Biophysical homoeostasis of leaf temperature: a neglected process for vegetation and land-surface modelling

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Theory

- In steady state, net radiation (R_n) is balanced by the combined sensible and latent heat fluxes:

$$R_n - c_p g_b \Delta T - \lambda E = 0 \qquad (1)$$

leading (via the Penman linearization) to the classical energy balance equation:

$$\Delta T = (R_n - \lambda g \bullet D)/c_p(g_b + \varepsilon\, g \bullet) \qquad (2)$$

- Leaves have a small heat capacity, so they track the steady state (time scale ≈1 min)

Theory

- A simple approximation:

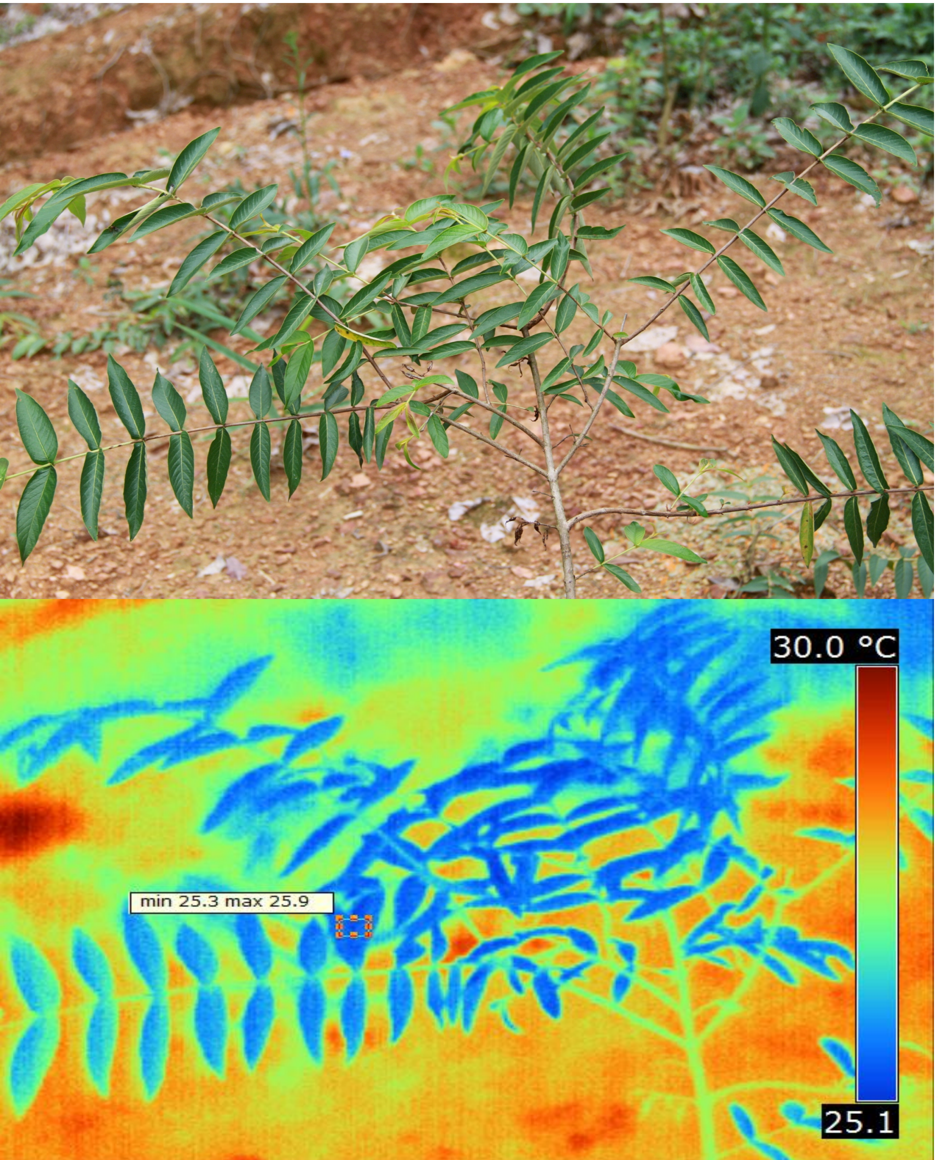
$$\lambda E = (1 + \omega)\,[s/(s + \gamma)]\,R_{\mathrm{n}} \qquad (3)$$

leads to a simplified equation:

