



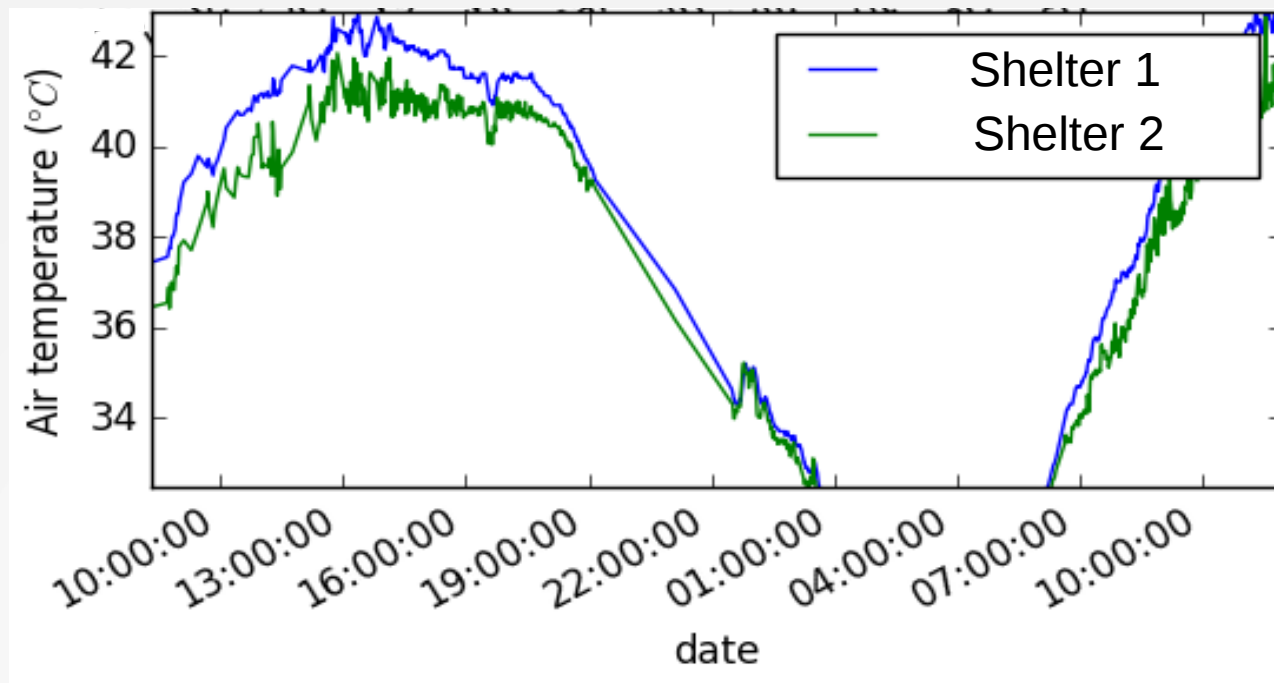
A semi-empirical model to characterize the error of air temperature measurement induced by the shelter used

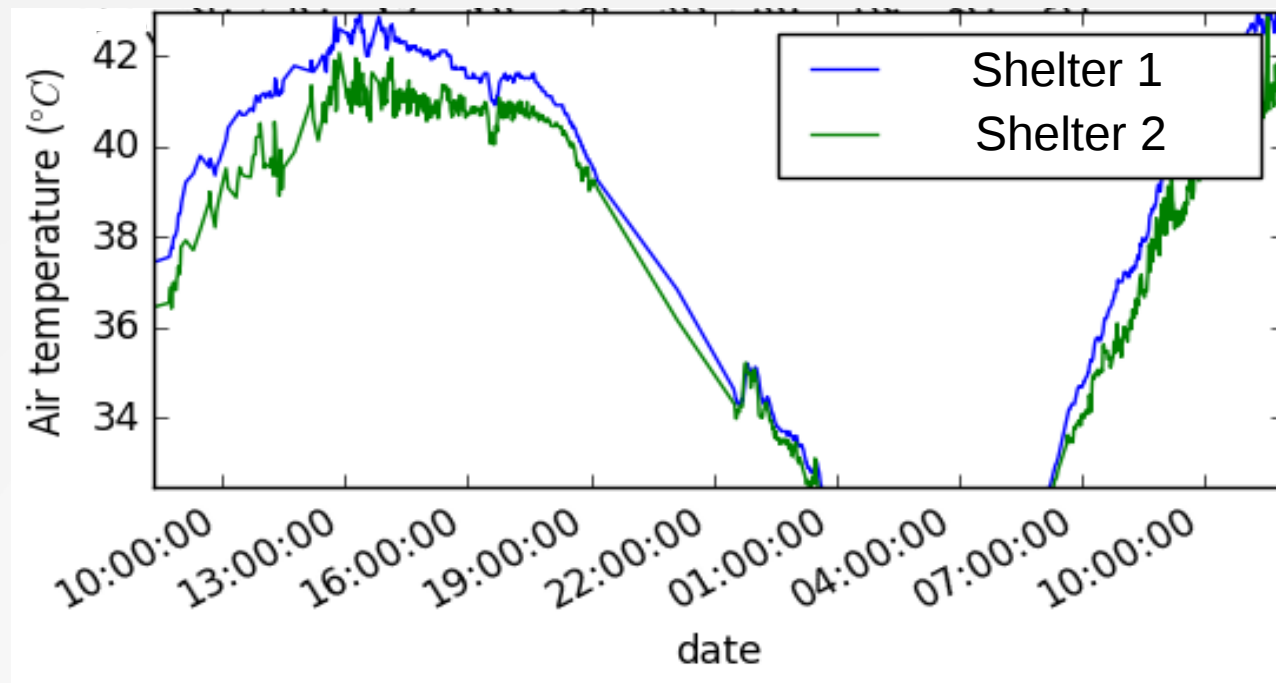
Jérémy BERNARD⁽¹⁾,
Pascal Kéравec, Benjamin Morille,
Erwan Bocher, Marjorie Musy,
Isabelle Calmet,

⁽¹⁾ LAB-STICC, CNRS, France

2018-09-05

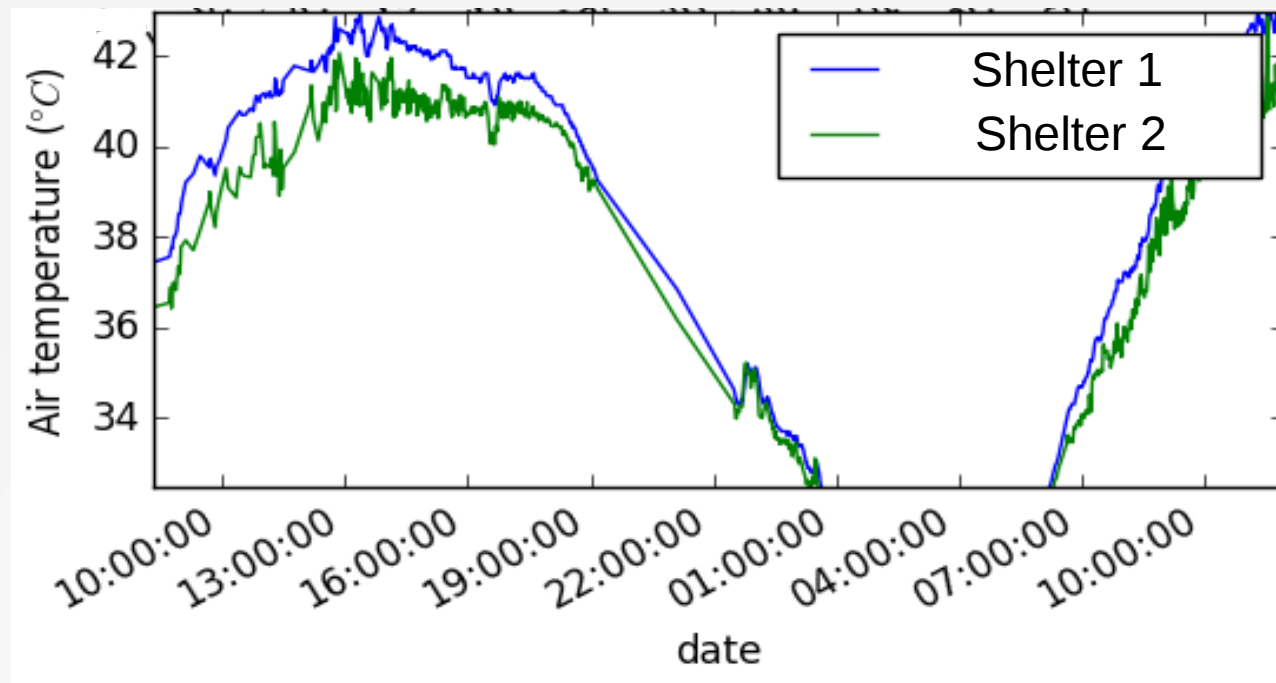






→ Correction models
have been proposed
(Nakamura et al., 2005; Cheng et al., 2014)

$$e_T = \phi_0 + \phi_1 \frac{Ray}{\rho C_p T_{ref} U} + \phi_2 \left(\frac{Ray}{\rho C_p T_{ref} U} \right)^2$$



Correction models

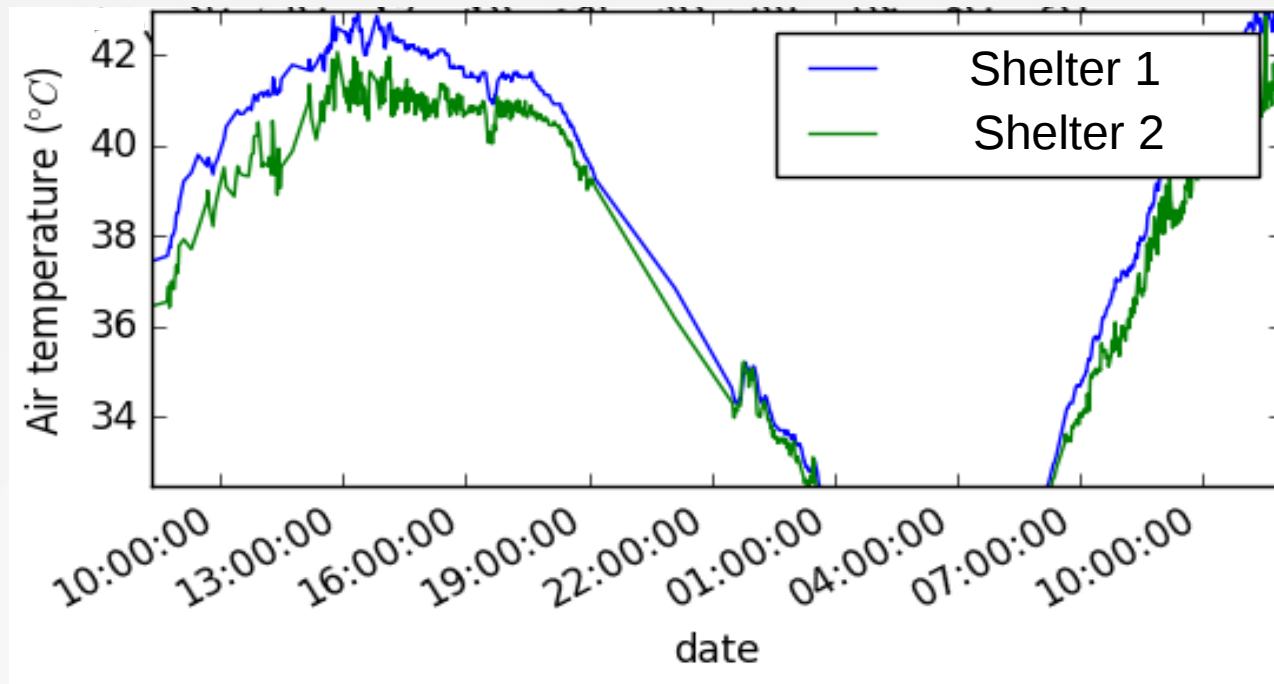
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Limitations:

- empirical models (lack of physical meaning)
- only few screens compared



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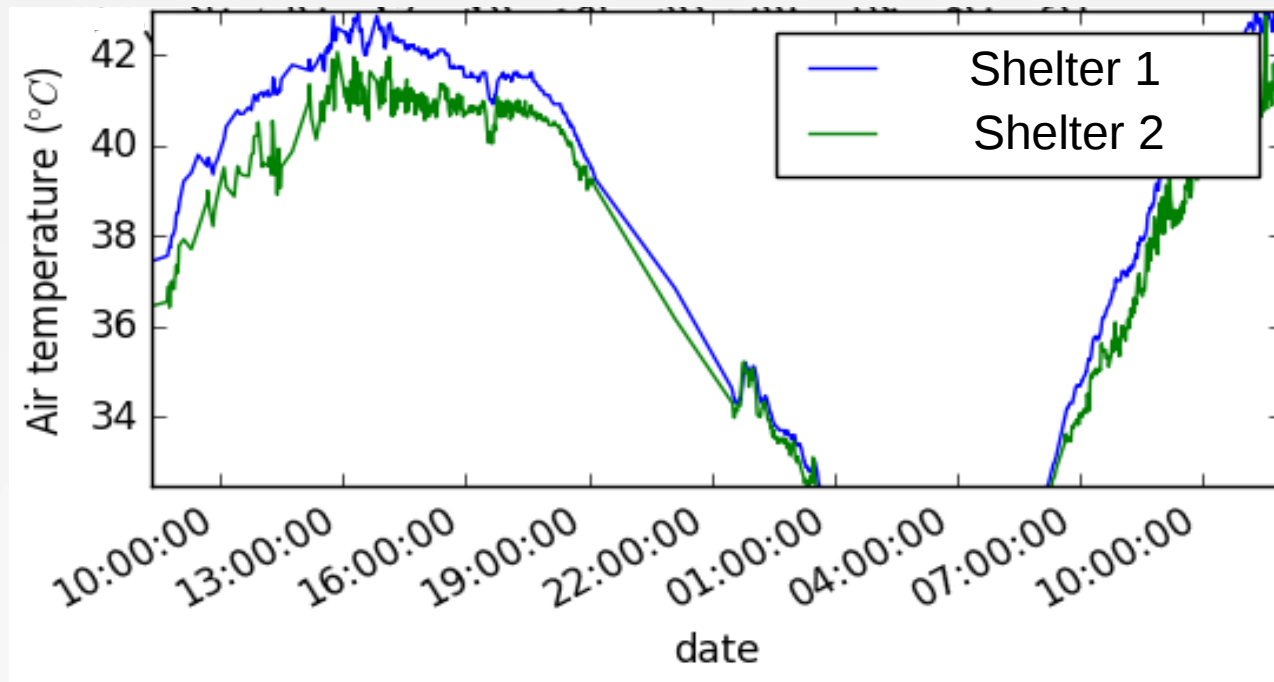
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Large intercomparison campaign has

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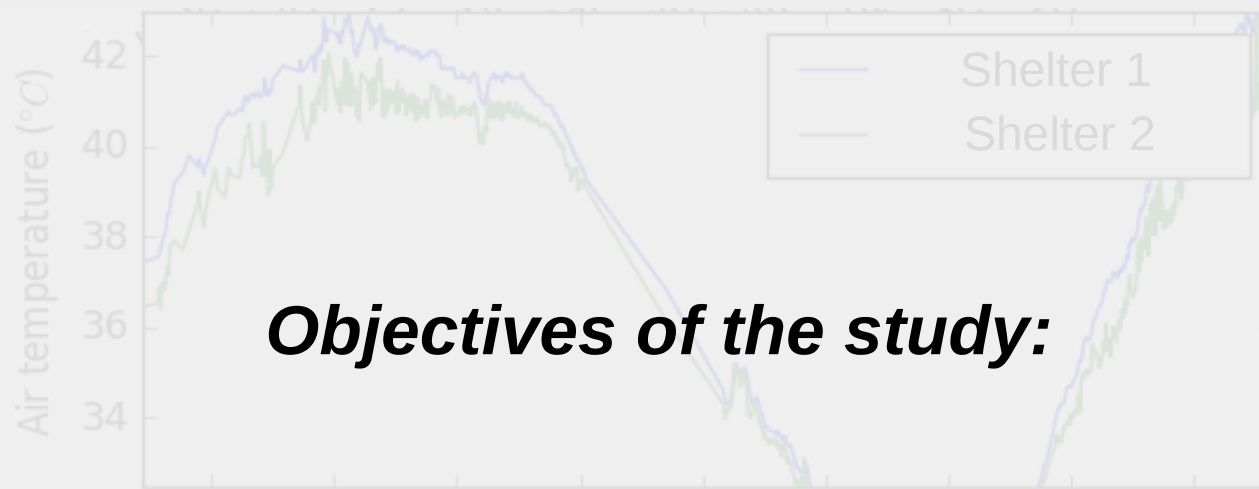
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(Lacombe et al., 2010; WMO, 2005)

Limitations:

→ *only observations*
 → *lag due to ventilation lack:*
method not robust



Objectives of the study:

→ *propose a simplified model based on a physical analysis*

→ *apply it to a large number of shelters*

→ *verify the physical consistency of the model according to observed data*

Limitations:

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Large intercomparison campaign has

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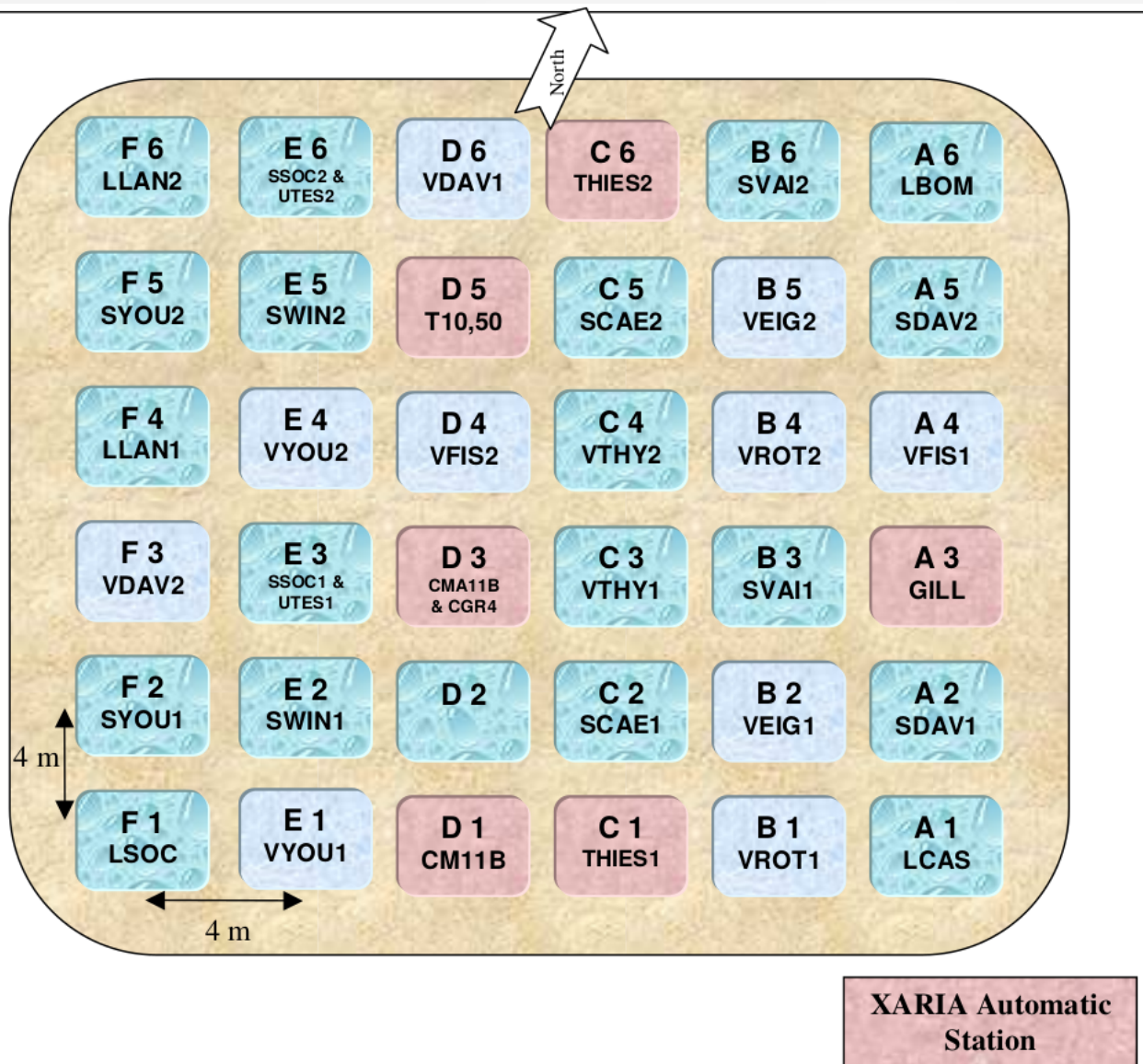
Data



