
- $I_{\text{dir}} = 1300$ W·m$^{-2}$, $I_{\text{diff}} = 300$ W·m$^{-2}$
- Comp. to Vaisala tables
  (B211356EN-A (White Paper), RSN2010)
Comparison $T$–difference RS41-RS92, raw data

- 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. $\ll$ difference of corrections from experiments → inconsistency of experiment-based Corrections (?)
Conclusions / Outlook

- Resilient experimental data sets for $\Delta T$ 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:
  \[(p = 10 \text{ hPa}, \nu = 5 \text{ m/s}^{-1}, I_a = 1000 \text{ W/m}^2)\]

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- Correction model:
  Use experimental parameterization $\Delta T(I, p, \nu)$, reduced by “geometry” factor $f_{\text{geo}}$ 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 $\rightarrow$ large RS92-correction
  - RS92-RS41 mismatch (?)
- Further deficiencies / disregarded effects with experimental setup (?)

$\rightarrow$ Check validity of “geometry” factor $f_{geo}$ by measuring $T$- effect in chamber as function of sensor orientation

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

$\rightarrow$ 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 $U_{\text{fan}}$:
  \[ v = f(p) \cdot U_{\text{fan}} \]
- Uncertainty:
Results: parameterization of maximal $T$-response ($\Delta T$)

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