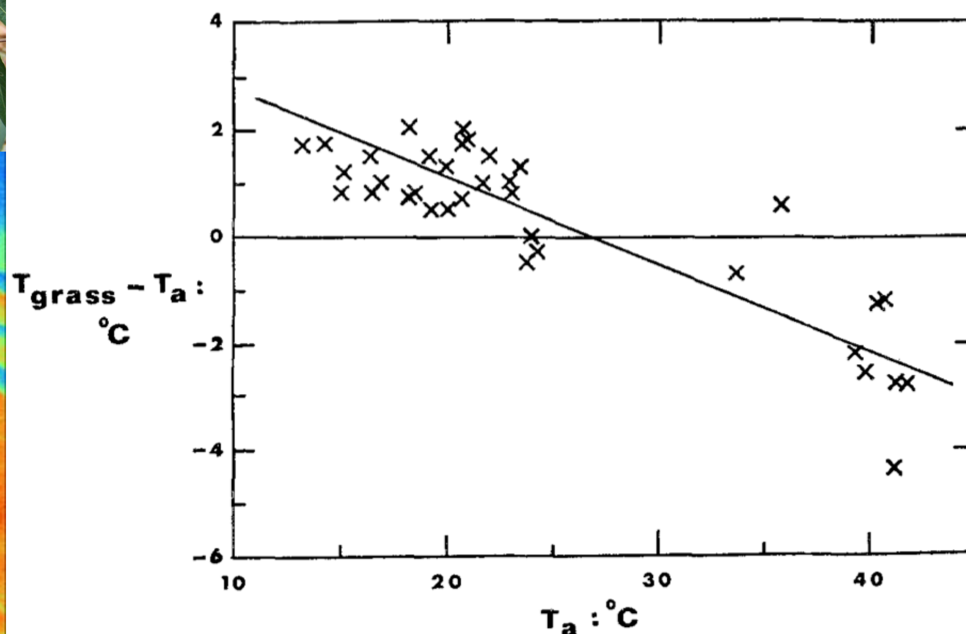
$$\Delta T = R_{\mathrm{n}}\{1 - (1 + \omega)[s/(s + \gamma)]\}/c_p g_b \qquad (4)$$

- ΔT decreases with increasing temperature
- $\Delta T < 0$ above ≈ 30˚C (‘crossover temperature’)