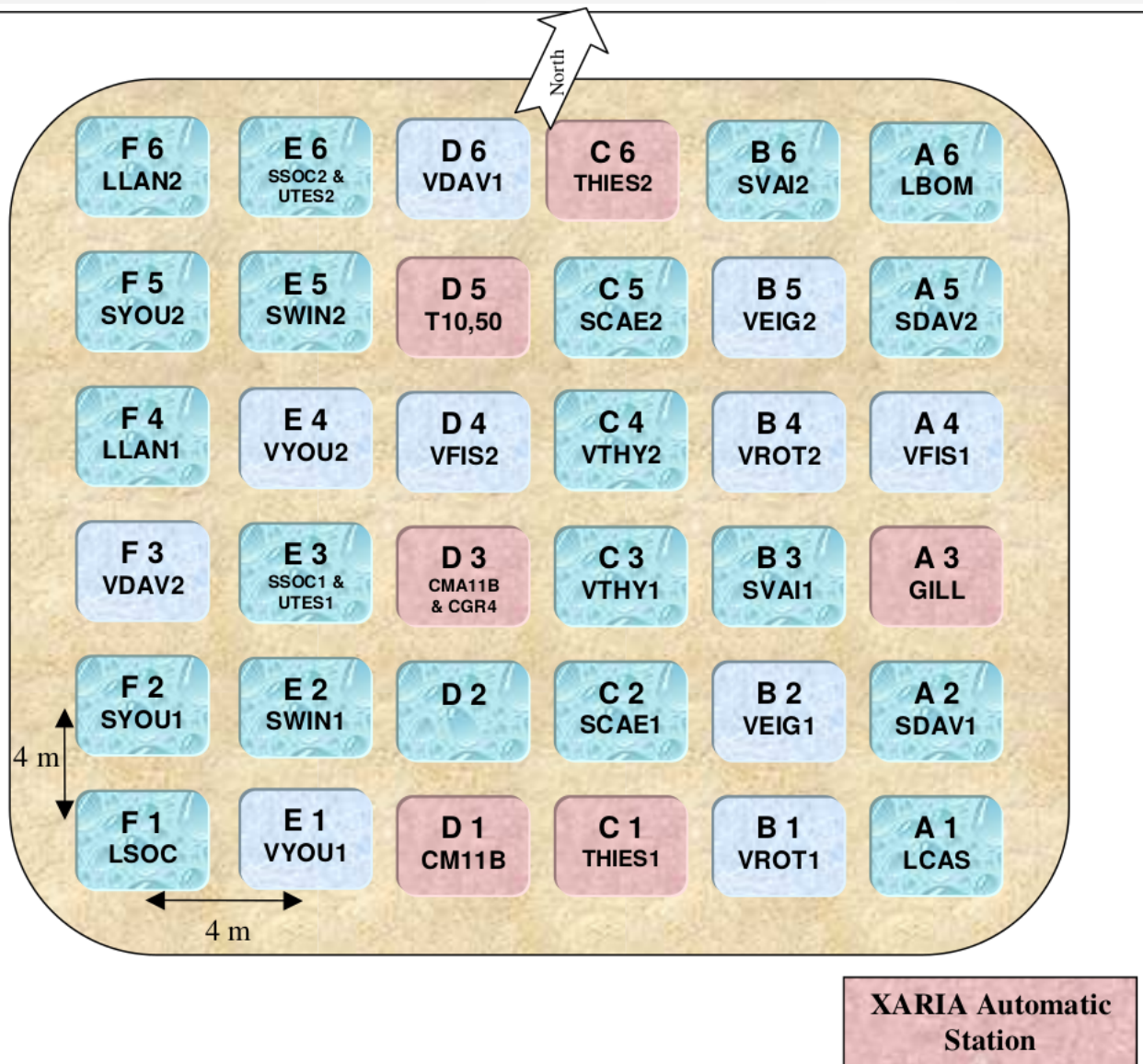
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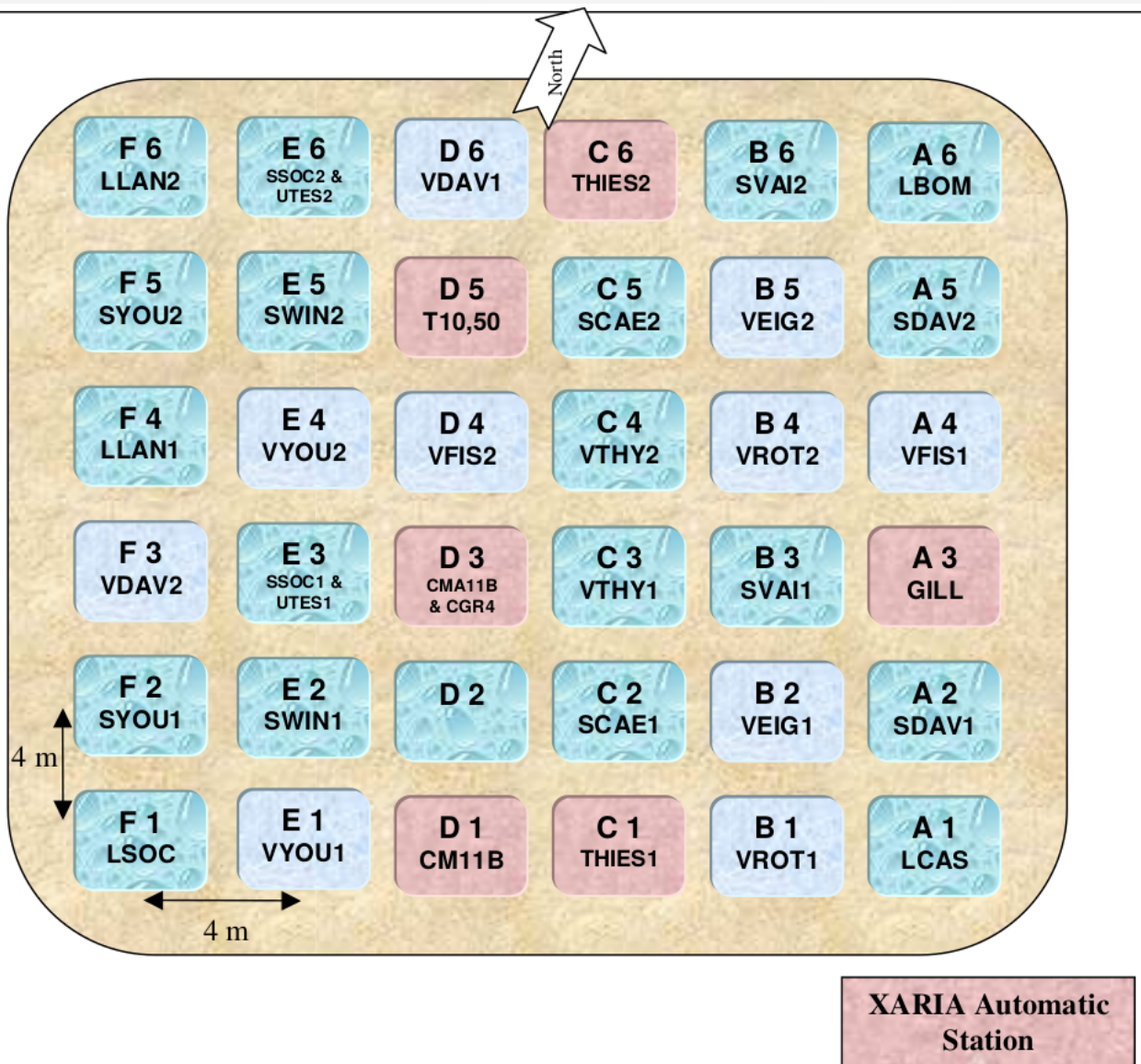
Screens

Ventilated

Non-Ventilated

A1 : Casella
 A2, A5 : Davis
 A4, D4 : Fischer
 A6: Stevenson
 B1, B4: RS 12T Rotronic
 B2, B5: LAM 630 Eigenbrodt
 B3, B6: HMT 330 Vaisala
 C2, C5: TU 20 AS CAE
 C3, C4: VTP 37 Thygan
 D6, F3: Davis
 E1, E4: Young
 E2, E5: T351 Windspeed
 E3, E6: Socrima
 F1: Large Socrima
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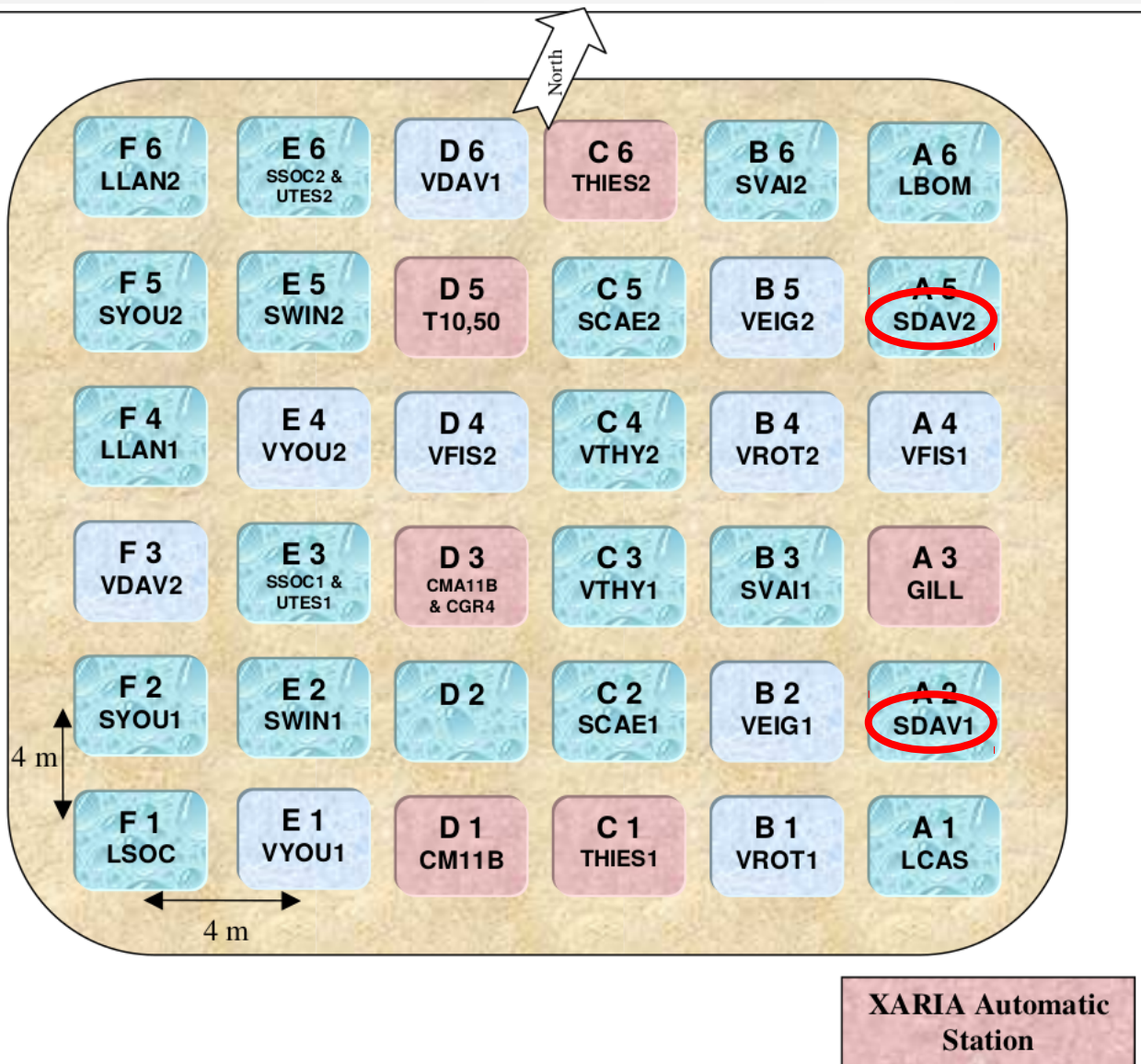
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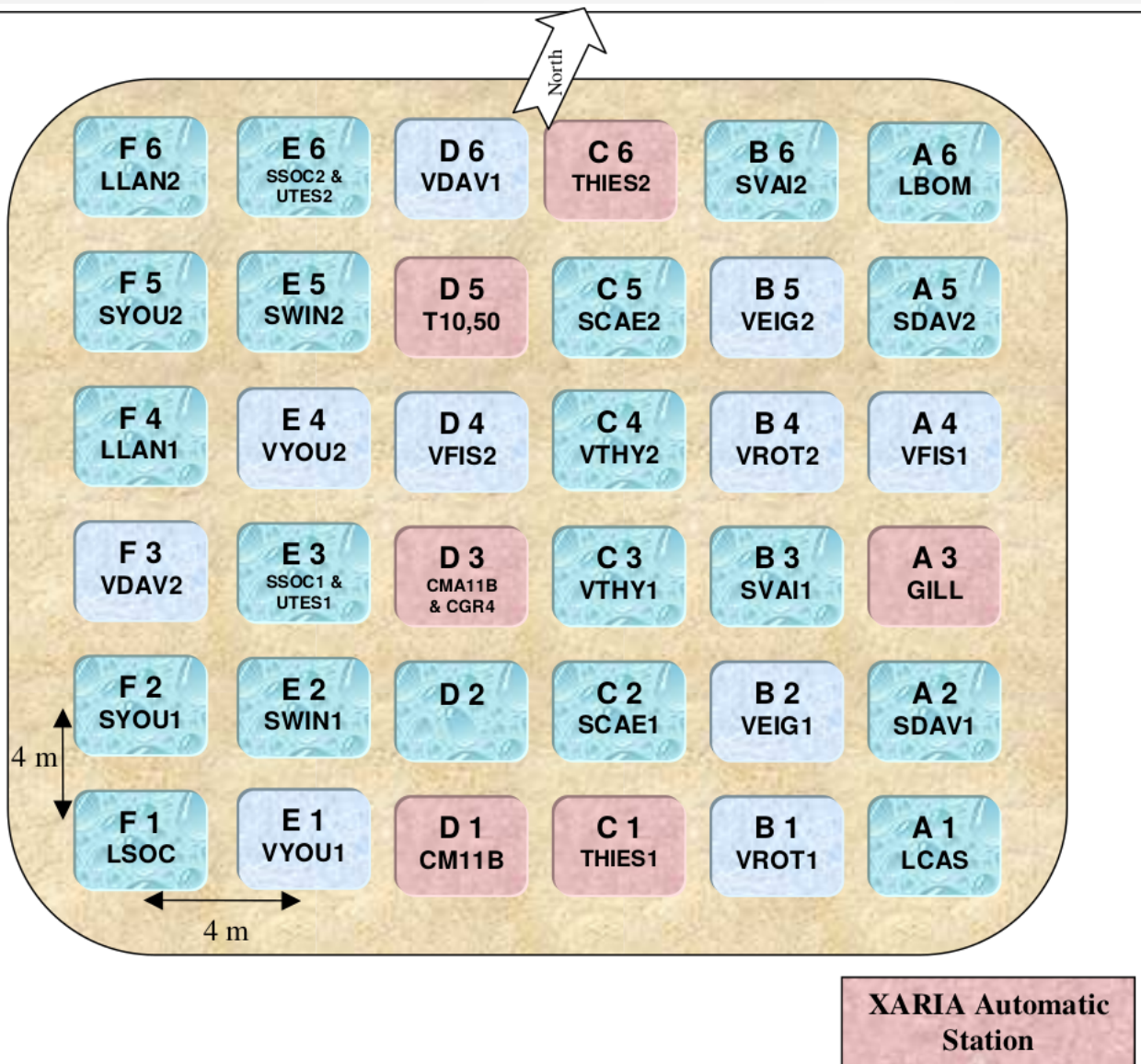
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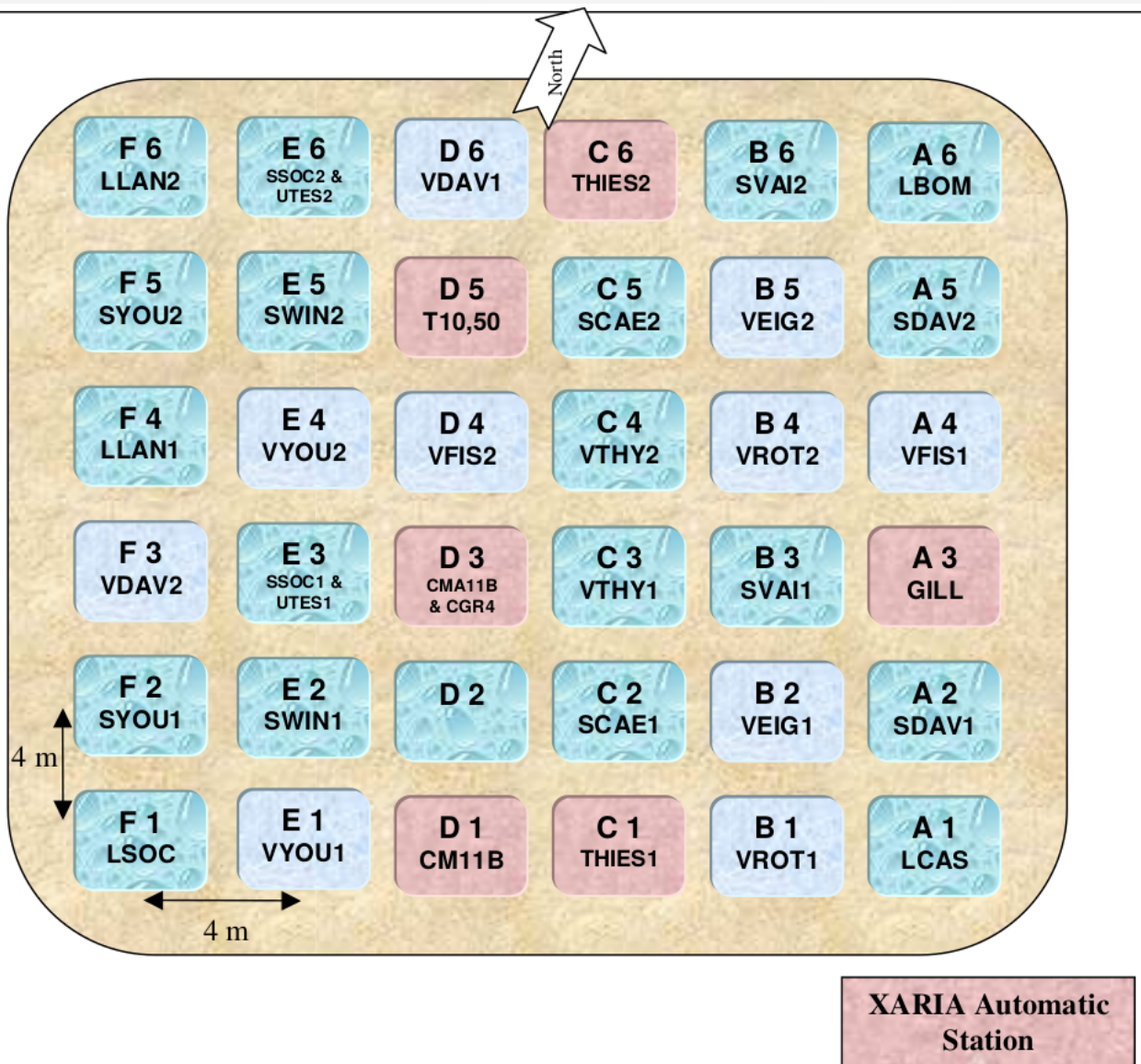
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Ancillary measurements


A3: Windsonic Gill
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D5 : Ground, +10 +50 cm temperatures
Xaria : (P,T,U,RR,SD)

Data



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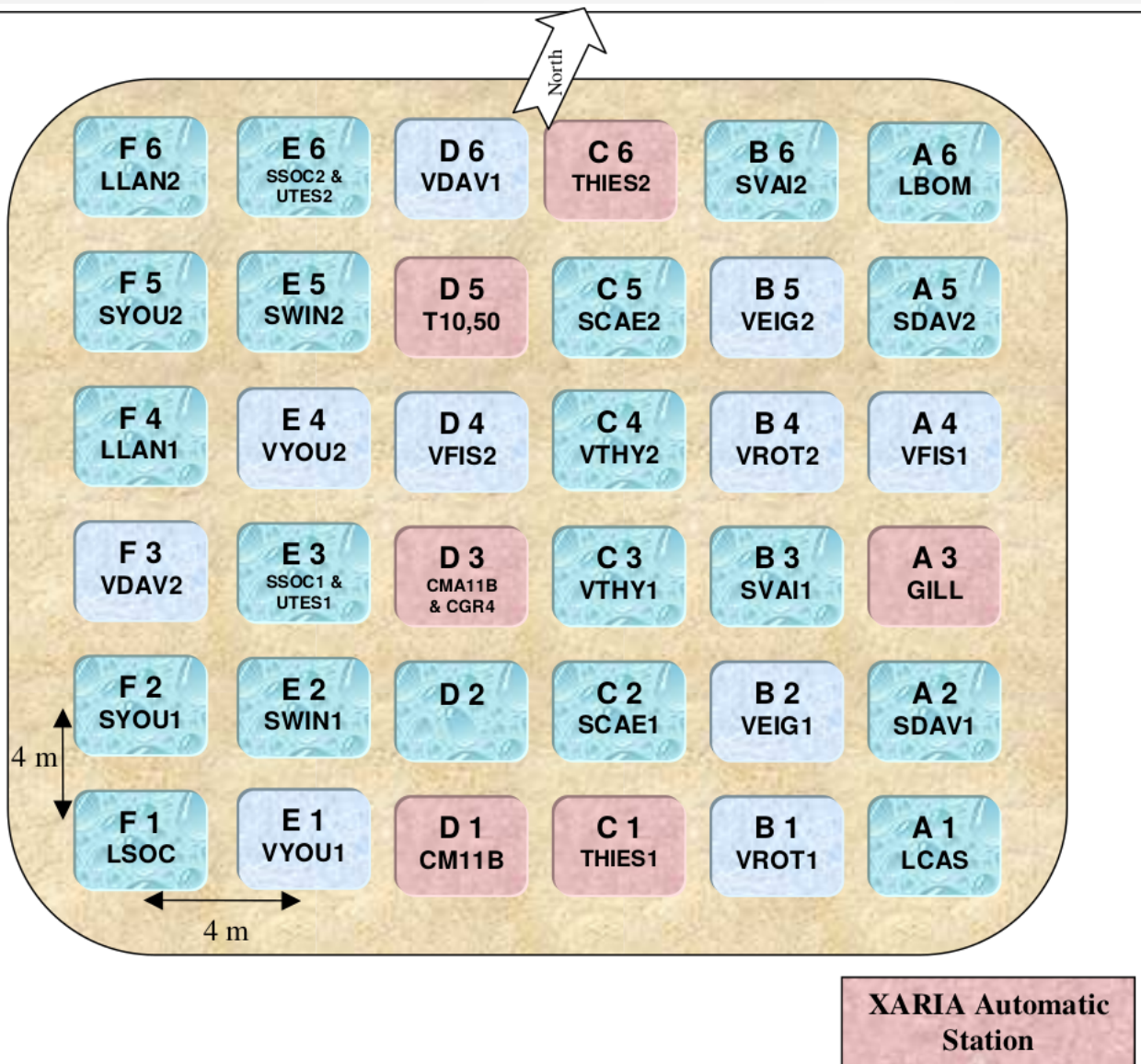
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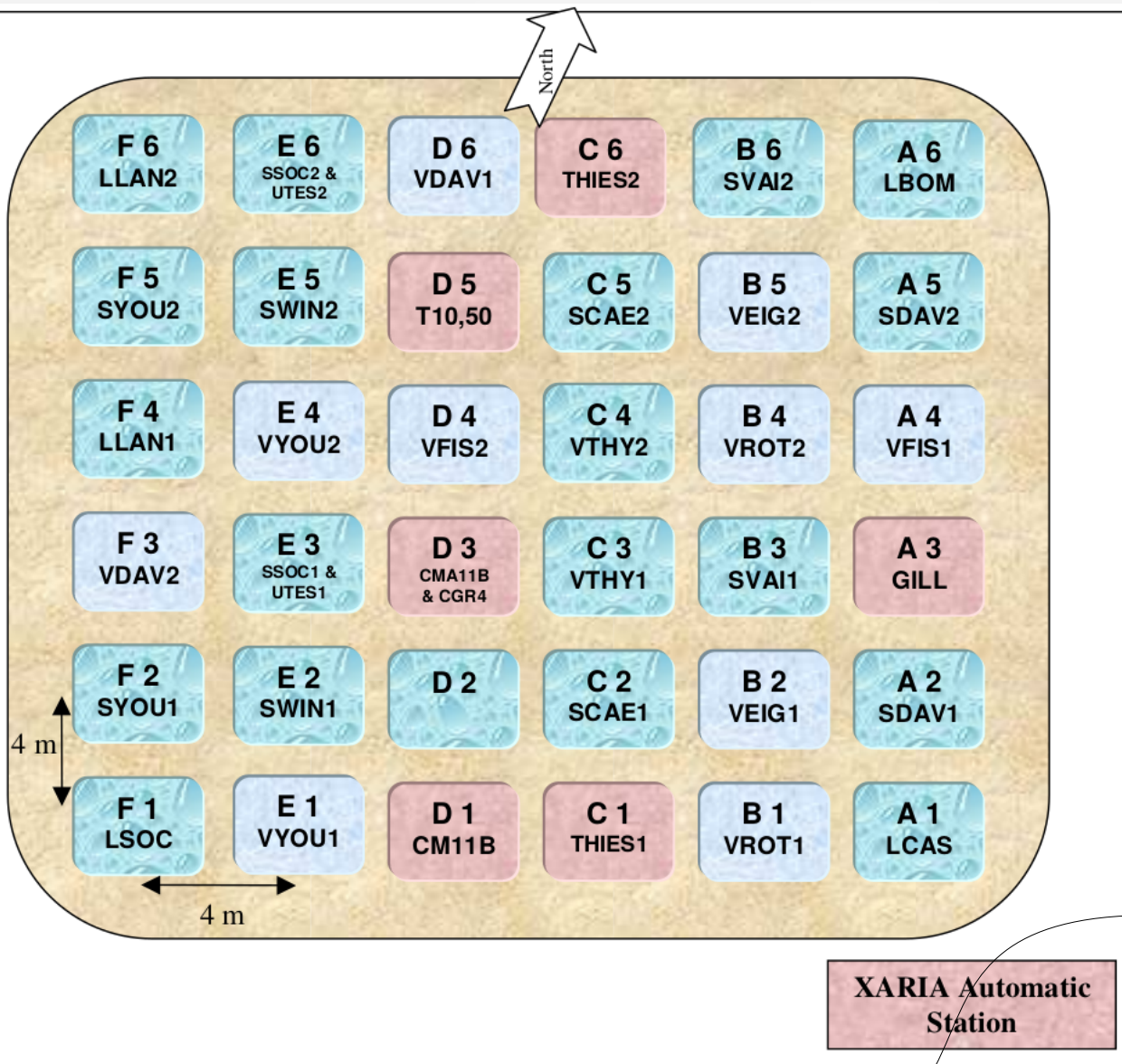
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 $U(t)$

Data



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Non-Ventilated

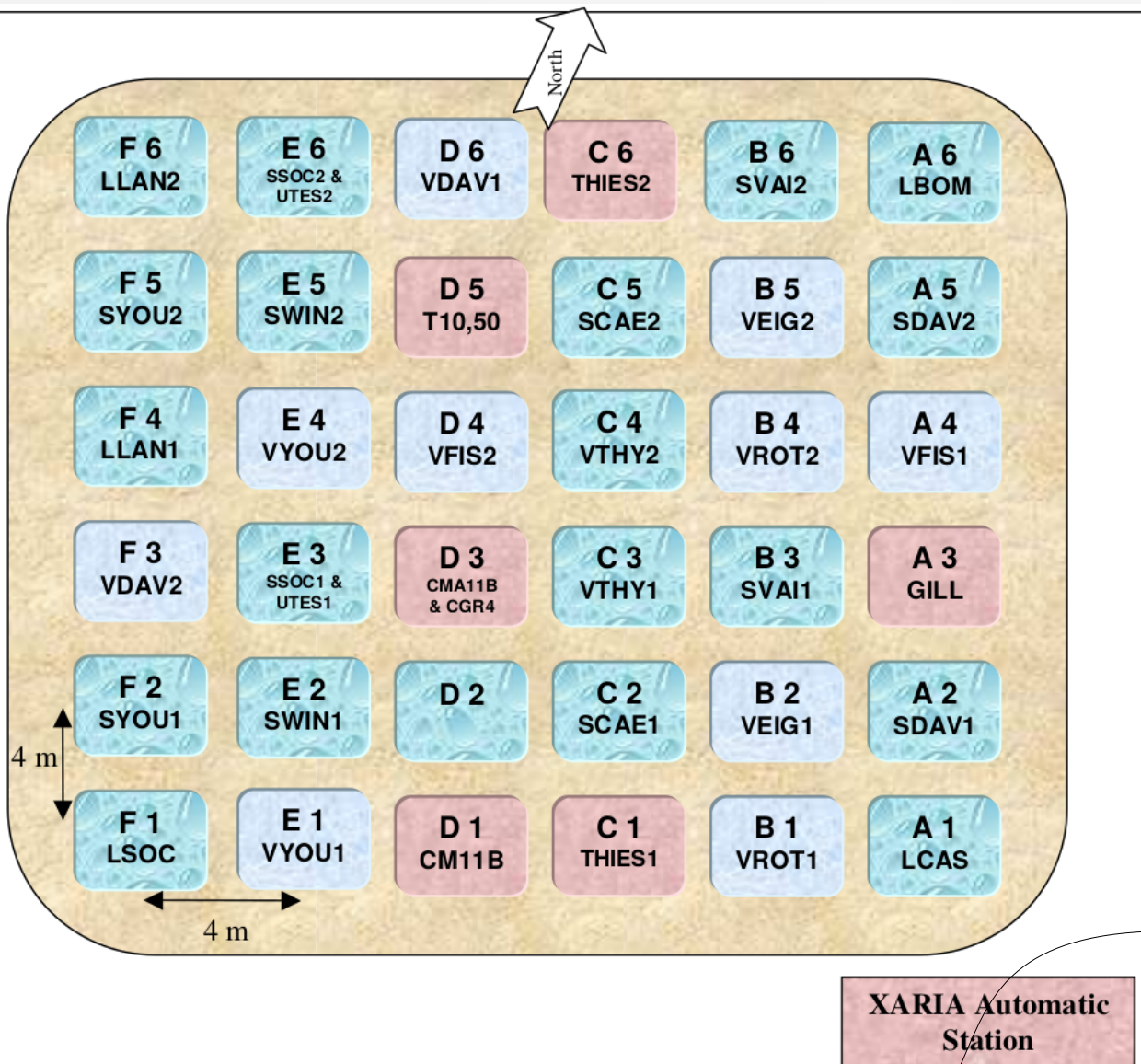
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Data



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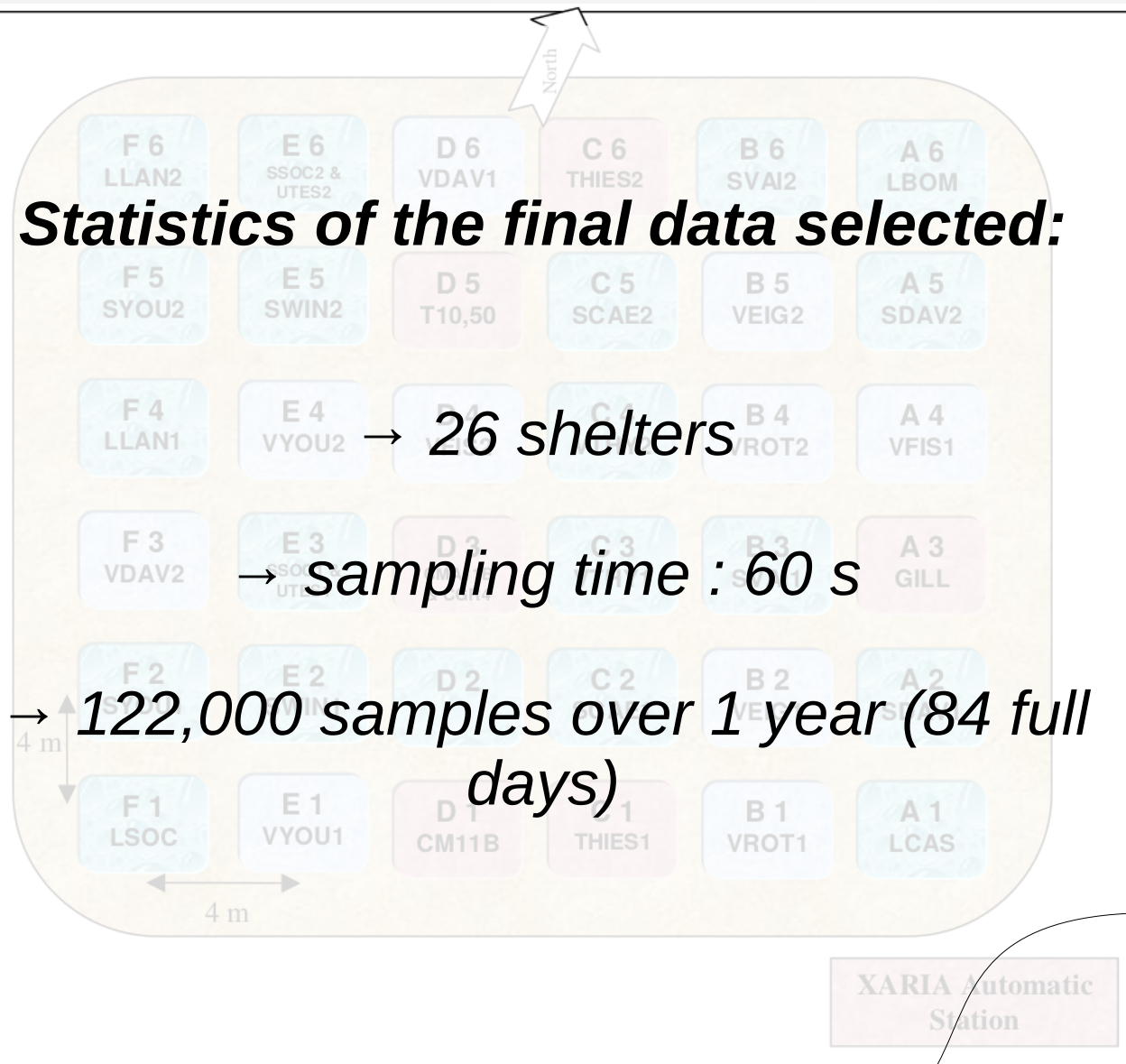
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Data

Statistics of the final data selected:

Screens

Ventilated

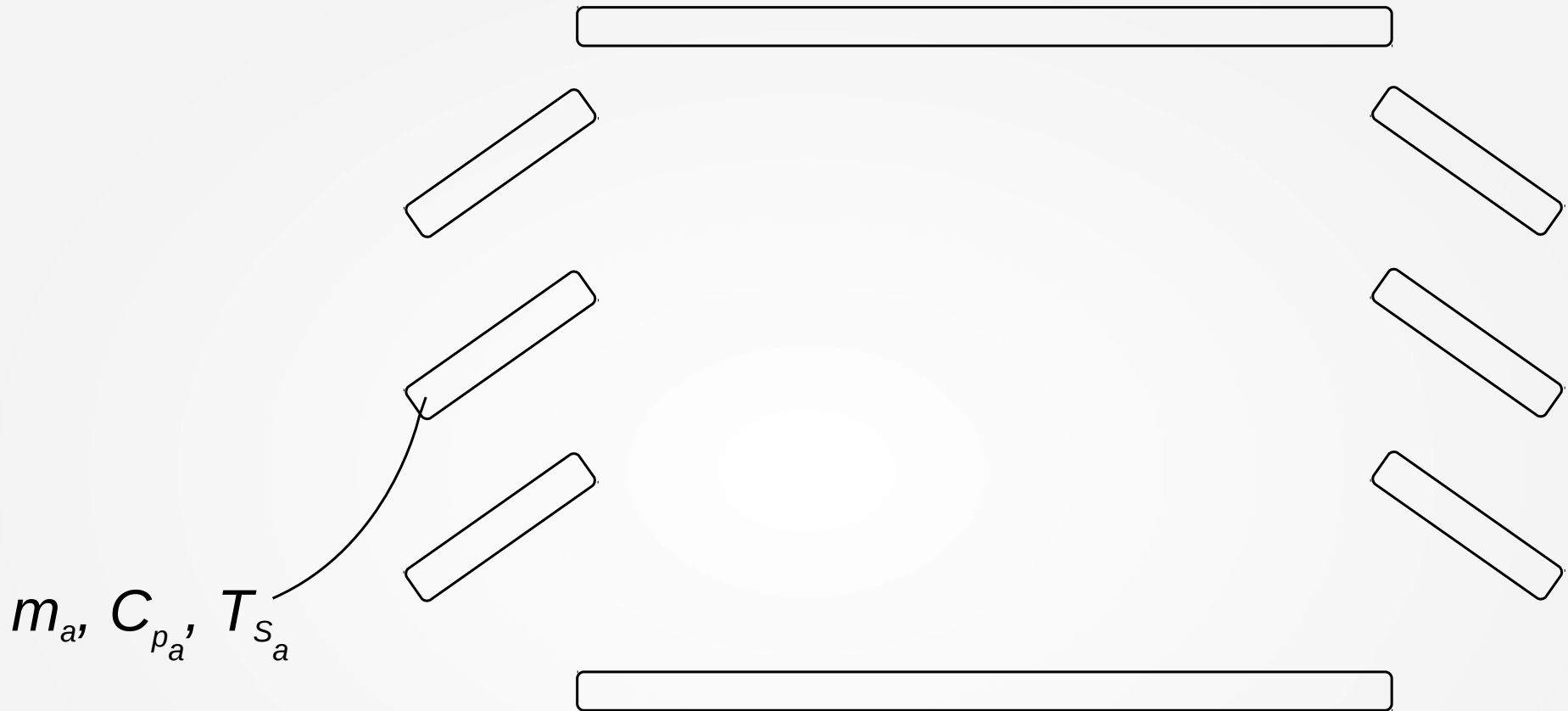
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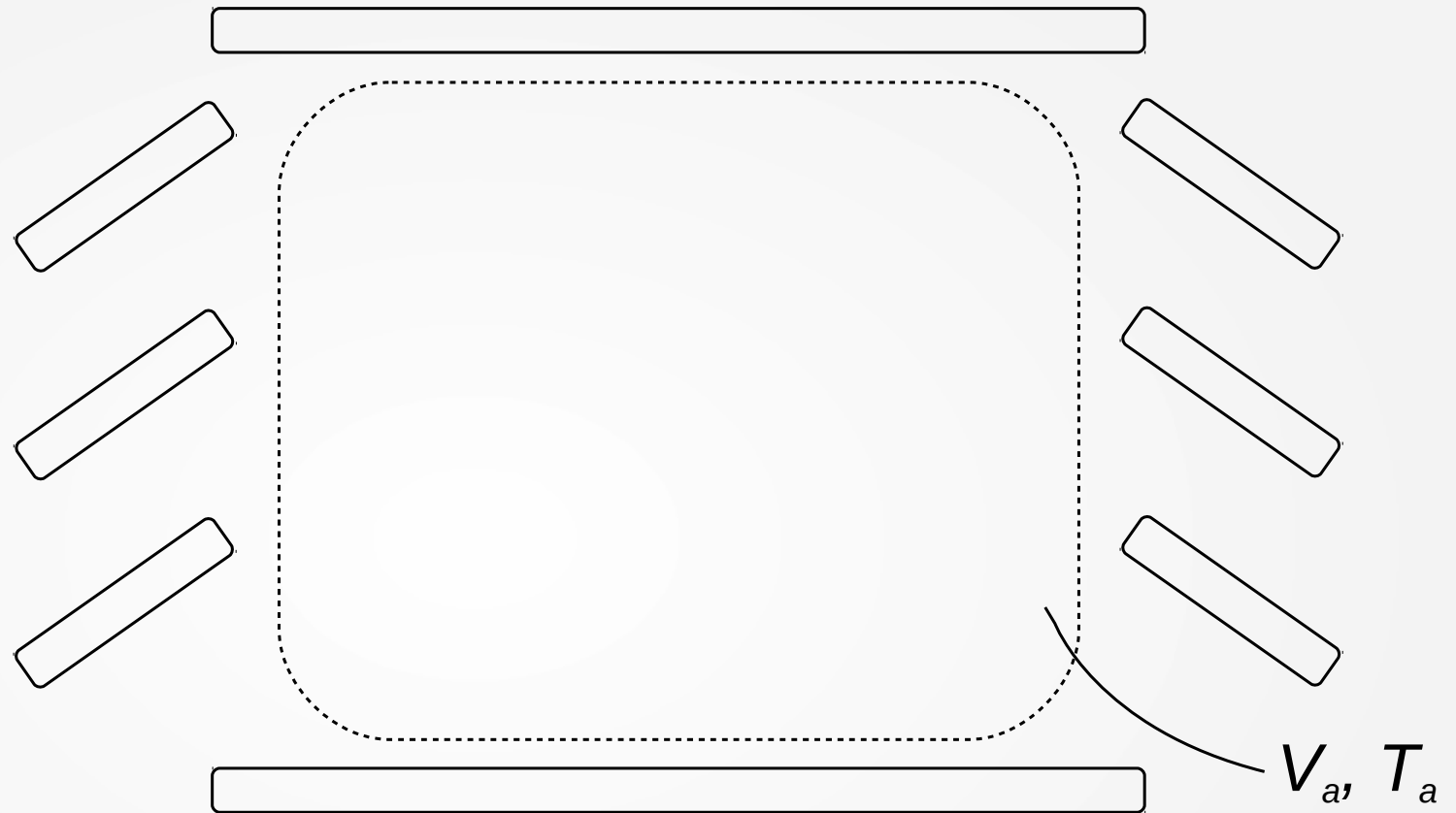
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A simplified shelter...