Background

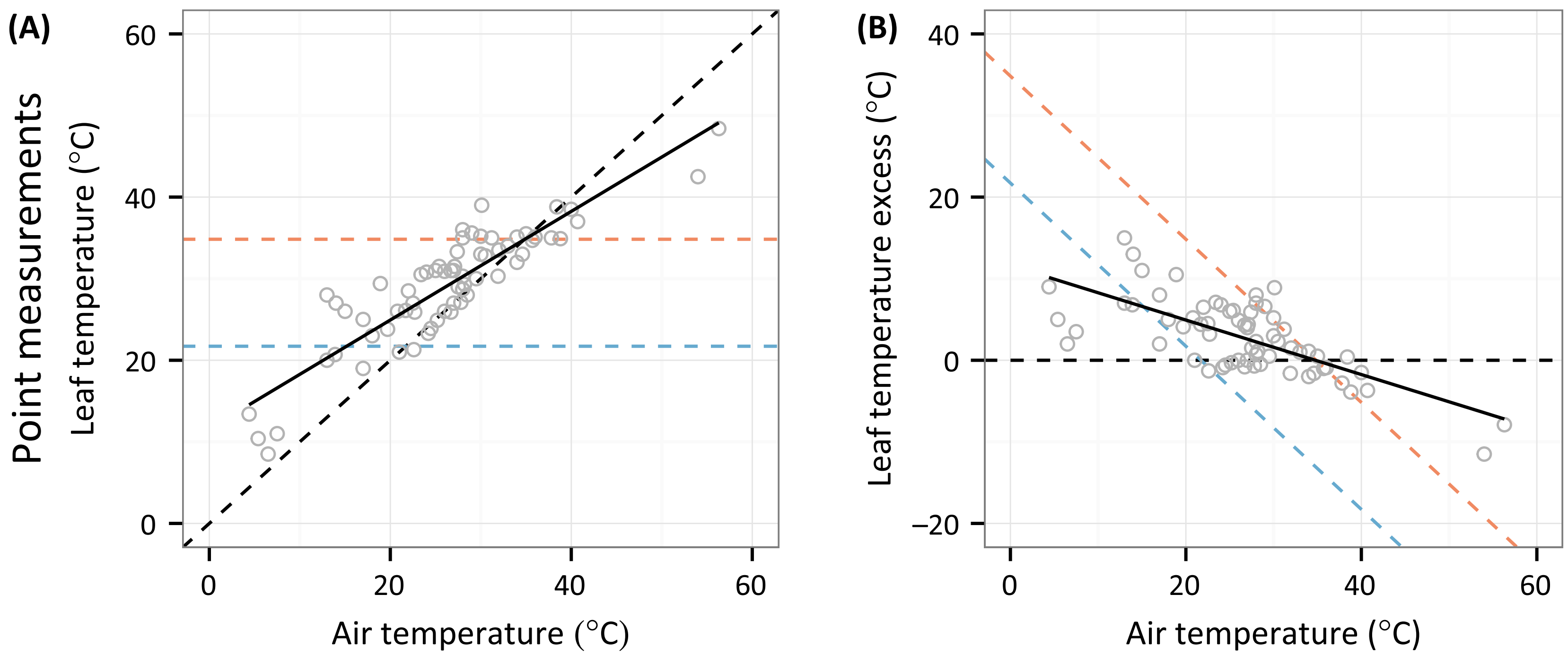


- Transpirational cooling
- Crossover temperature



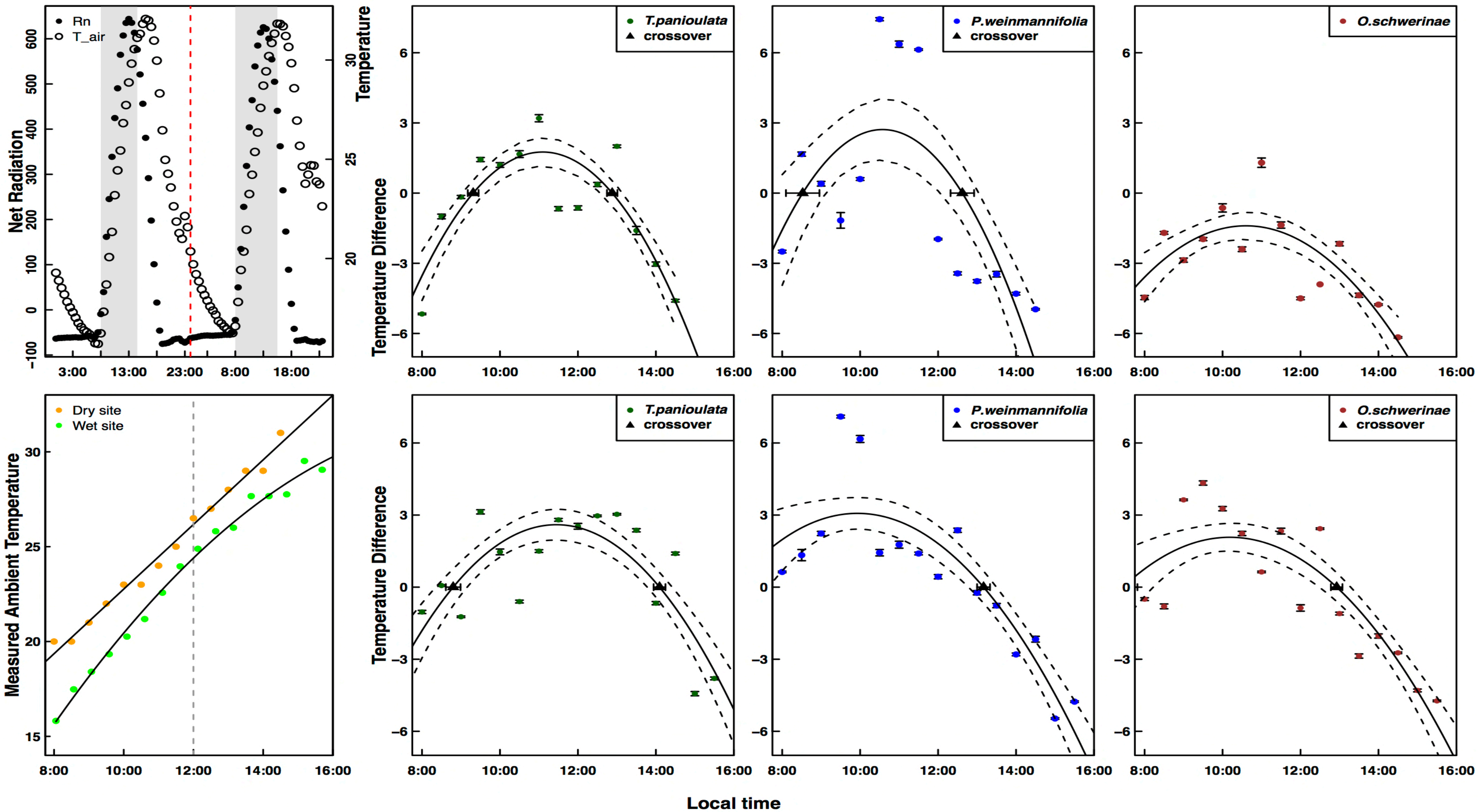
Linacre ET (1967) AFM

More observations of *ΔT*



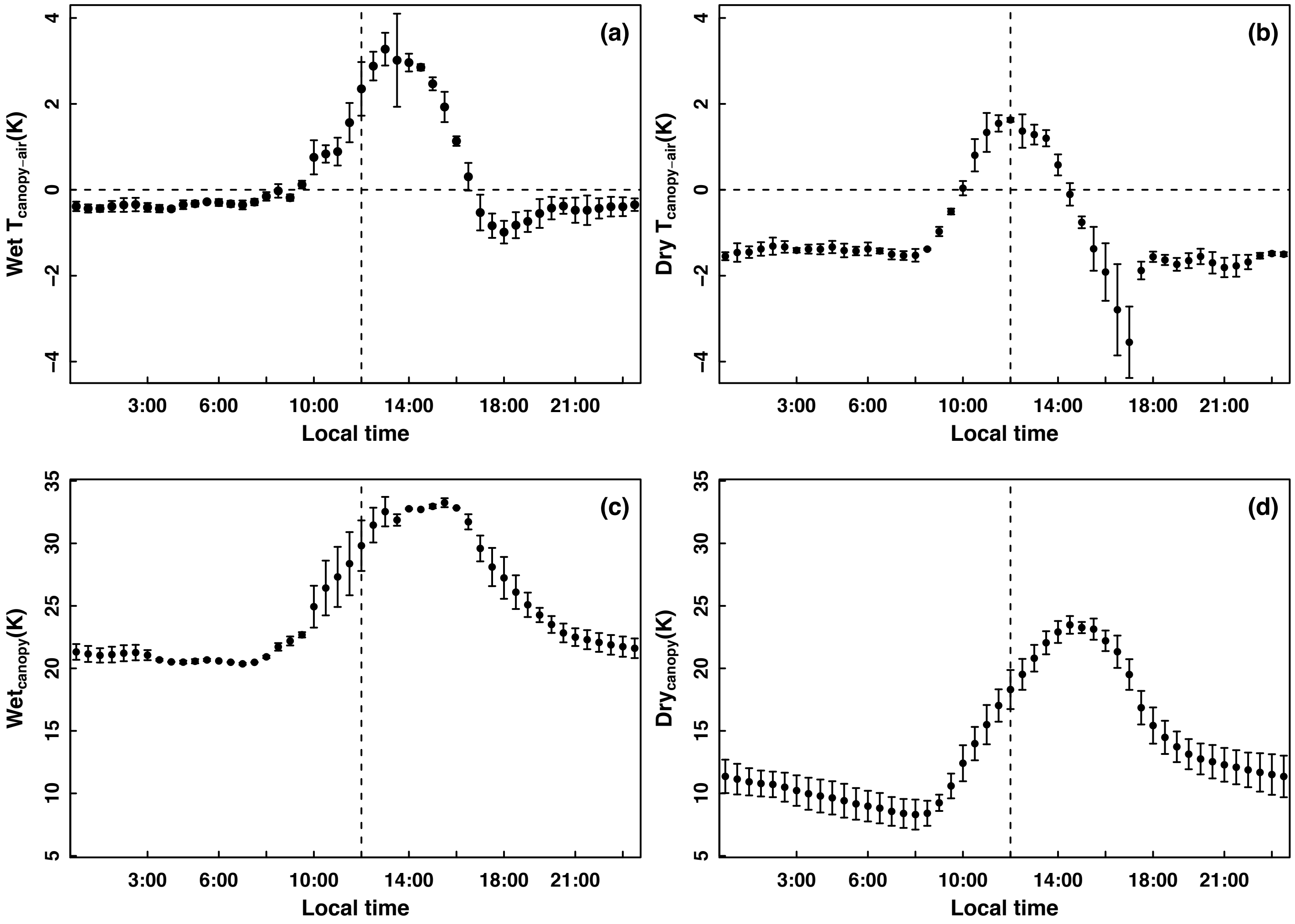