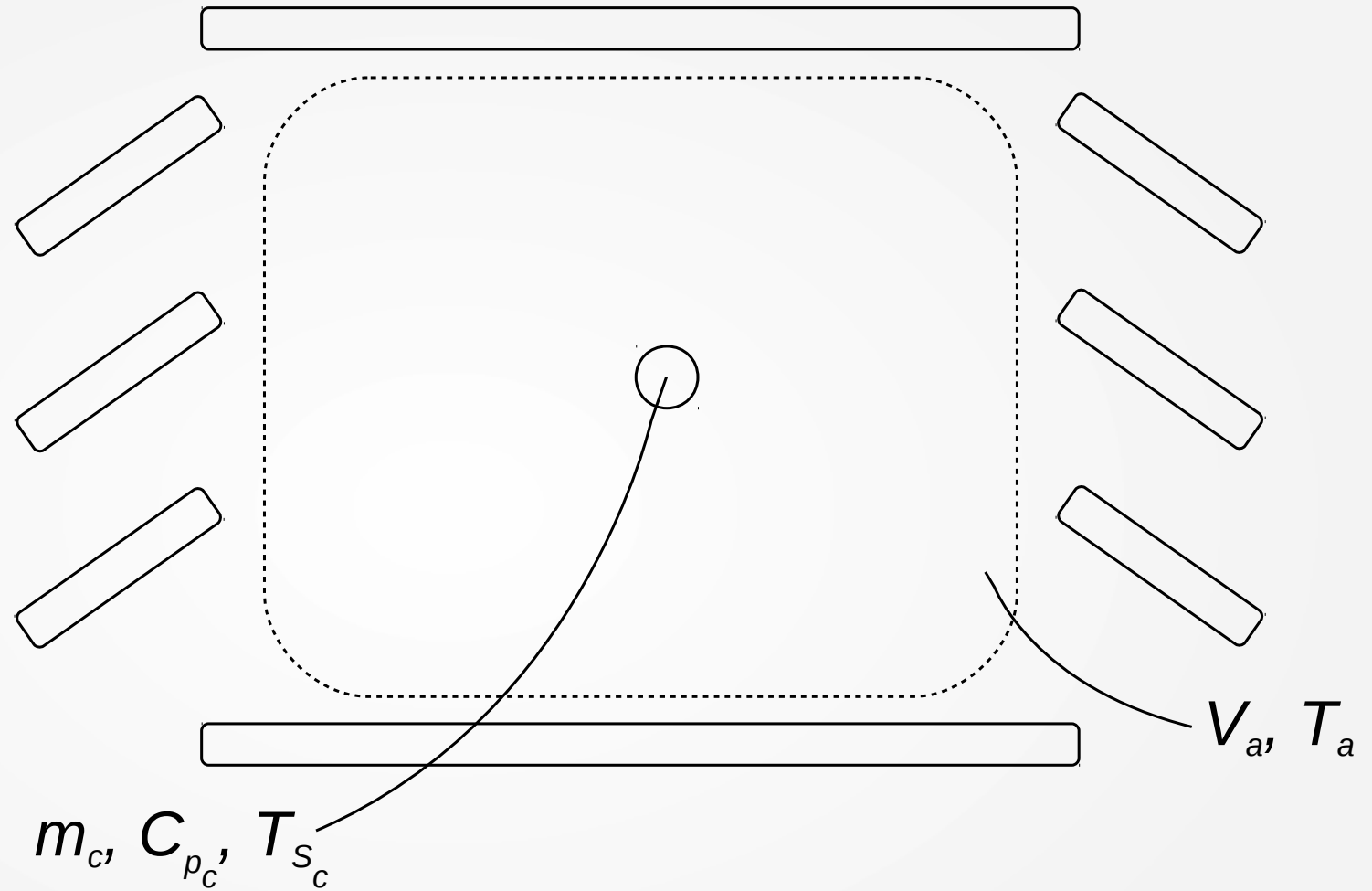


Assumption 1 : T_{s_a} *is homogeneous*

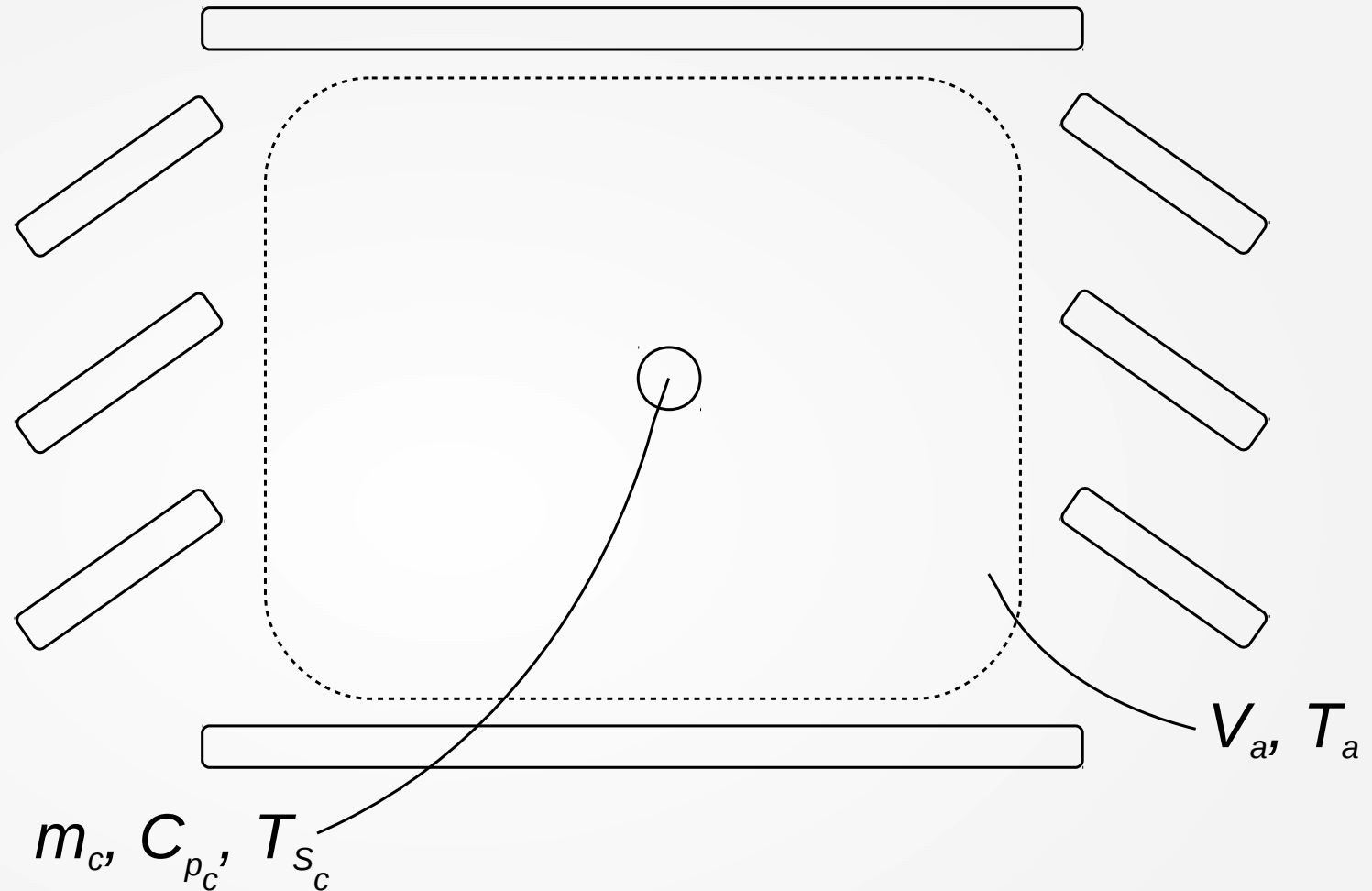
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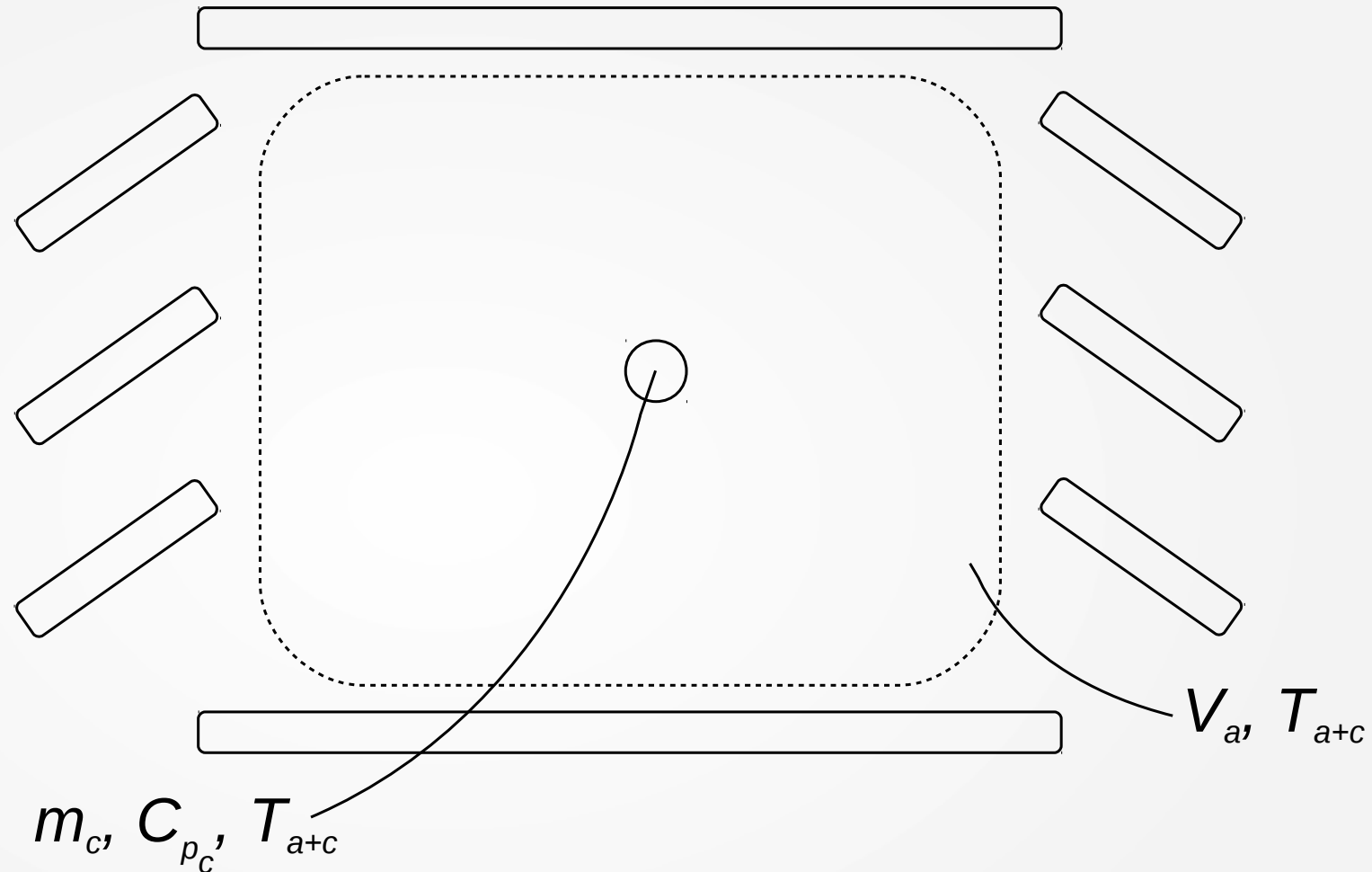


A simplified shelter...



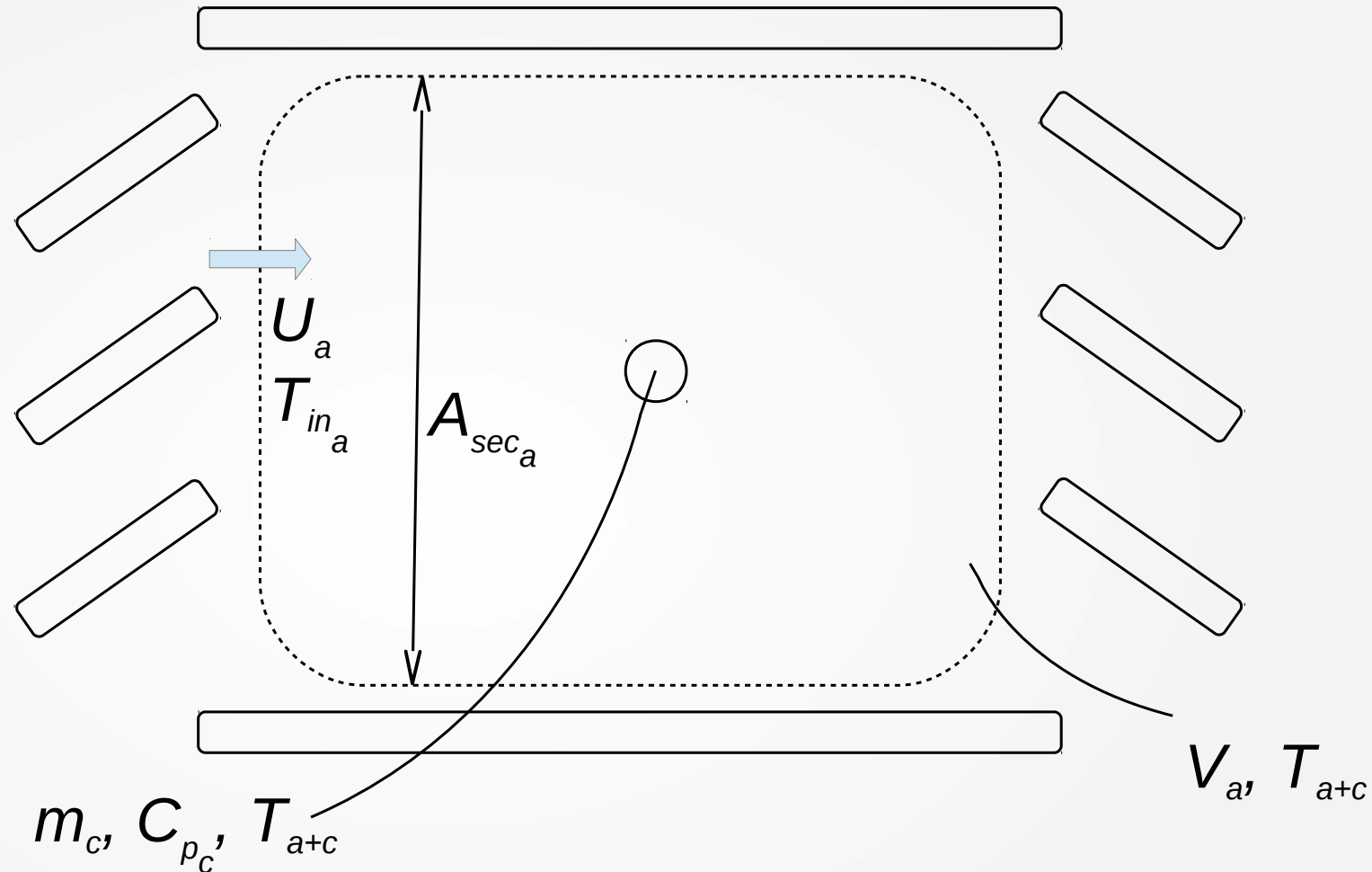
Assumption 2 : $T_{s_c} = T_a (= T_{a+c})$

A simplified shelter...



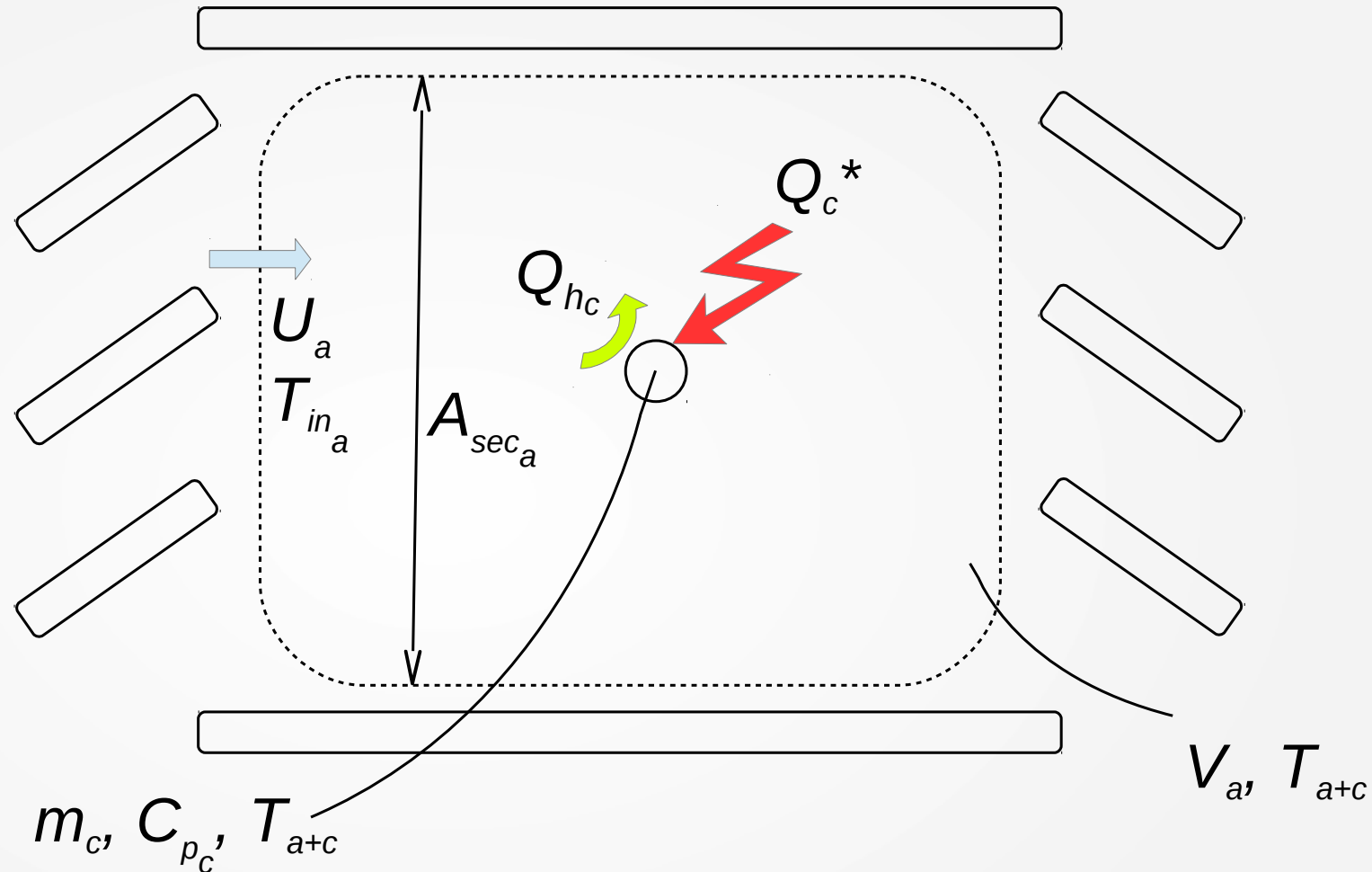
$$(m_c C_{p_c} + V_a C_{p_a}) \dot{T}_{a+c} =$$

A simplified shelter...



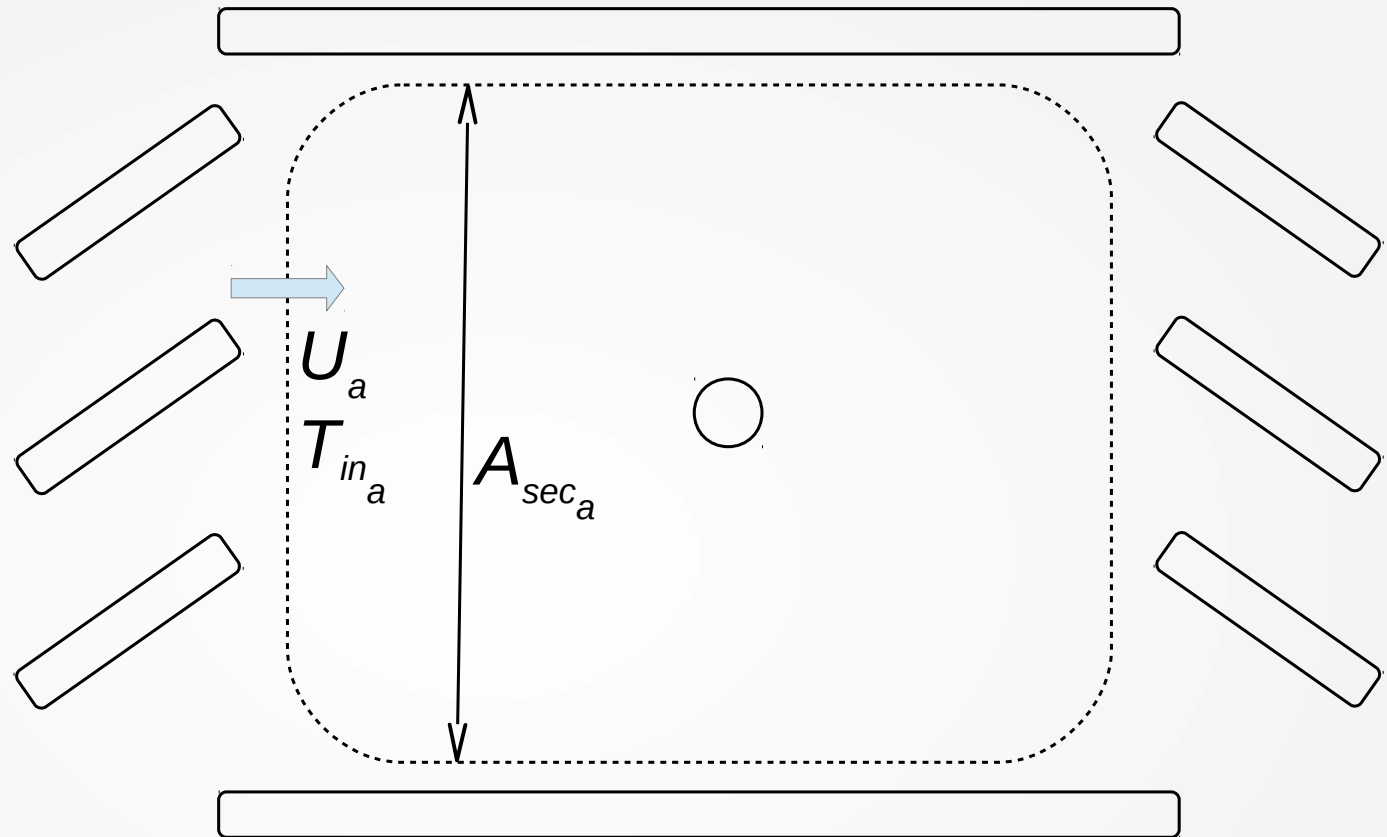
$$(m_c C_{p_c} + V_a C_{p_a}) \dot{T}_{a+c} = A_{sec_a} U_a C_p (T_{in_a} - T_{a+c})$$

A simplified shelter...