Michaeletz et al. (2015) *TREE*

Crossover observed at leaf level



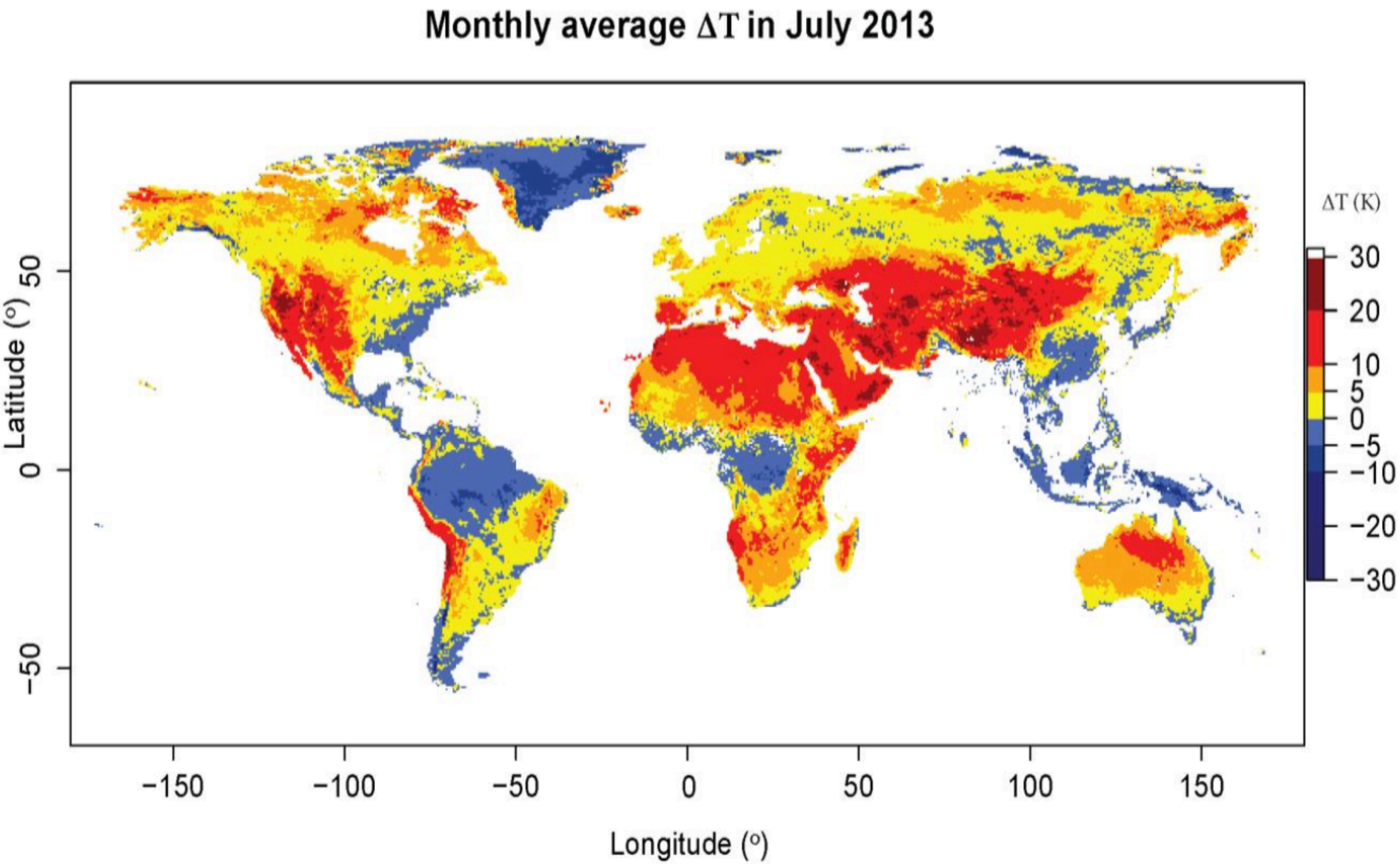
N Dong et al., in revision

Crossover observed by canopy monitoring



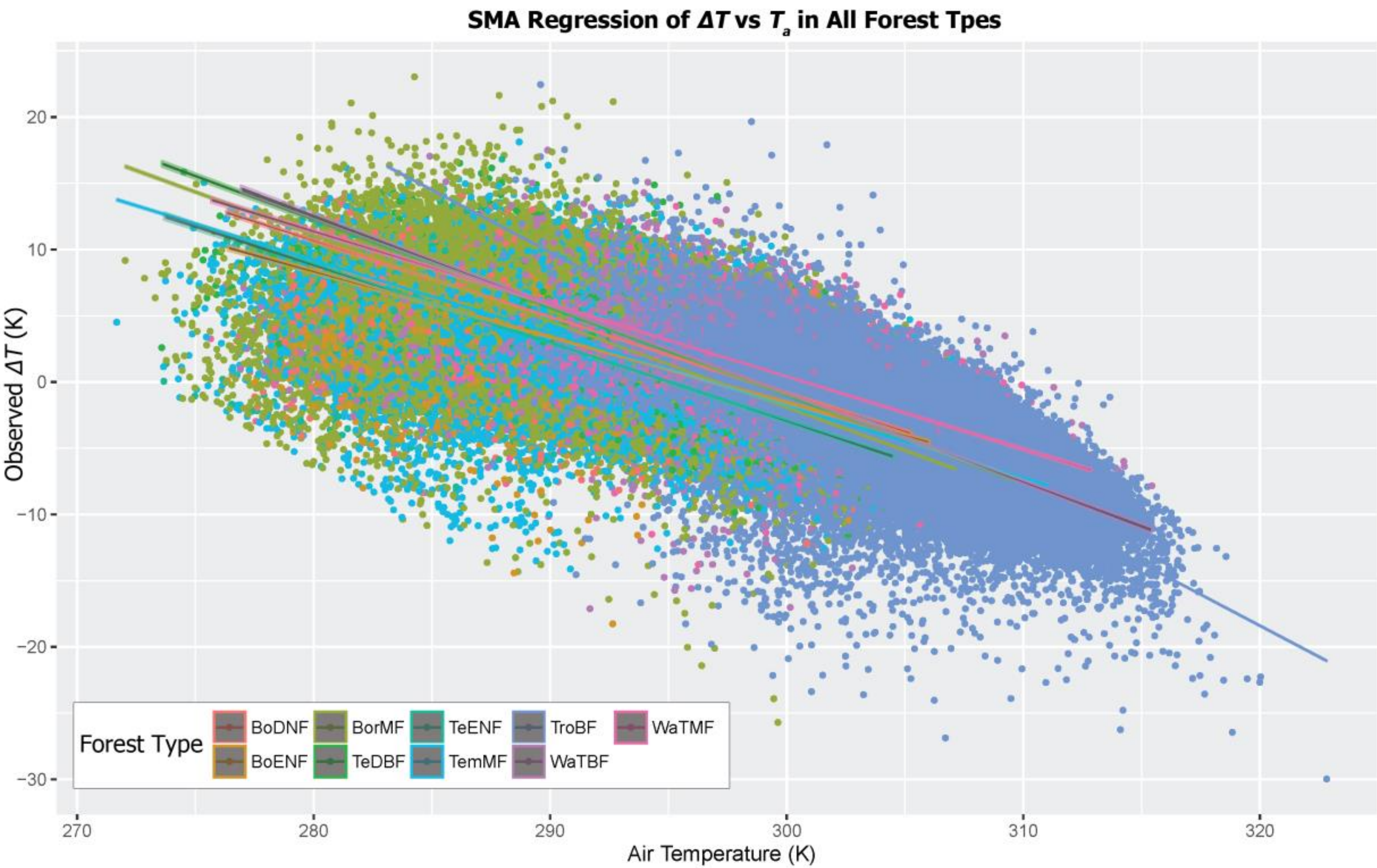
N Dong et al., in revision

Global pattern of *ΔT* using MODIS LST



A Kamolphat, 2016

Crossover observed in MODIS LST



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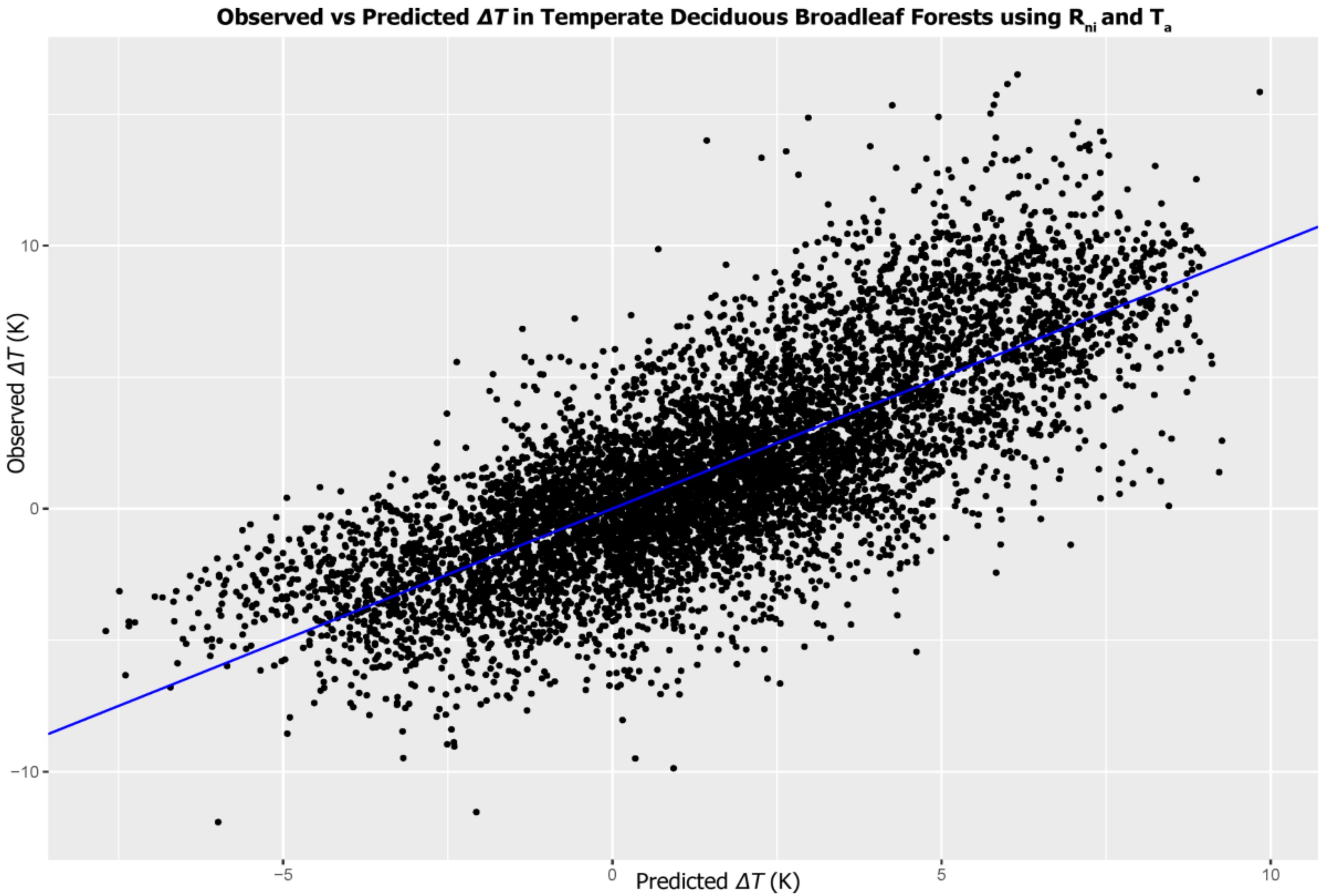