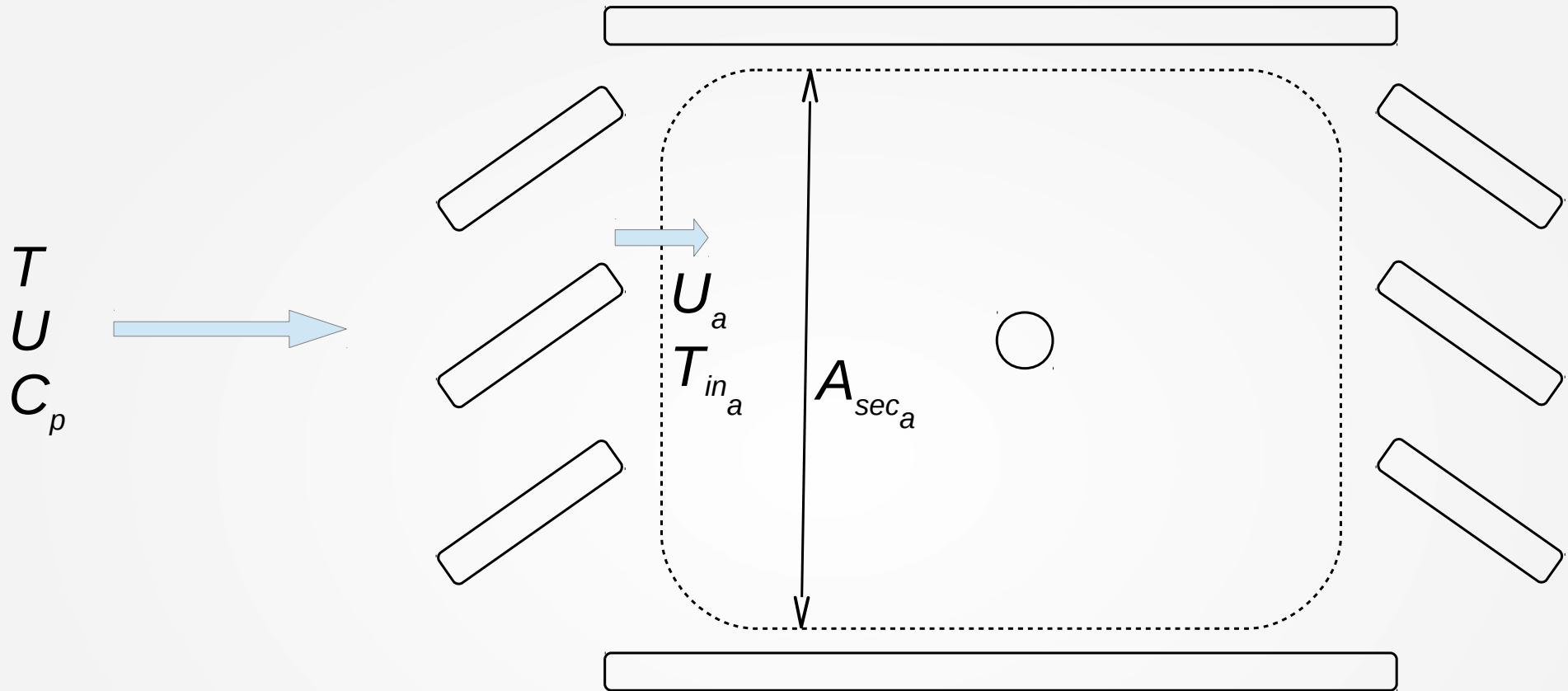
$$(m_c C_{p_c} + V_a C_{p_a}) \dot{T}_{a+c} = A_{sec_a} U_a C_p (T_{in_a} - T_{a+c}) + A_c Q_c^* \quad (1)$$

A simplified shelter...



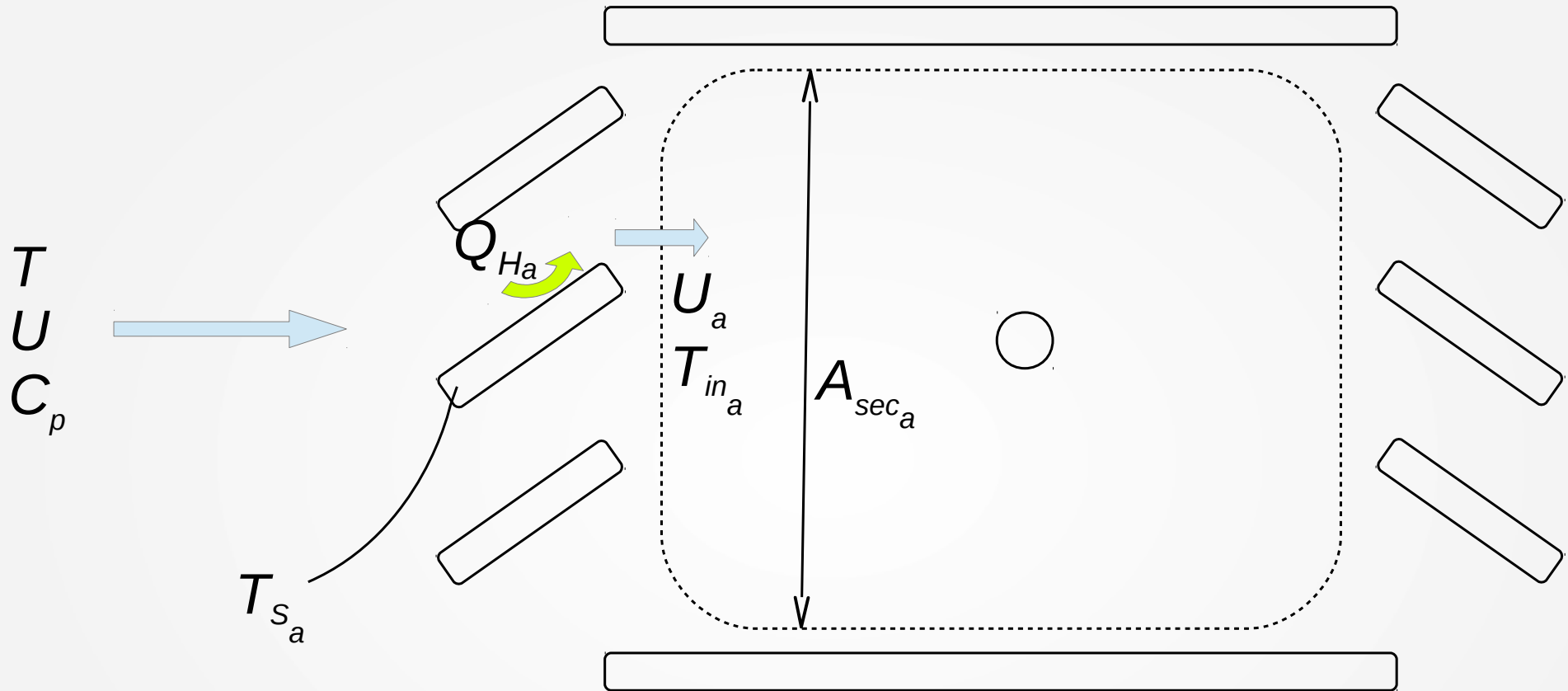
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A simplified shelter...



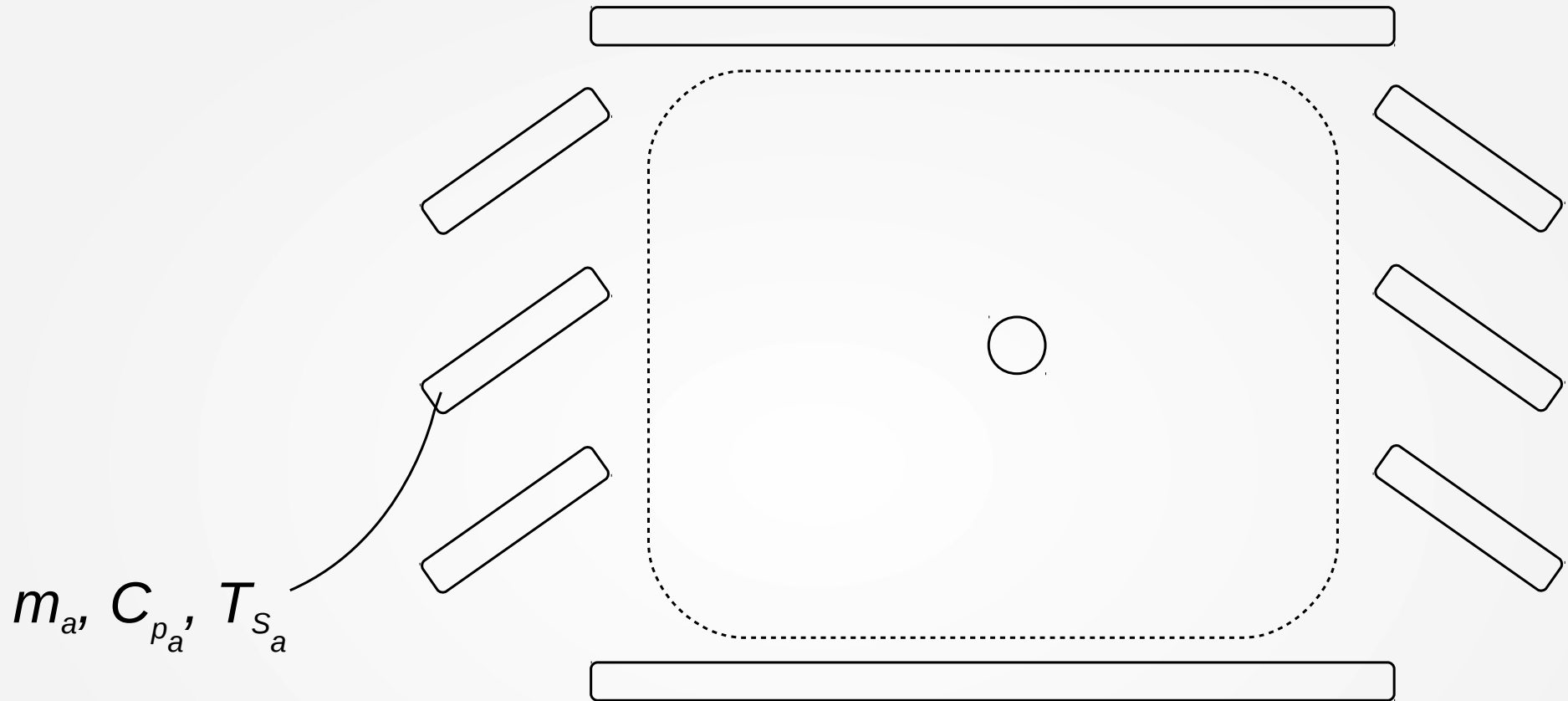
$$A_{sec_a} U_a C_p T_{in_a} = A_{sec_a} U_a C_p T$$

A simplified shelter...



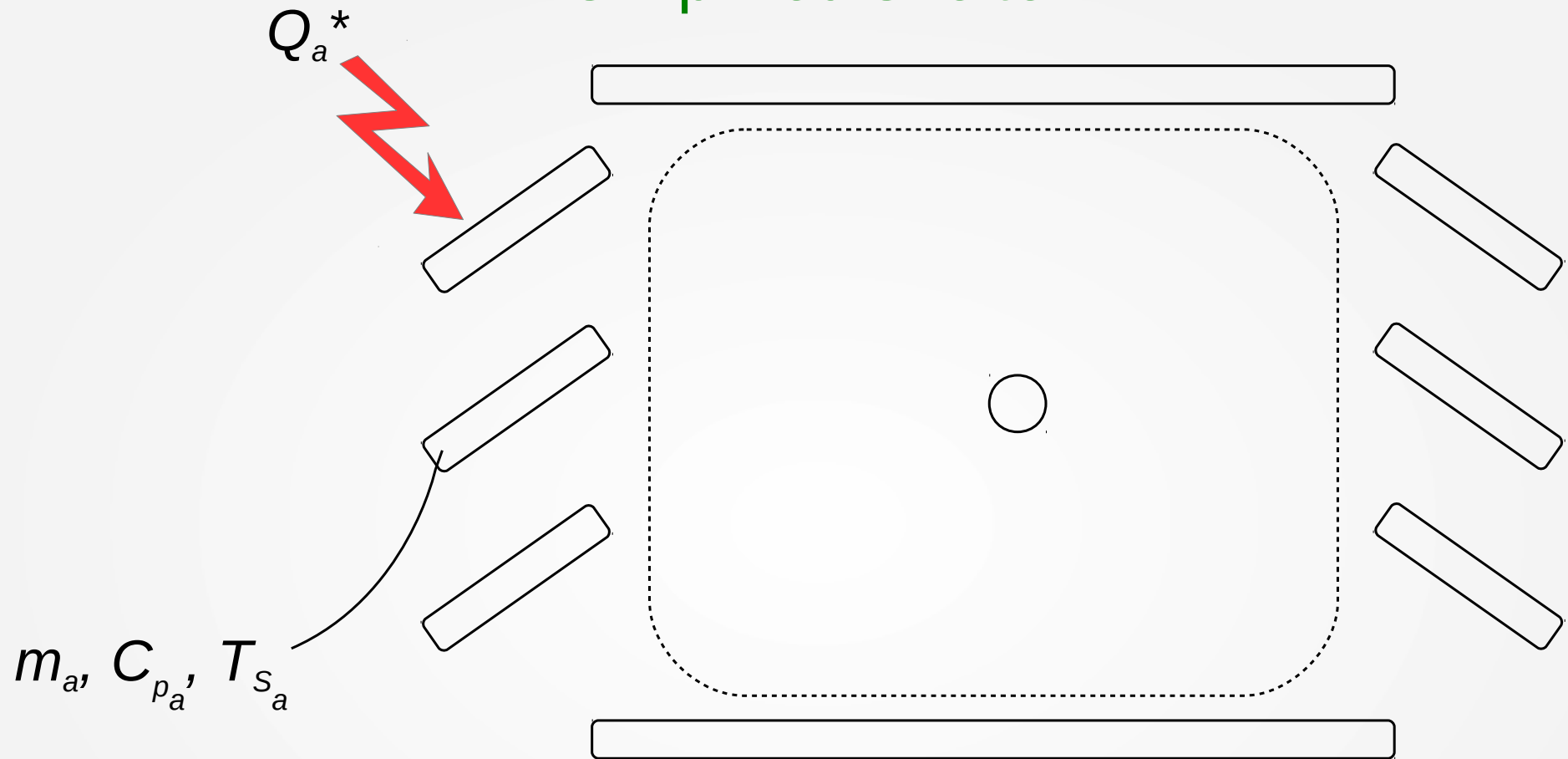
$$A_{sec_a} U_a C_p T_{in_a} = A_{sec_a} U_a C_p T + h_a A_a (T_{S_a} - T) \quad (2)$$

A simplified shelter...



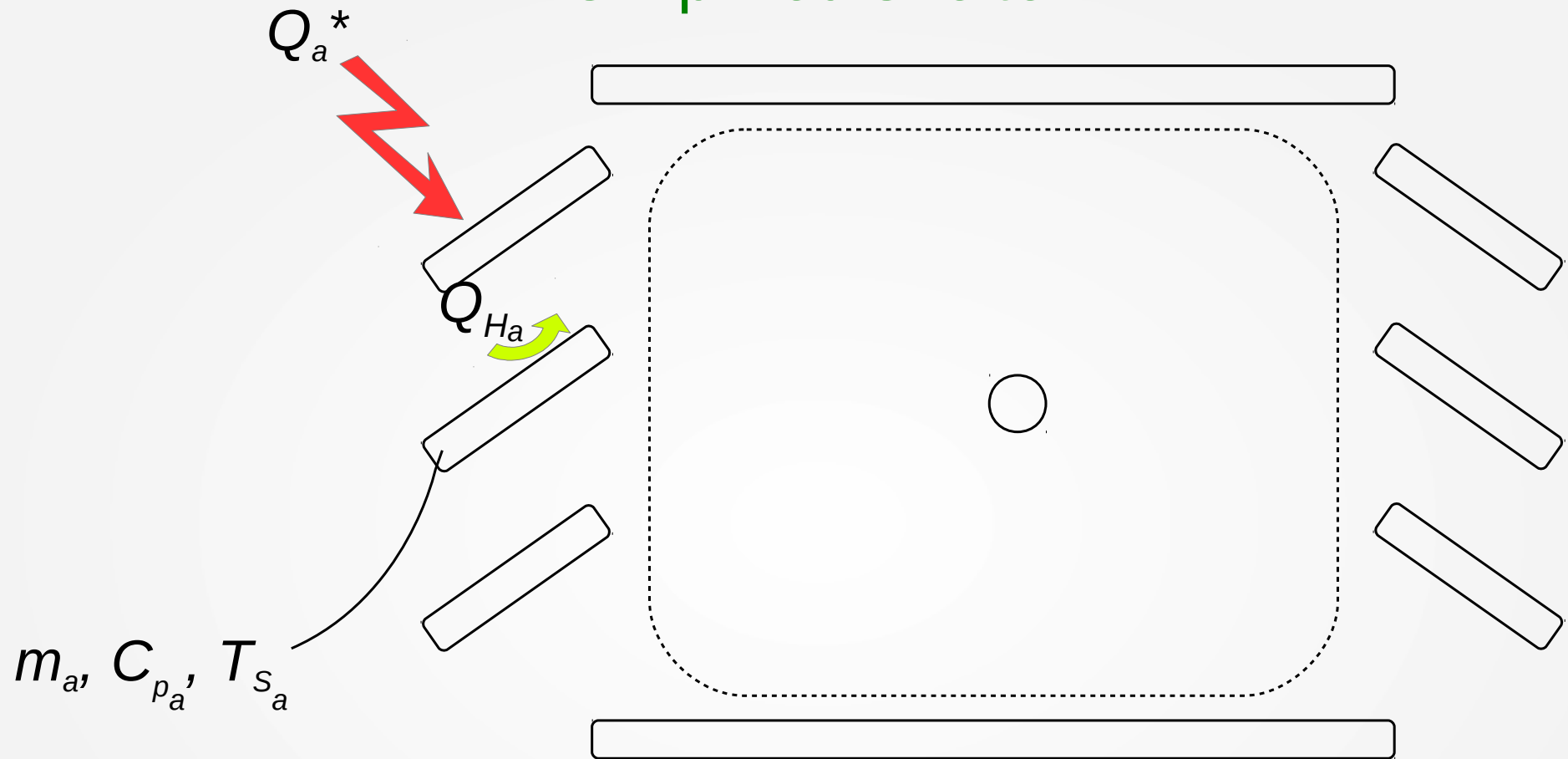
$$m_a C_{p_a} \dot{T}_{S_a} =$$

A simplified shelter...



$$m_a C_{p_a} \dot{T}_{S_a} = A_a Q_a^* \quad (3)$$

A simplified shelter...



$$m_a C_{p_a} \dot{T}_{S_a} = A_a Q_a^* - h_a A_a (T_{S_a} - T) \quad (3)$$

...for a simplified equation

Assumption 3: *all $\dot{M}V = 0$ between two samples
(except T and T_{a+c})*

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Combining (1), (2) and (3):

$$\dot{T}_{a+c}(t) + \frac{A_{sec_a} U_a}{V_a} T_{a+c}(t) = \frac{A_a Q_a^* + A_c Q_c^*}{V_a C_p} + \frac{A_{sec_a} U_a}{V_a} T(t) \quad (4)$$

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We define $e_T(t) = T_{a+c}(t) - T(t)$, inject it into (4):

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$$\dot{e}_T(t) + \epsilon e_T(t) = \zeta - \dot{T} \quad (5)$$

→ 1st order differential equation with constant coefficient and constant second term

...for a simplified equation

$$e_T(n) = \frac{1}{\zeta_1} \cdot (e^{-\zeta_1 U_a dt} - 1) \left(\frac{\dot{T}}{U_a} - \zeta_3 \frac{Q_a^*}{U_a} - \zeta_4 \frac{Q_c^*}{U_a} \right) + e_T(n-1) \cdot e^{-\zeta_1 U_a dt} \quad (6)$$

...for a simplified equation

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...for a simplified equation

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$$\rightarrow e_T(n) = (e^{-p_1 U dt} - 1) \left(\frac{1}{p_1} \frac{\dot{T}}{U} - p_2 \frac{Q_{K^\uparrow, K^\downarrow, L^\downarrow}}{U} \right) + e_T(n-1) e^{-p_1 U dt} \quad (7)$$

$$p_2 = \frac{\alpha_2}{\zeta_1} = \alpha_2 \frac{A_{sec}}{V_a} = \frac{\frac{\alpha_1 \alpha_2 A_a}{V_a C_p}}{p_1} = \frac{\gamma}{p_1}$$

Resolution method

$$e_T(n) = \frac{1}{\zeta_1} \cdot (e^{-\zeta_1 U_a dt} - 1) \left(\frac{\dot{T}}{U_a} - \zeta_3 \frac{Q_a^*}{U_a} - \zeta_4 \frac{Q_c^*}{U_a} \right) + e_T(n-1) \cdot e^{-\zeta_1 U_a dt} \quad (6)$$

$$Y = (e^{-p_1 X_1} - 1) \left(\frac{1}{p_1} X_2 - p_2 X_3 \right) + X_4 e^{-p_1 X_1}$$

p_1 and p_2 calculated

- by non-linear regression
- for different solar angle ranges

Assumption 5: $\zeta_3 \frac{Q_a^*}{U_a} + \zeta_4 \frac{Q_c^*}{U_a} = \alpha_2 \frac{K^\uparrow + K^\downarrow + L^\downarrow}{U_a} = \alpha_2 \frac{Q_{K^\uparrow, K^\downarrow, L^\downarrow}}{U_a}$

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Error due to lag

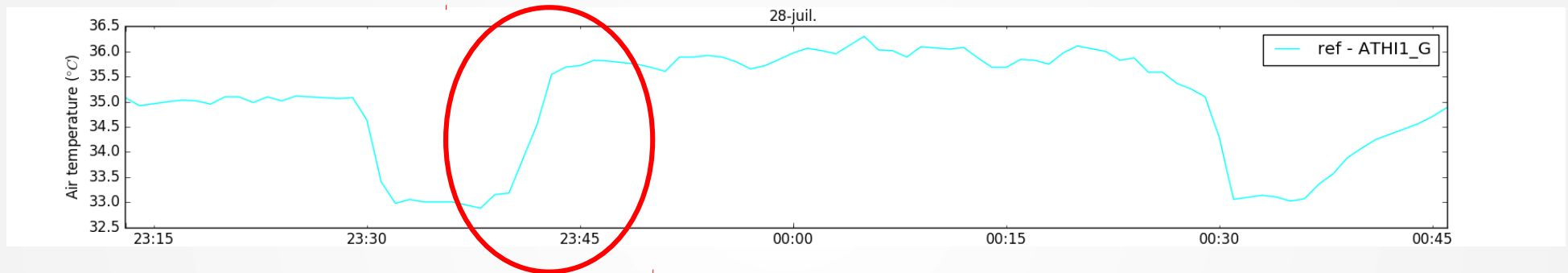
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$$\rightarrow \tau = \frac{1}{p_1 U}$$