Prediction of ΔT with the simple model (temperate deciduous forest)



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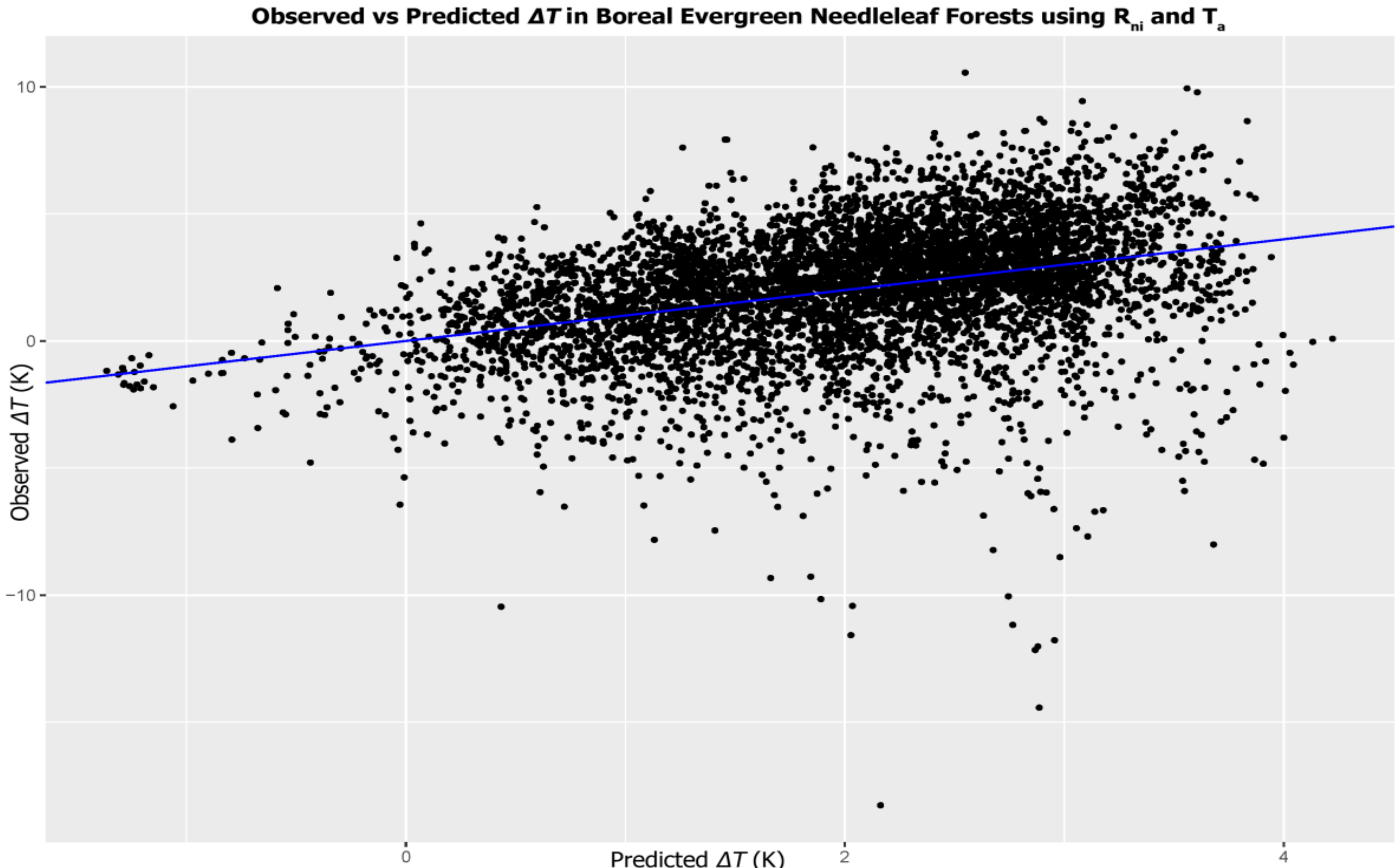
Prediction of ΔT with the simple model (boreal forest)