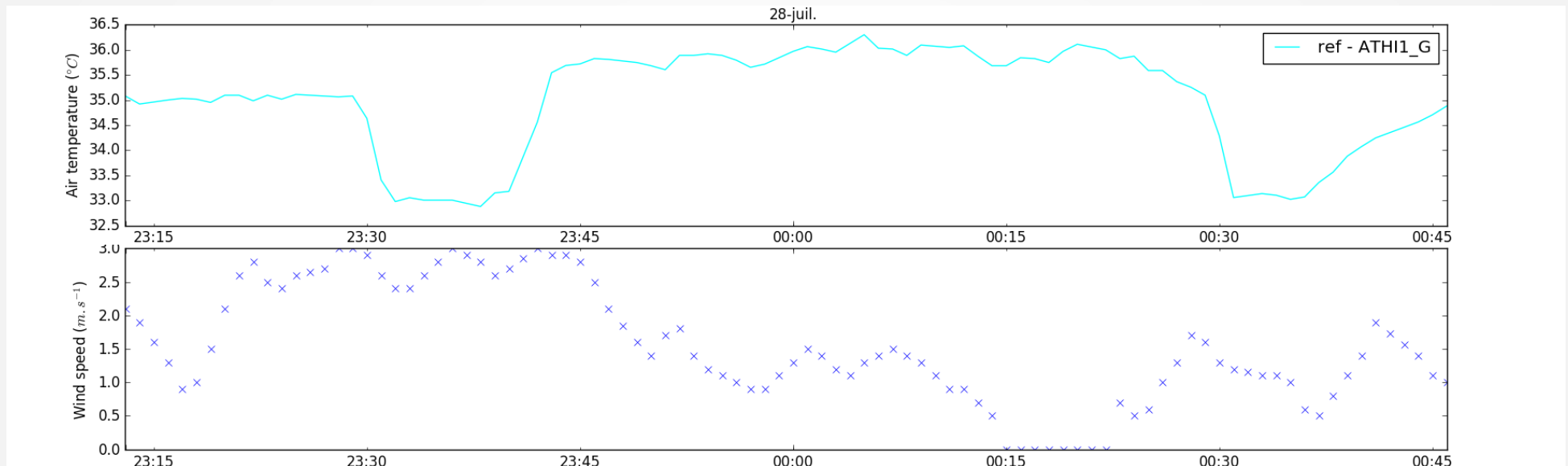
Error due to lag

$$e_T(n) = (e^{-p_1 U dt} - 1) \left(\frac{1}{p_1} \frac{\dot{T}}{U} - p_2 \frac{Q_{K^\uparrow, K^\downarrow, L^\downarrow}}{U} \right) + e_T(n-1) e^{-p_1 U dt}$$
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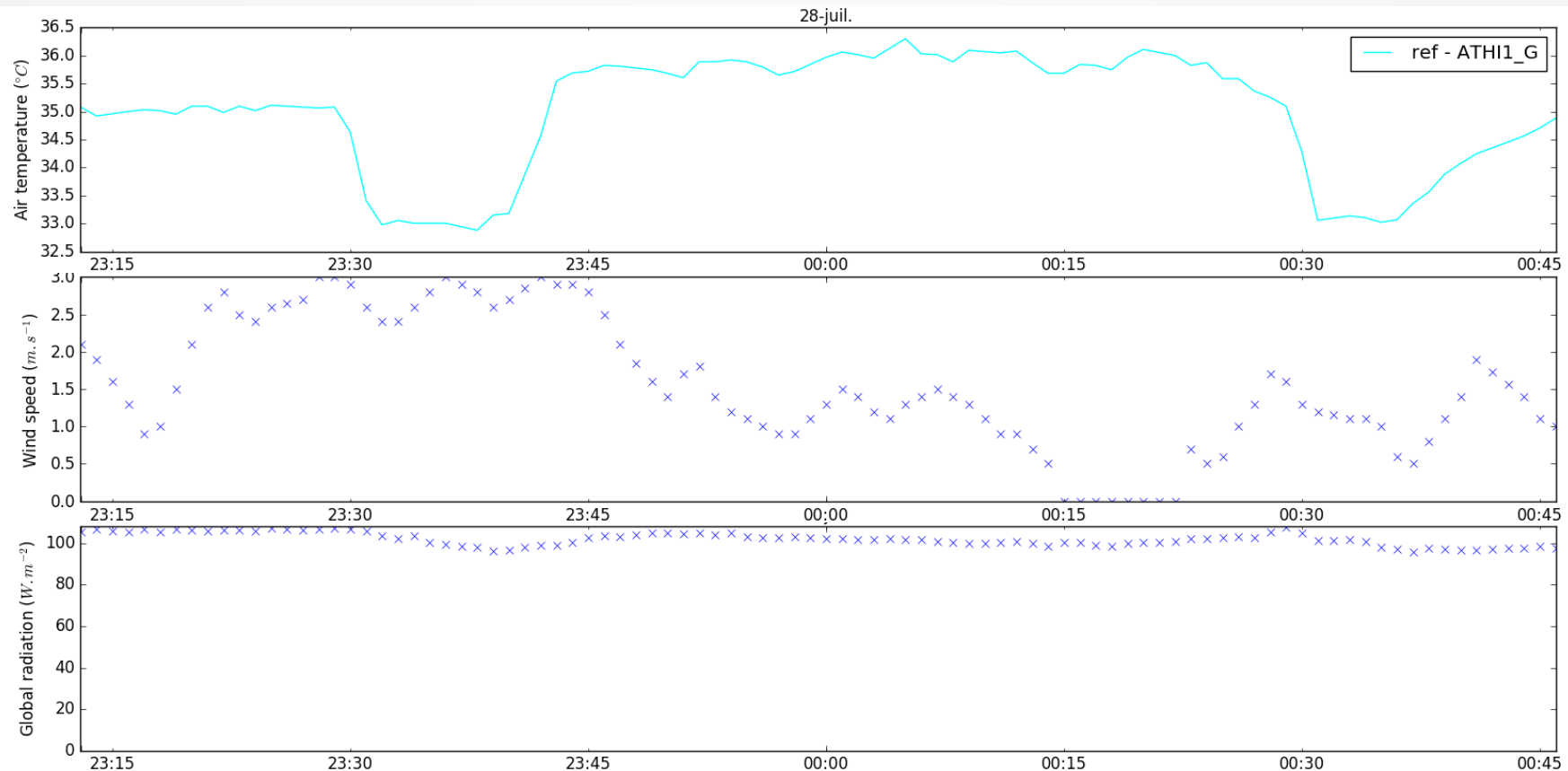
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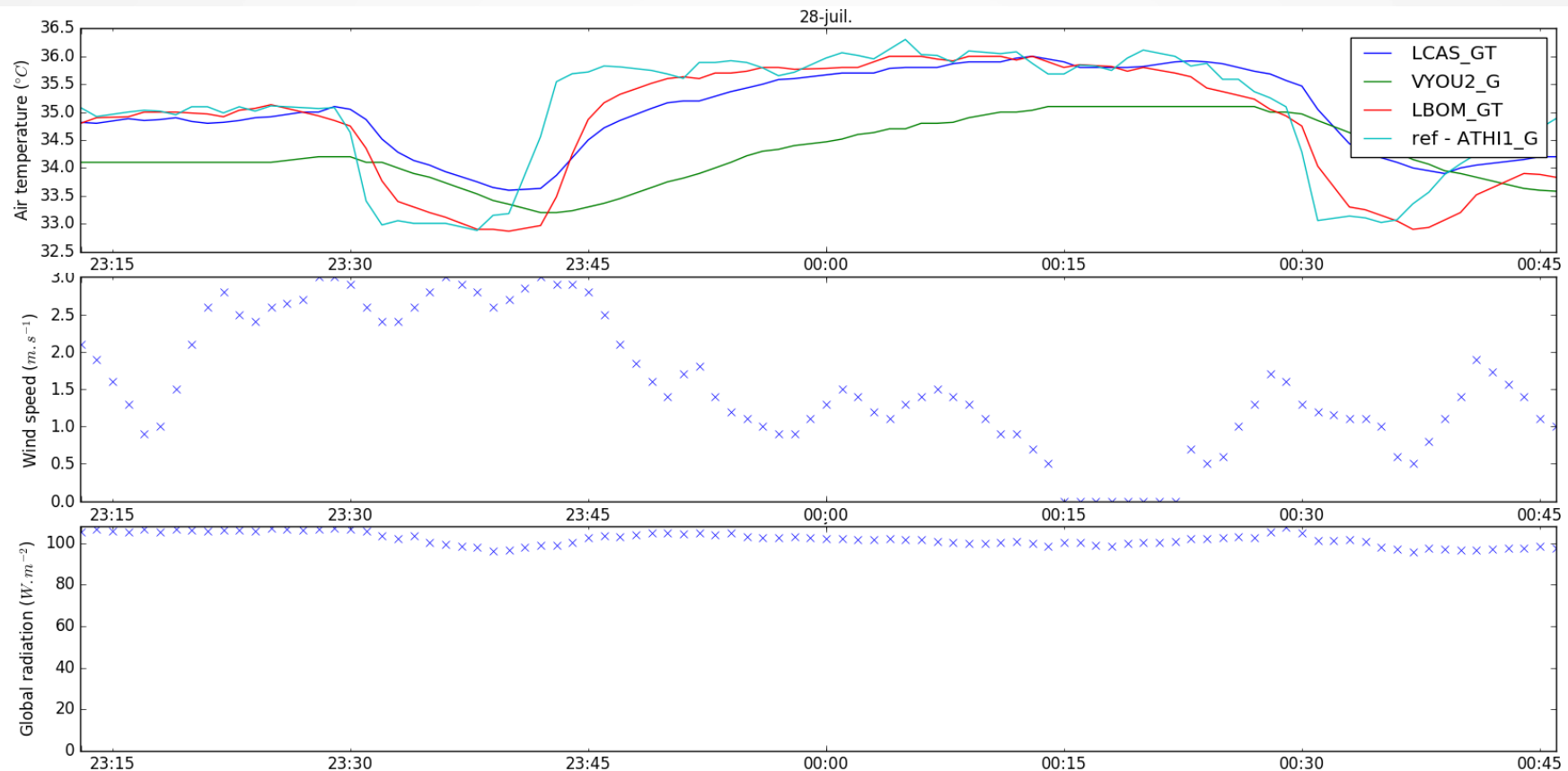
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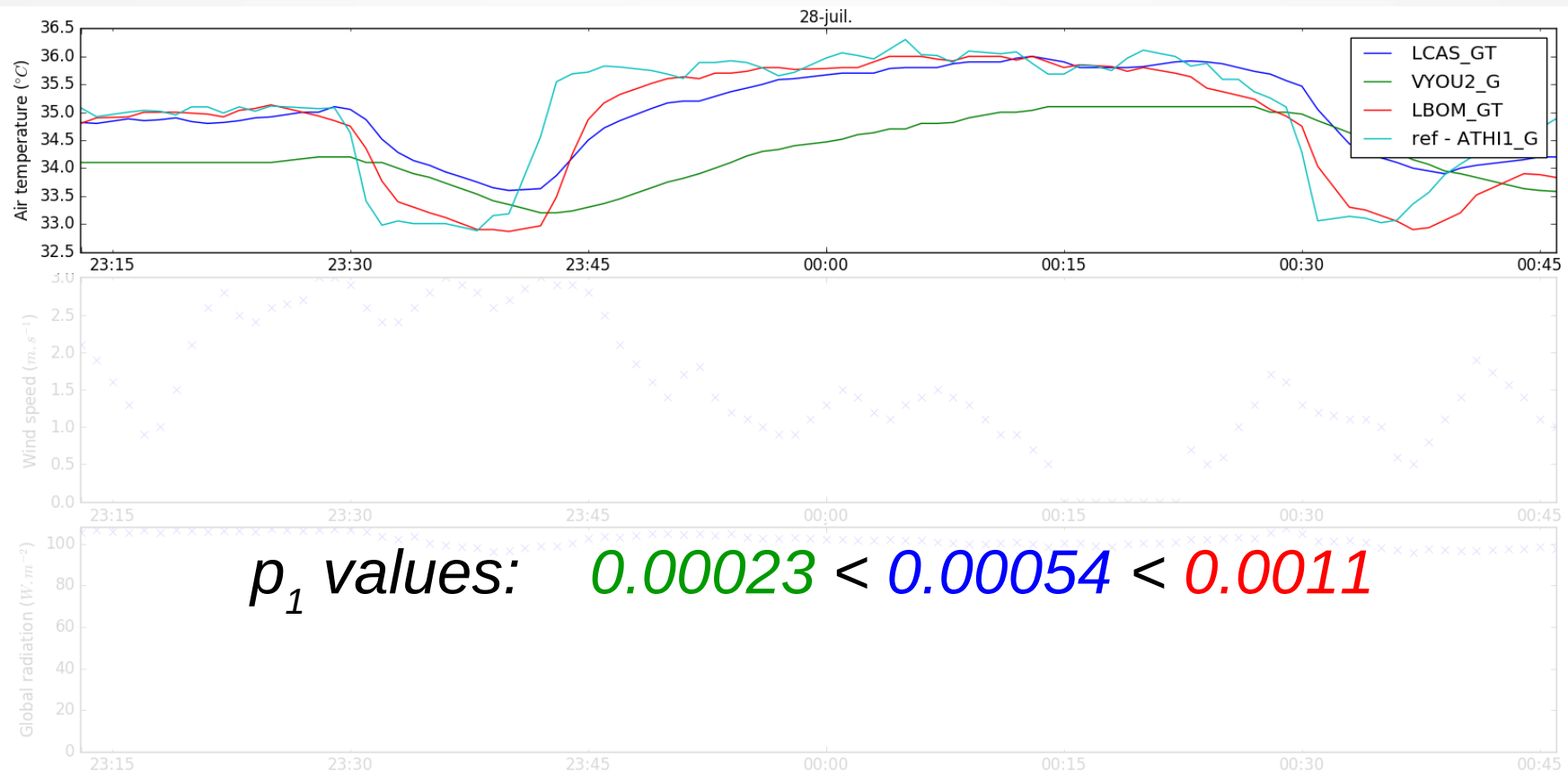
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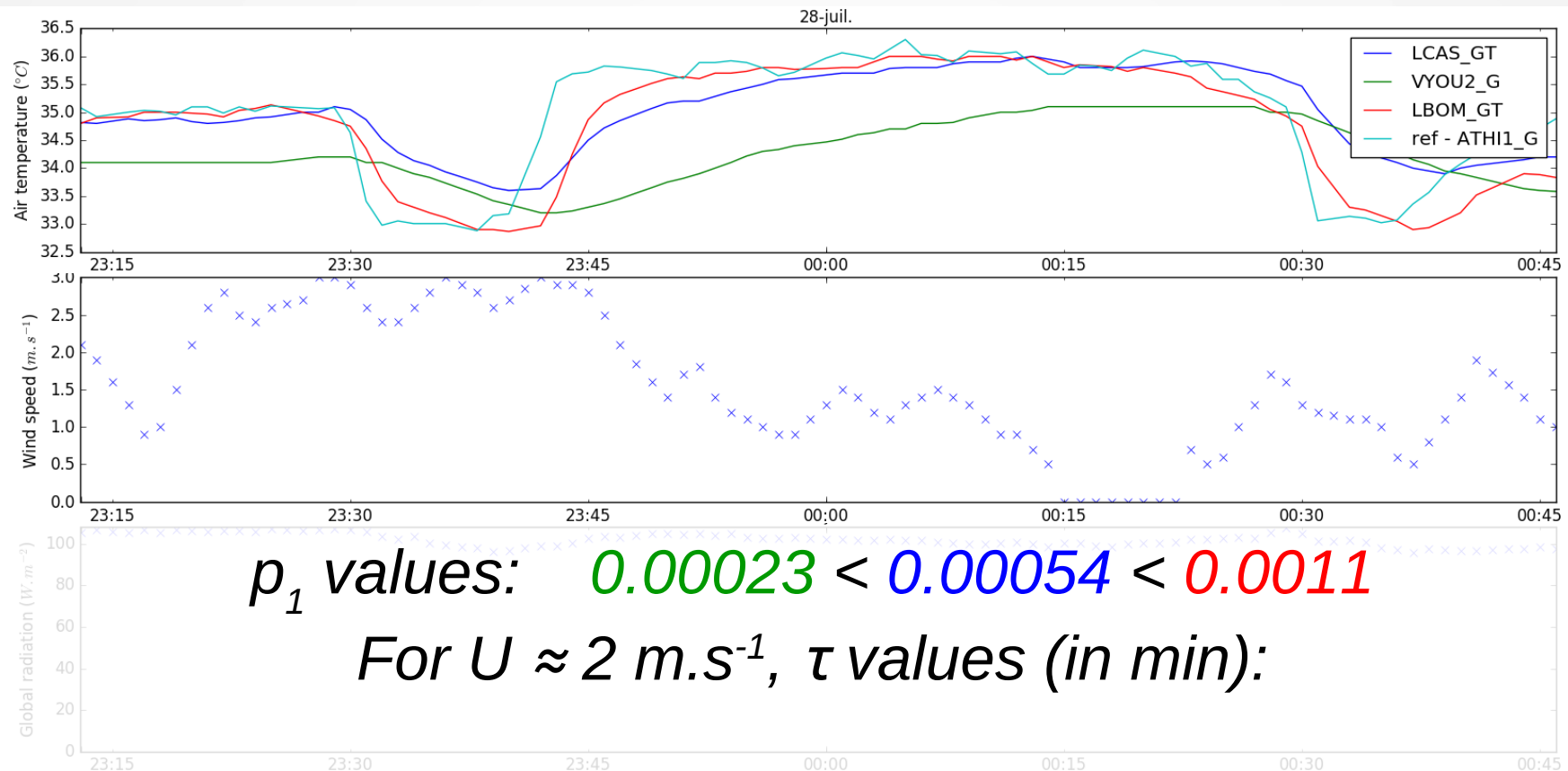
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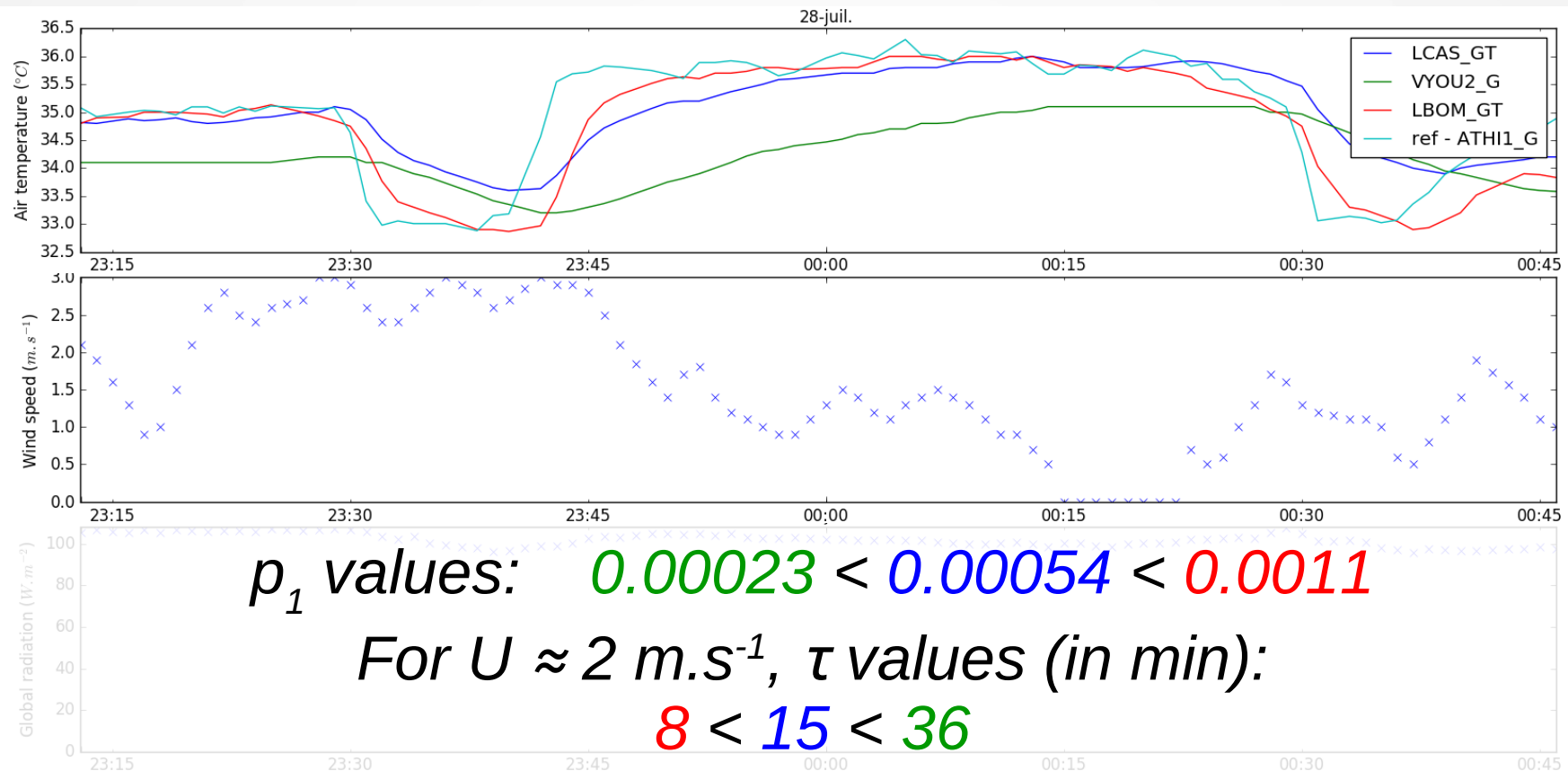
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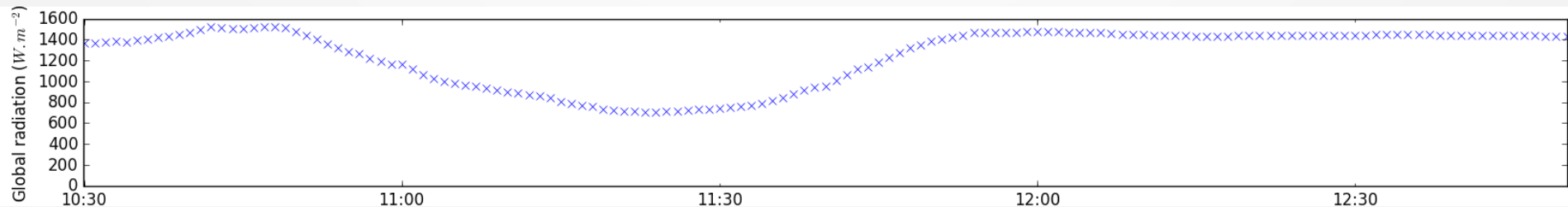