A Kamolphat, 2016

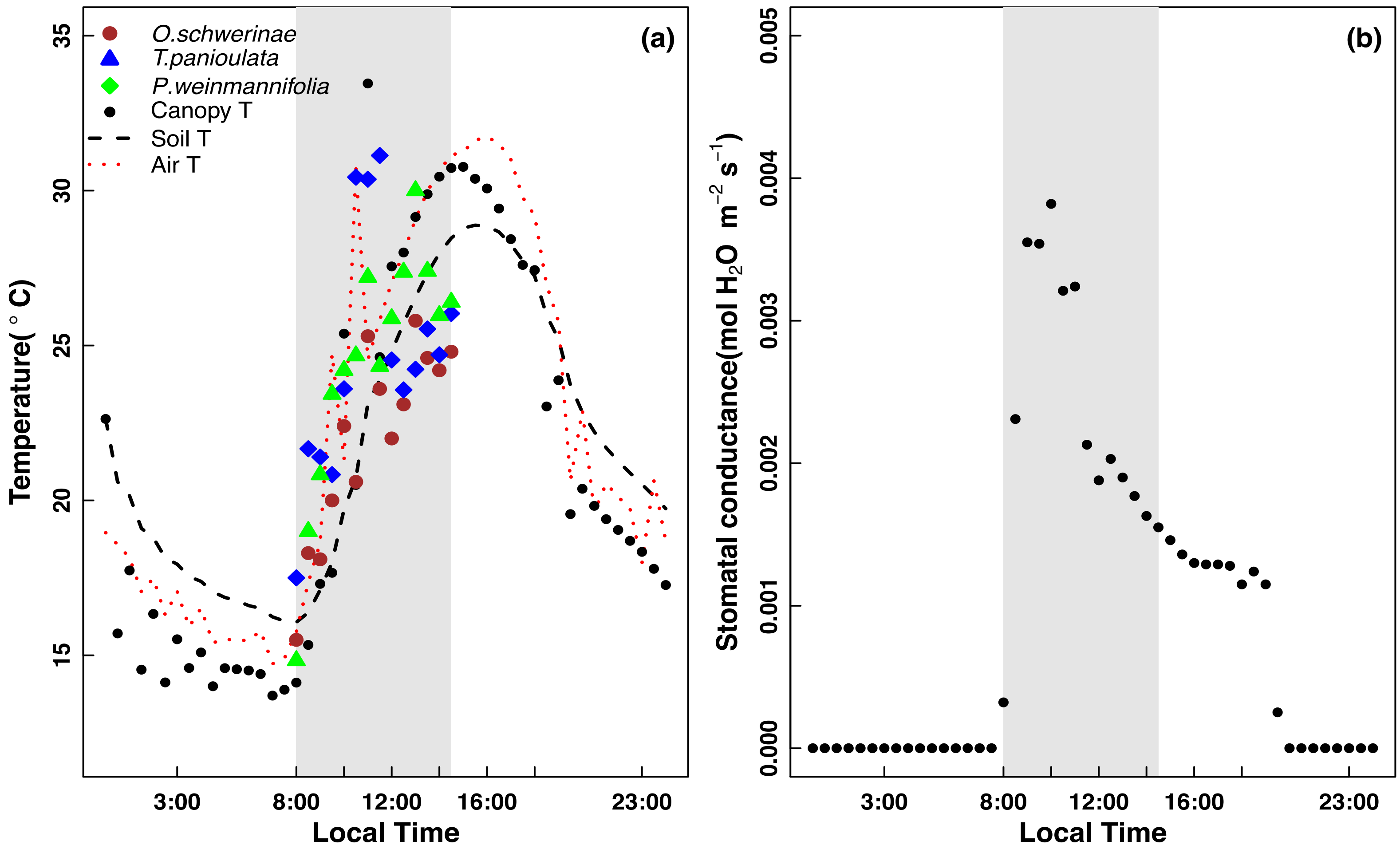
Key quantities can be inferred

- Crossover temperature: Cr, $\alpha_0 = 1 + \omega$, and g_b, $k{:}c_p g_b$ inferred from MODIS LST and WFDEI data