Error due to radiation

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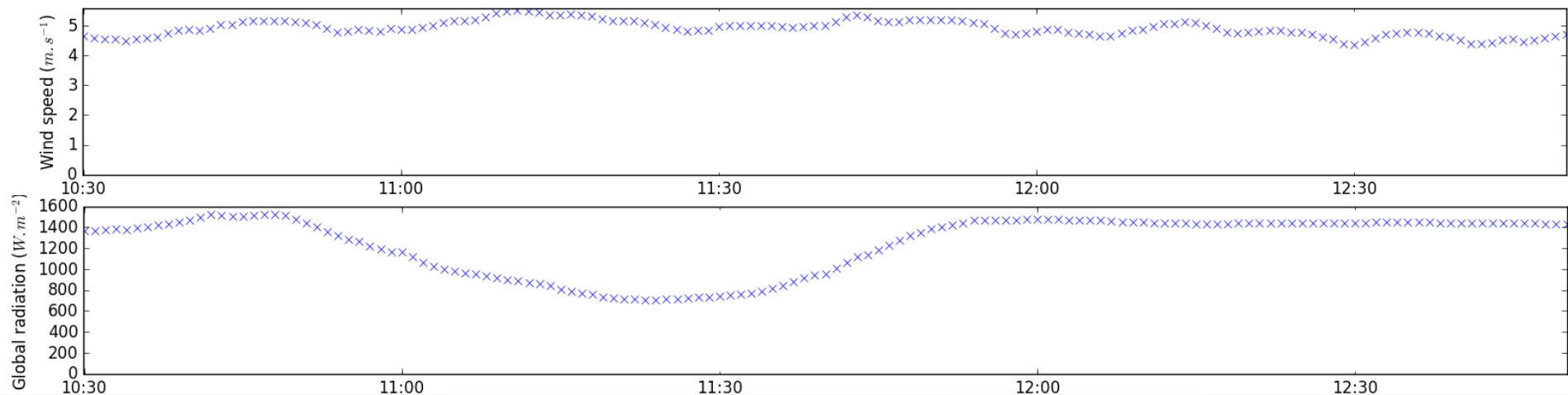
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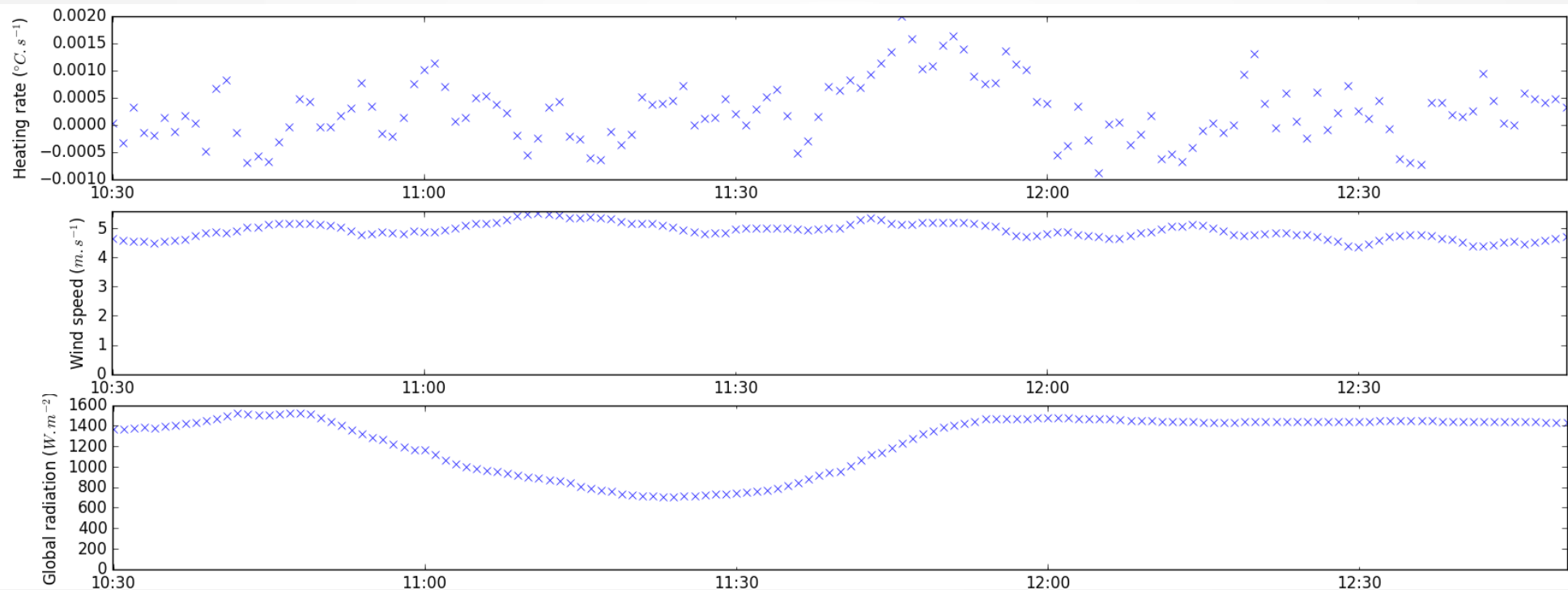
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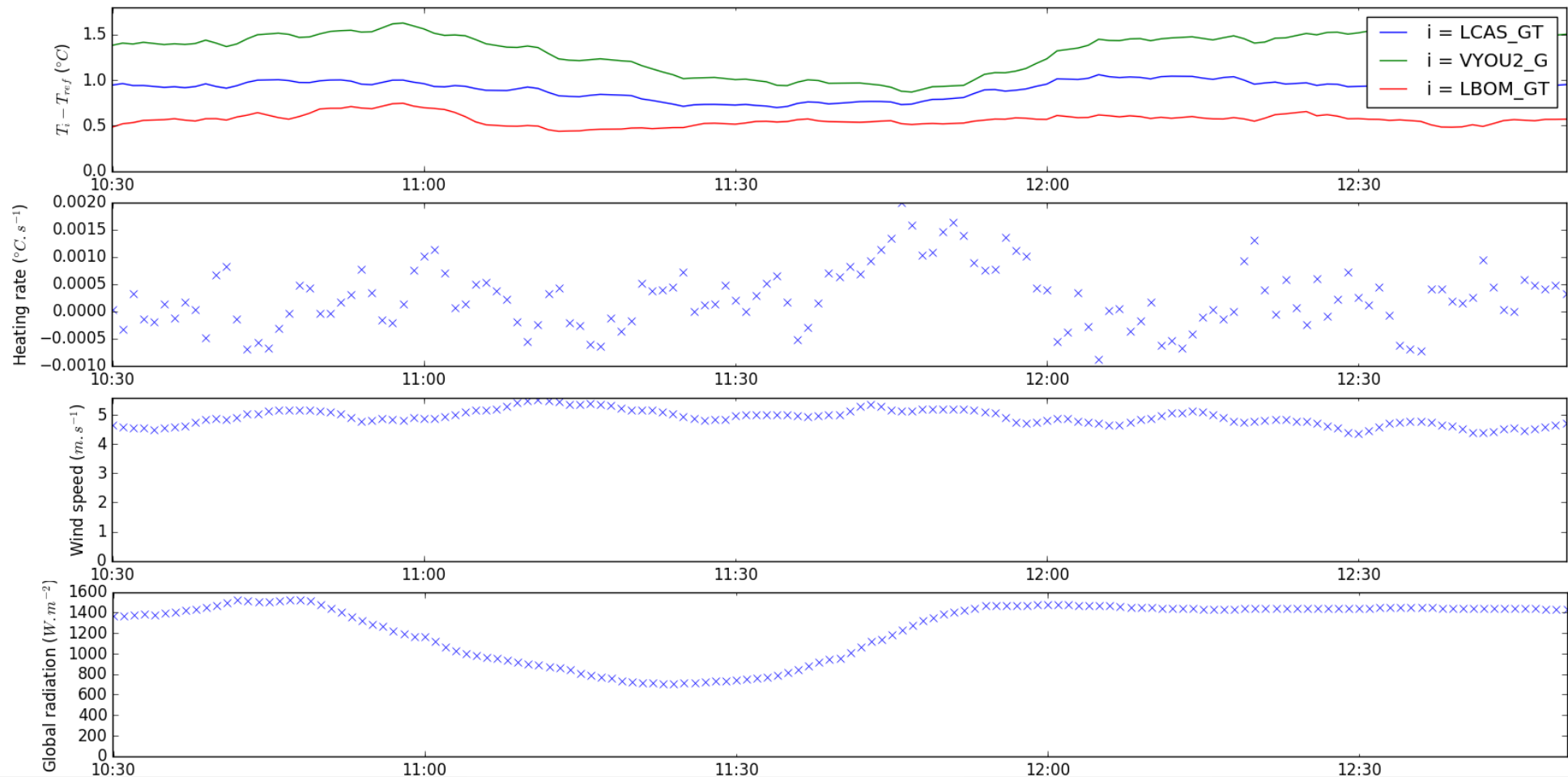
Error due to radiation

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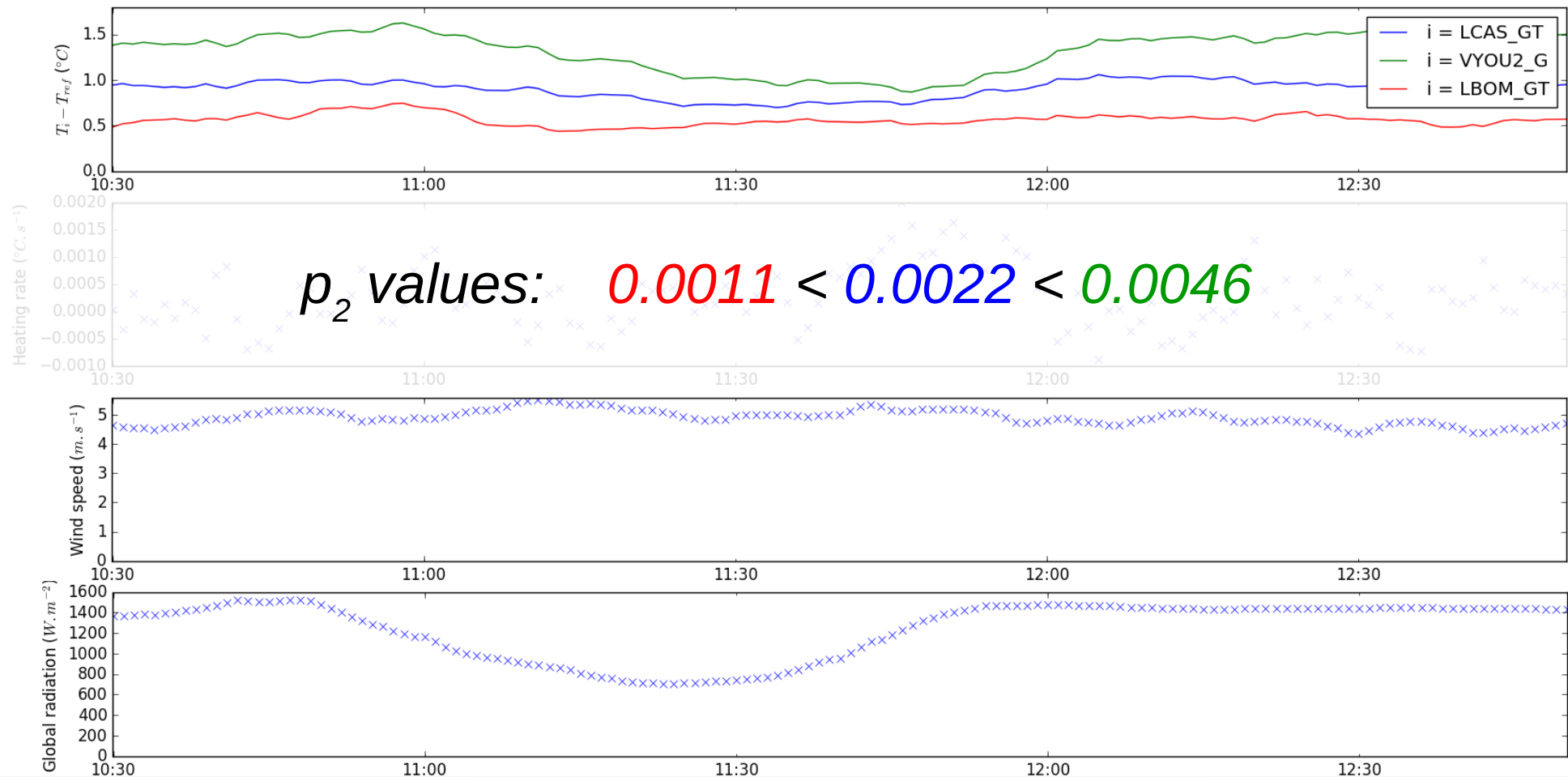
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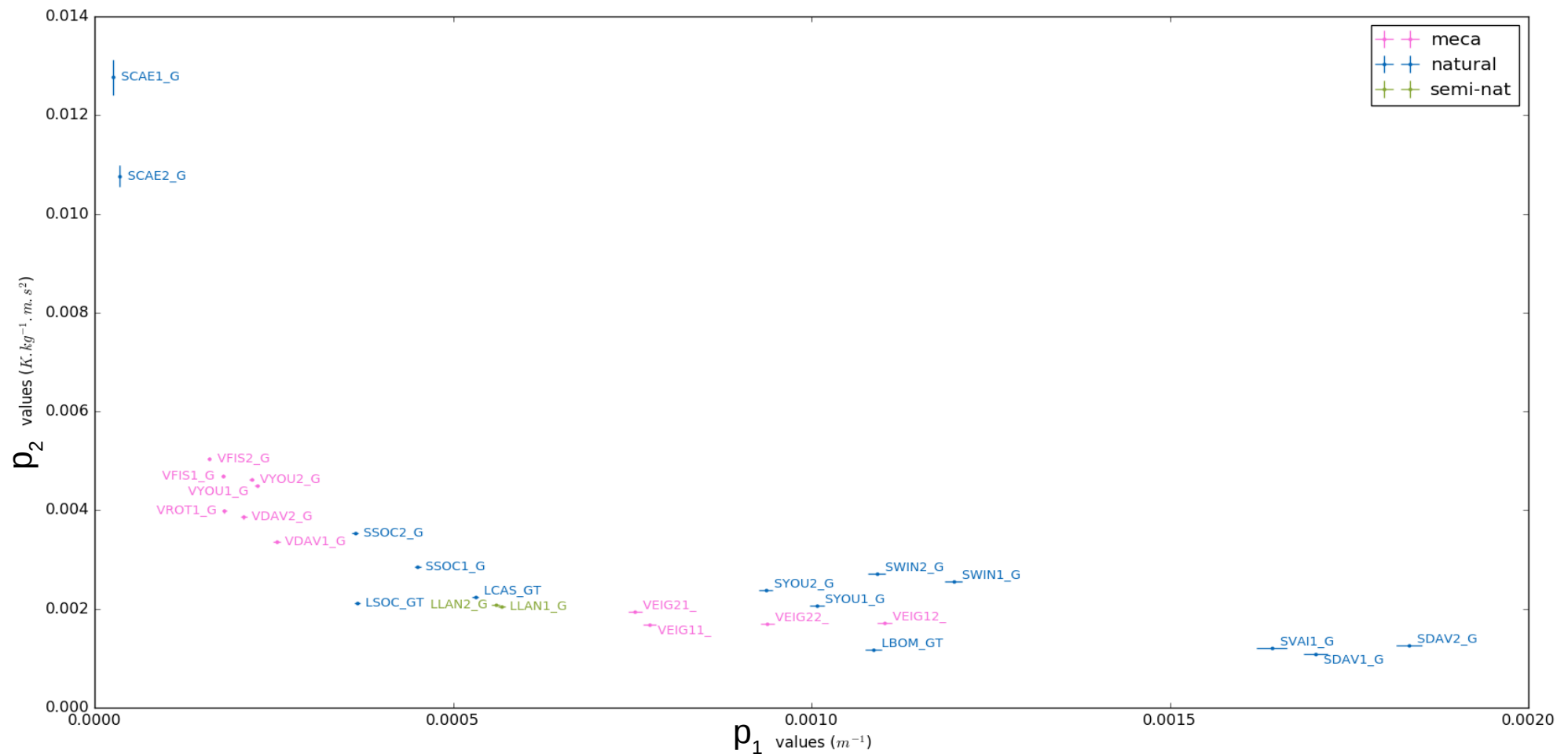


Relationship between p_1 and p_2

$$p_2 = \frac{\alpha_2}{\zeta_1} = \alpha_2 \frac{A_{sec}}{V_a} = \frac{\frac{\alpha_1 \alpha_2 A_a}{V_a C_p}}{p_1} = \frac{\gamma}{p_1}$$

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Relationship between p_1 and p_2 (night-time)

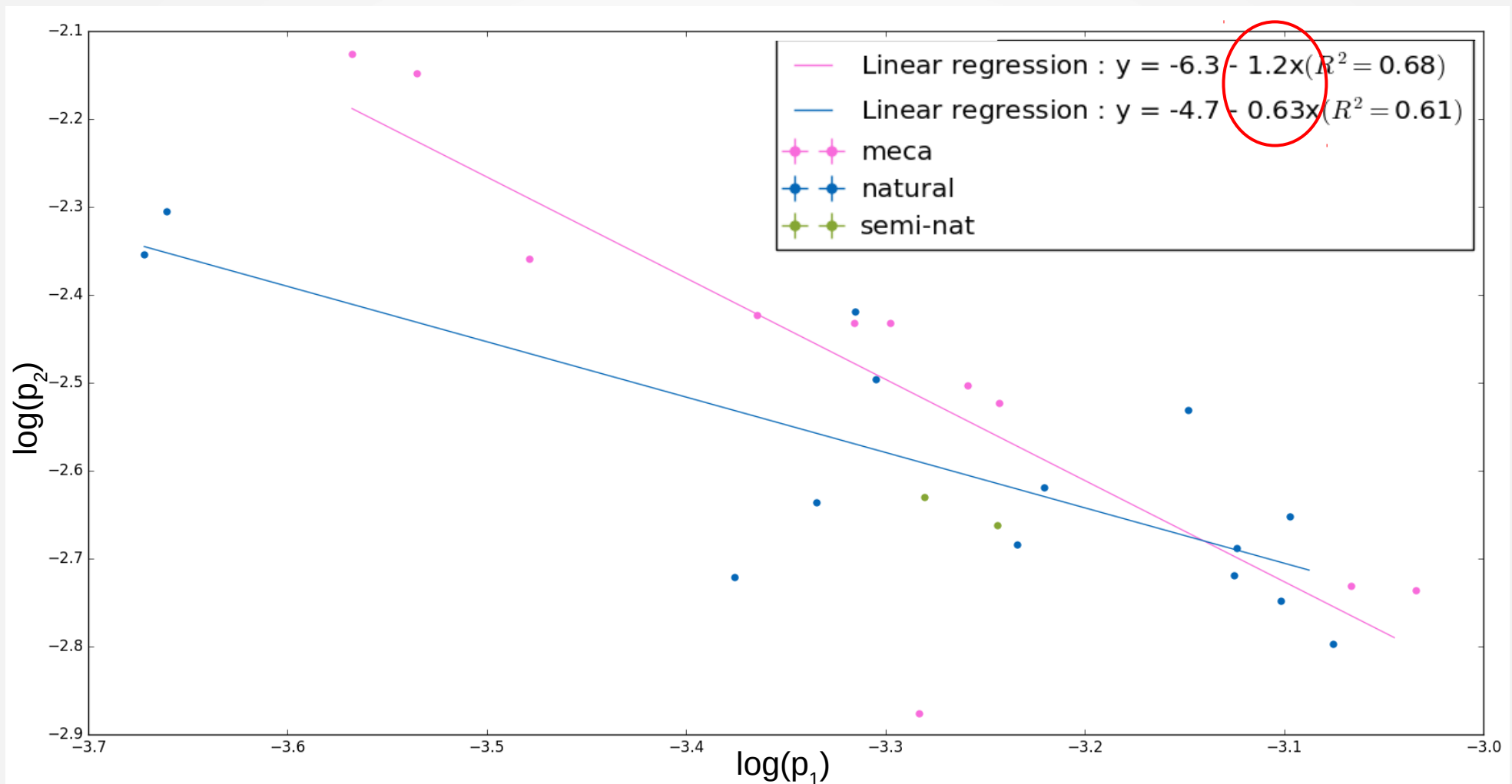
$$p_2 = \frac{\gamma}{p_1} \quad \Leftrightarrow \quad \log(p_2) = \log(\gamma) - \log(p_1)$$