Forest type	Predicted k	Observed Cr temp. (°C)	Observed α_0	Observed k	Inferred g_H
TroBF	7.60	27.27	1.32	9.31	0.32
WaTBF	12.01	25.61	1.35	15.87	0.54
WaTMF	16.34	27.62	1.32	19.72	0.67
TeDBF	12.00	25.36	1.35	16.03	0.55
TemMF	20.44	23.62	1.39	29.52	1.01
TeENF	20.21	21.89	1.42	31.54	1.08
BorMF	16.44	23.90	1.38	23.46	0.80
BoENF	27.01	23.77	1.38	38.76	1.32
BoDNF	20.08	25.42	1.35	26.76	0.91
All	10.33	25.17	1.36	13.93	0.48

A Kamolphat, 2016

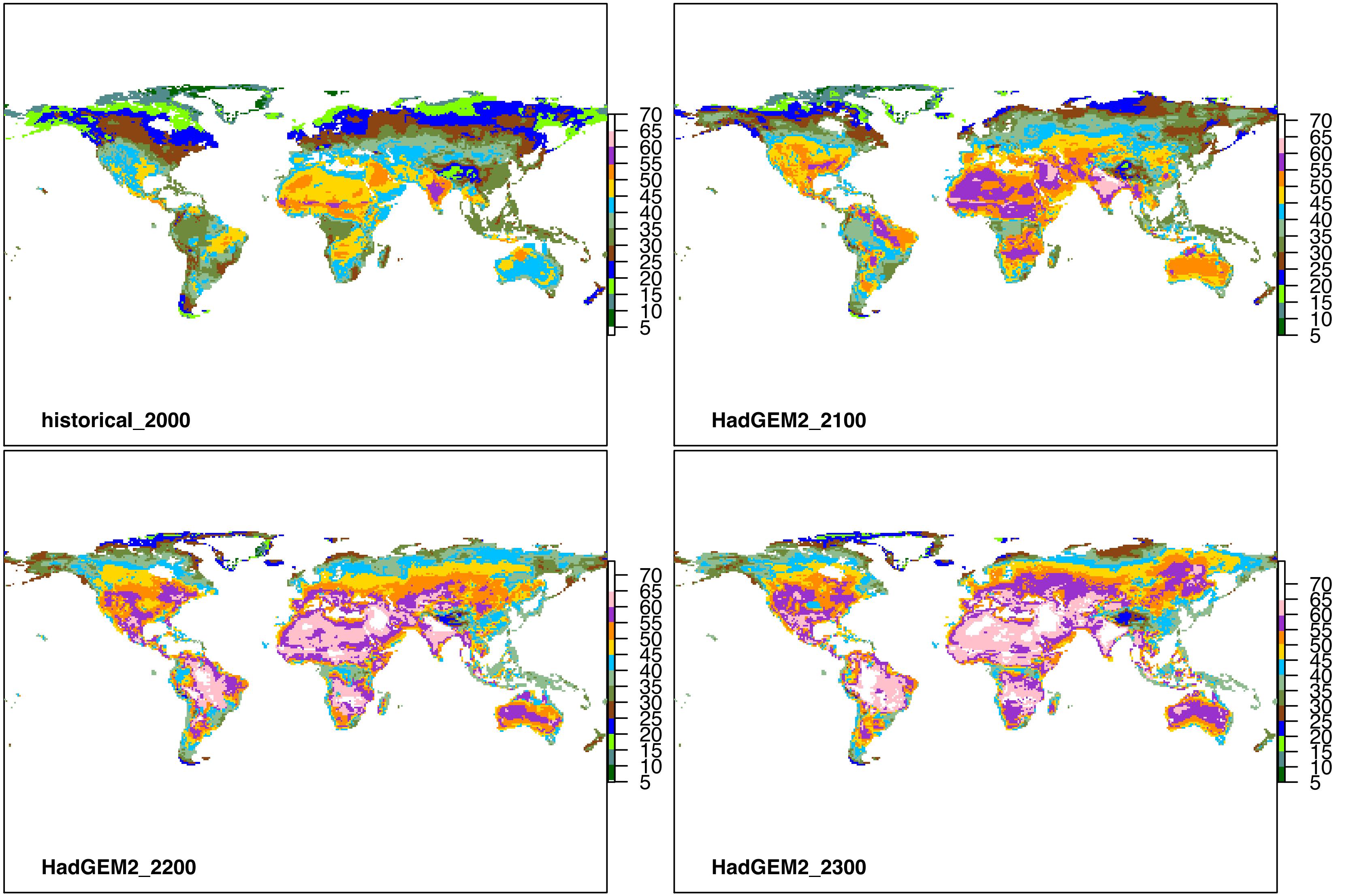
Can JULES simulate this phenomenon? Yes, but..



Diurnal time course of JULES-simulated and observed leaf temperatures in a tropical dry woodland

N Dong et al., in revision

Canopy T from future simulations by HadGEM2



N Dong, B Stocker, unpublished

Issues and future developments

- Why does the simple model work?
- How can leaves maintain a negative sensible heat flux (especially in a closed forest)?
- *ΔT* as a potential benchmark for g_s responses to temperature and vpd
- In-canopy measurements needed to assess influence of leaf size, leaf form, wind speed on *ΔT*

Conclusions

- Biophysical homoeostasis keeps leaves within a narrower temperature range than the air.
- This phenomenon is important for maintaining optimal leaf function.
- The mechanisms are only partly understood.
- Heat-stress vulnerability of tropical forests: need to model canopy T (well) – otherwise we may overestimate vulnerability.