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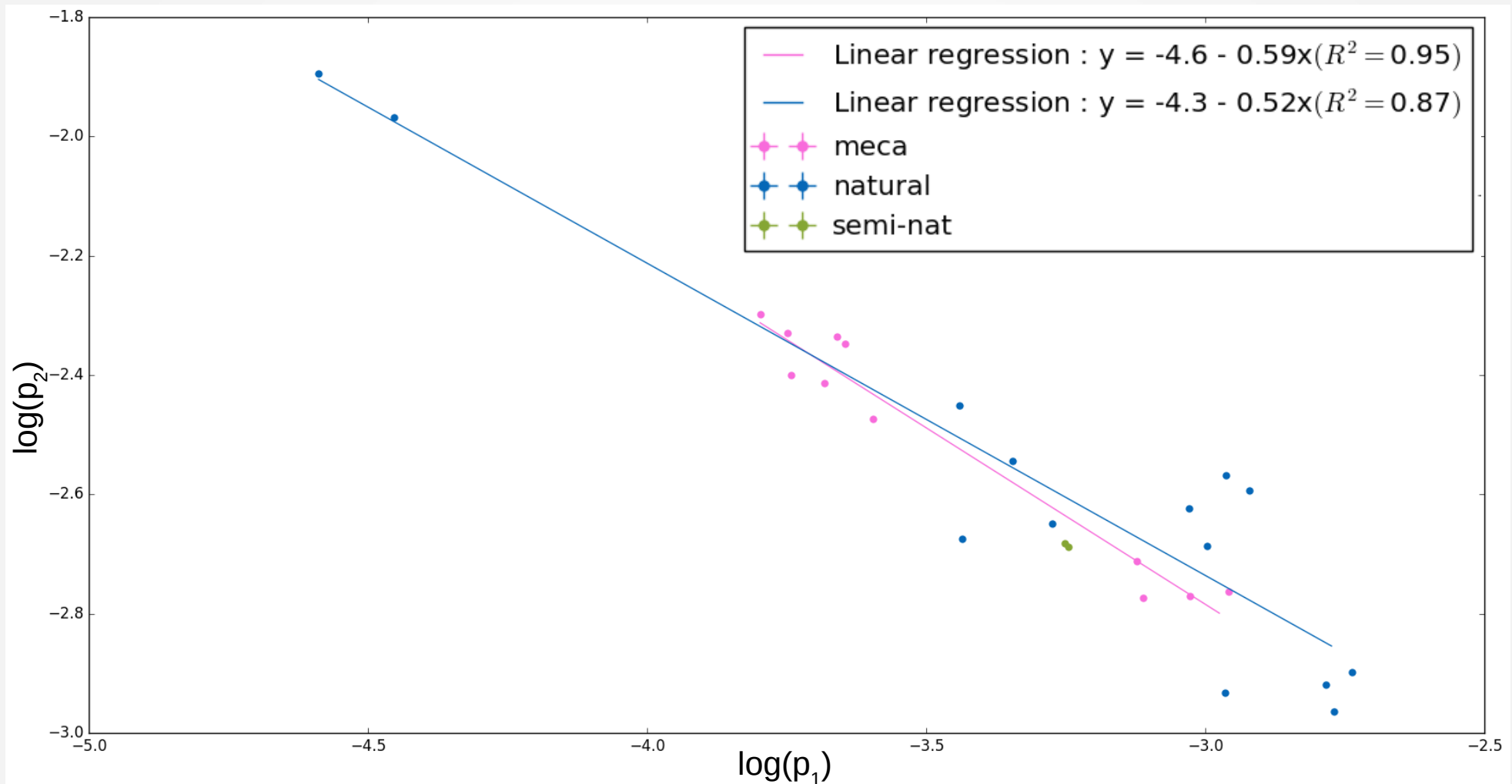
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Relationship between p_1 and p_2 (day-time)

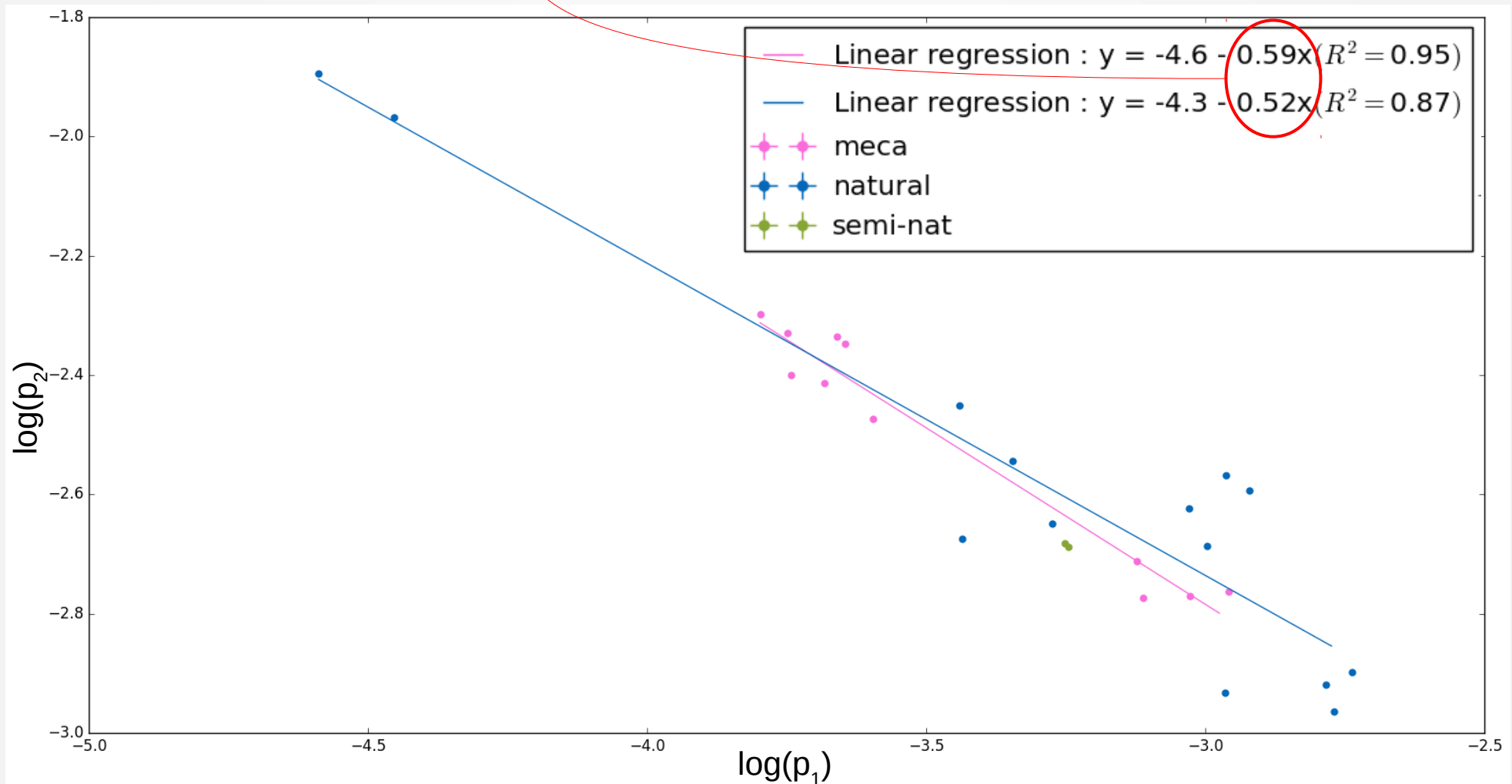
$$p_2 = \frac{\gamma}{p_1} \quad \Leftrightarrow \quad \log(p_2) = \log(\gamma) - \log(p_1)$$
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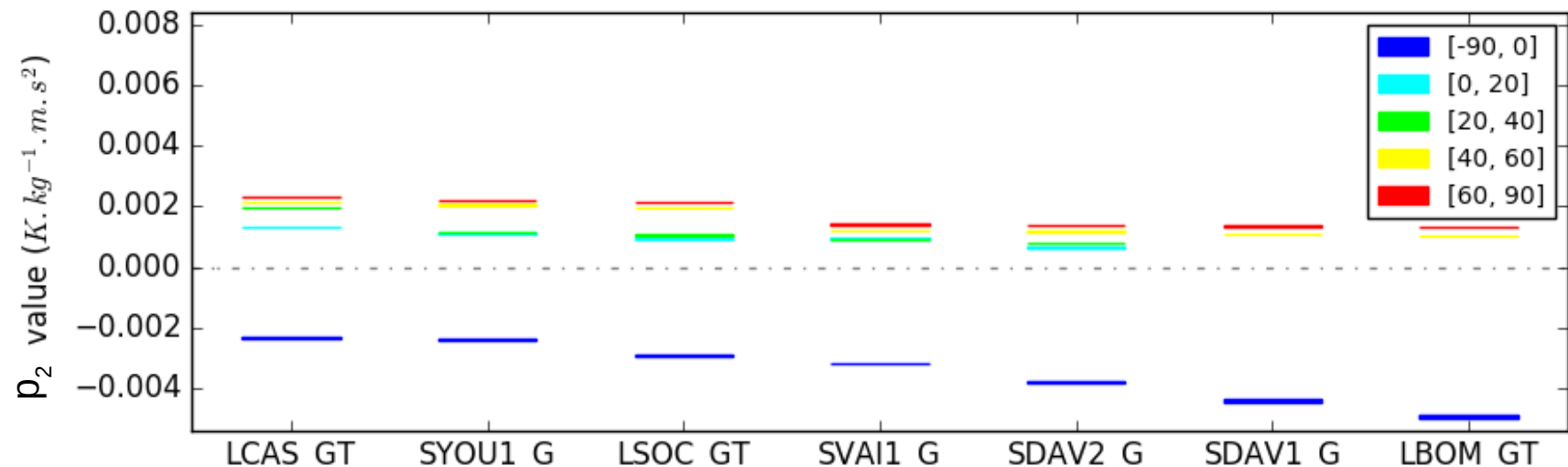
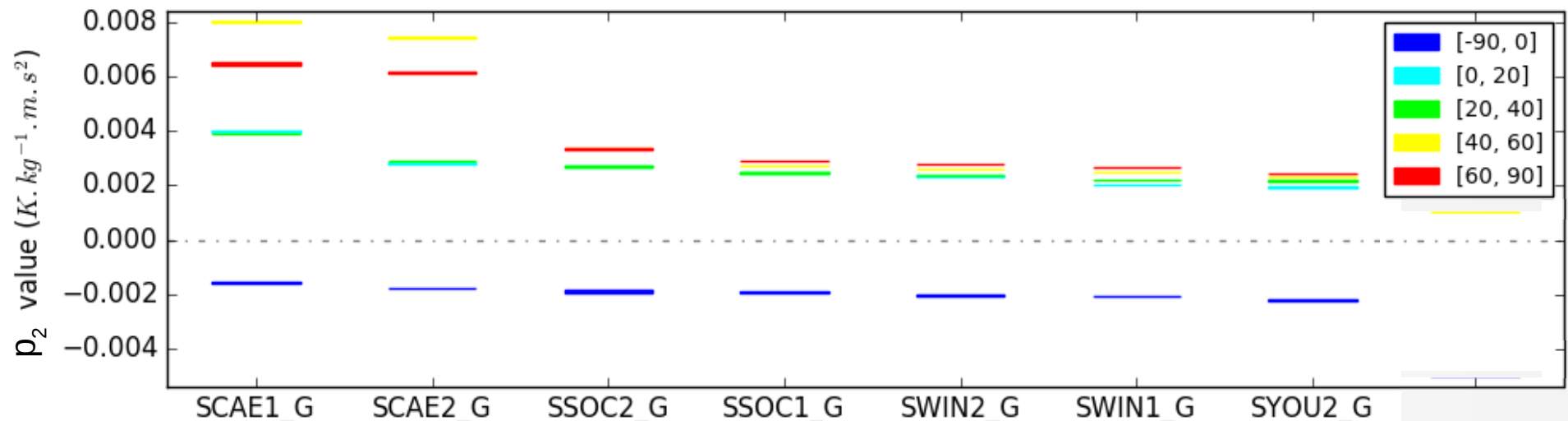
Relationship between p_1 and p_2 (day-time)

$$p_2 = \frac{\gamma}{p_1^{0.5}} \Leftrightarrow \log(p_2) = \log(\gamma) - \log(p_1)$$

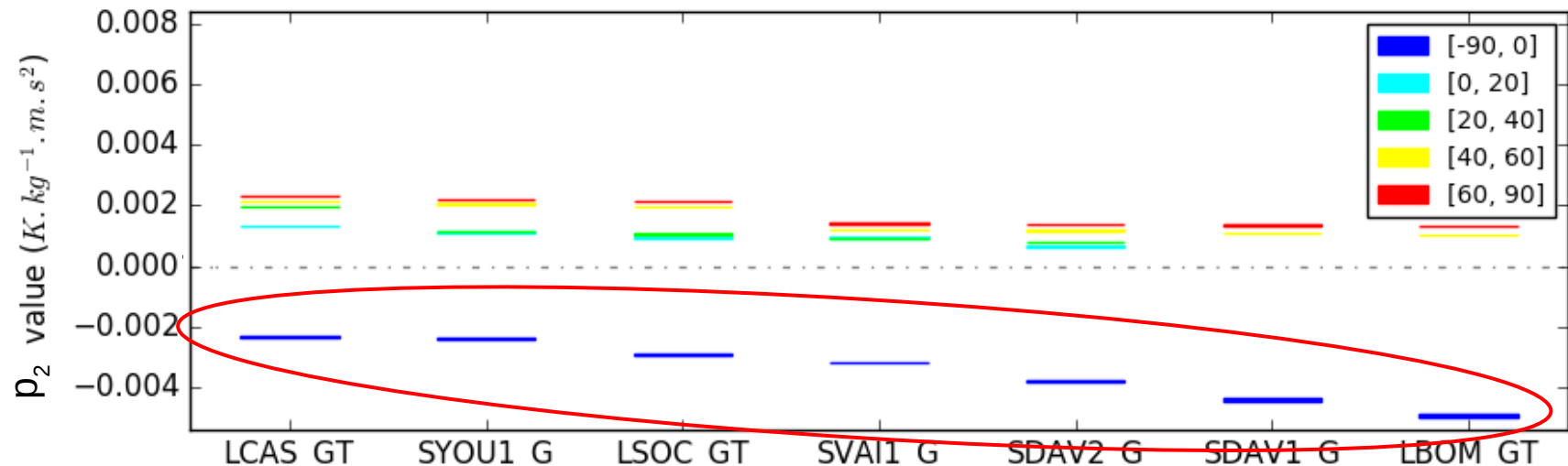
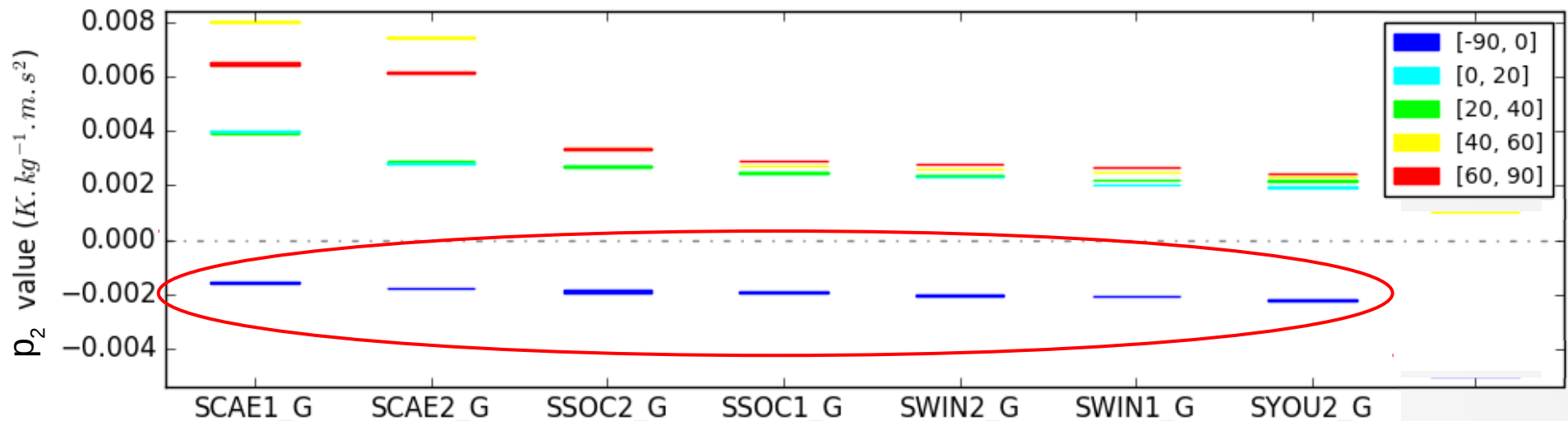
$$\rightarrow f(x) = a - 1x$$



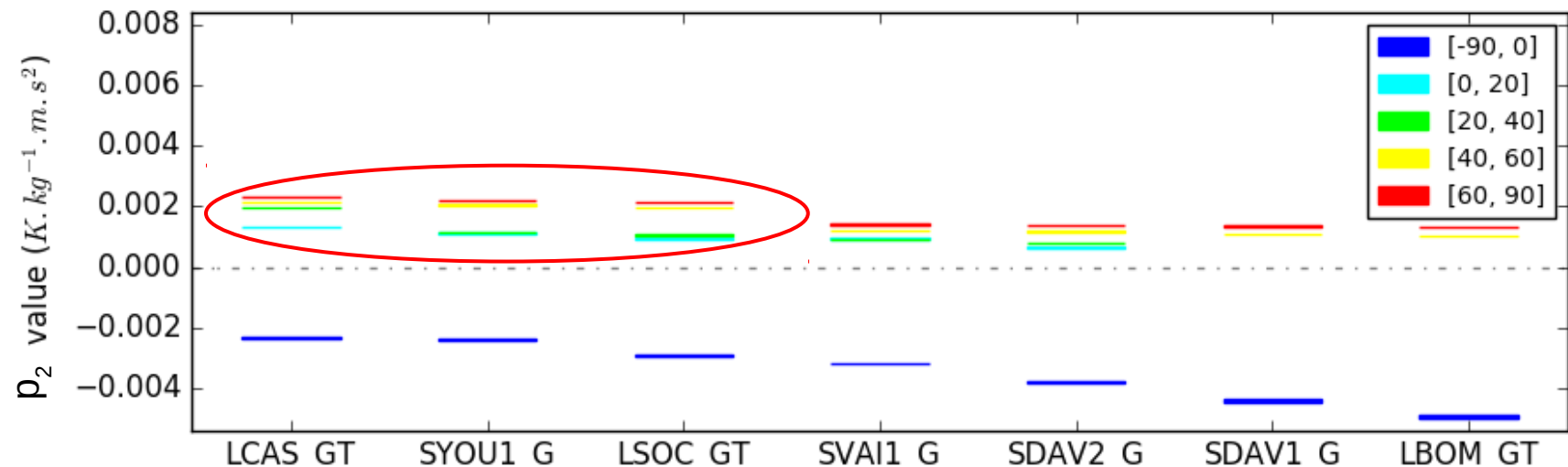
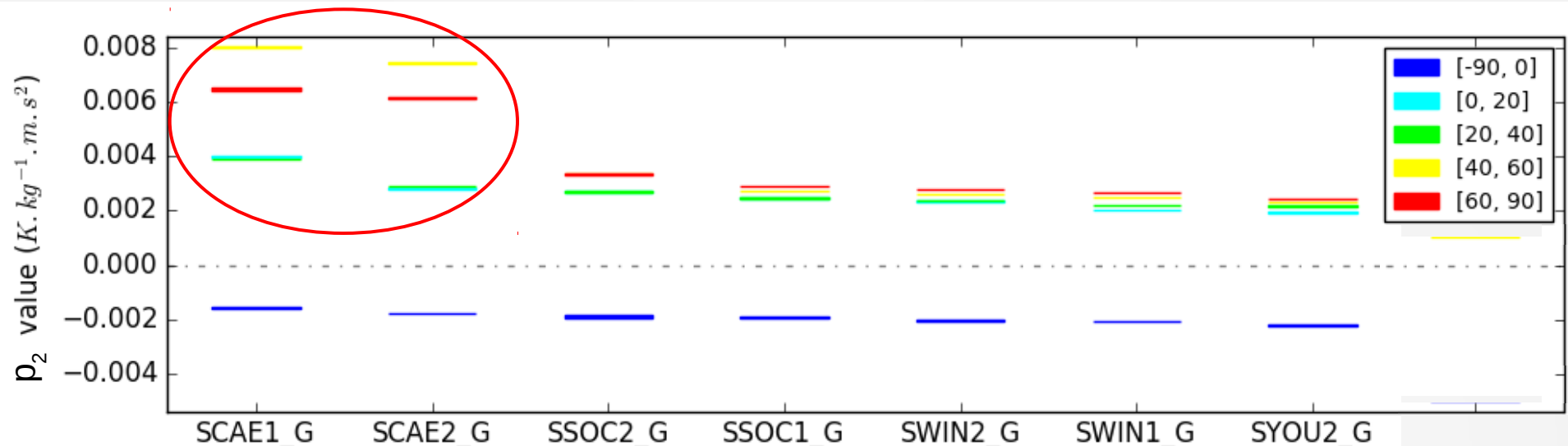
Solar angle influence (naturally ventilated)



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Main findings

- *The equation coefficient values seems consistent with observation*
 - *lag*
 - *radiation sensitivity*
- *Solar angle effect: crucial for some shelters*

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Openings

- *Better understanding the physical relationship between $p1$ and $p2$*
- *Data **correction** using this model should be tested*

Thanks to WMO for their agreement to freely use their data

And...

Thank you for your attention

Work funded by :

