The work of E. Rinne, J.-P. Tuovinen and M. Aurela has received funding from the Research Council of Finland, project ‘Quantifying the potential of boreal peatland rewetting for climate change mitigation (RESPEAT)’, grant no. 341752. E. Rinne has received funding from the Research Council of Finland, project ‘Atmosphere and Climate Competence Center (ACCC)’, grant no. 359342, and the centre of excellence in ‘Peatlands, Climate Change and Ecological Restoration’, grant no. 374132. The authors also acknowledge support from the Finnish Ministry of Transport and Communications through the Integrated Carbon Observing System (ICOS) Finland. The authors would like to thank the personnel at the Finnish Meteorological Institute involved in the measurements and data processing. CSC – IT Center for Science, Finland, is acknowledged for computational resources.

# Attributing surface temperature difference between a northern mire and forest to their biophysical properties

Erkka Rinne (erkka.rinne@fmi.fi), Juha-Pekka Tuovinen, Maiju Linkosalmi and Mika Aurela;
Climate System Research, Finnish Meteorological Institute, Helsinki, Finland

Studies on the biophysical effect on **land surface temperature (LST)** difference between mires and forests are scarce. The topic is important for example in the context of peatland rewetting to assess the total climate effect of such land use change.

**Research questions:**

1. Which differences in the surface biophysical properties between a mire and a forest explain the differences in their daily mean LST?
2. How much do different surface properties contribute to the observed LST difference?
3. Does the attribution of LST differences vary with season and weather?

- We utilised components of the **surface energy balance (SEB)** and supporting meteorology measured from a pristine mire and an unmanaged forest in Sodankylä, Finland, in 2021–2025.
- We attributed the difference in LST between a boreal mire and forest to the differences in their biophysical properties: **albedo ($\alpha$)**, **total energy storage change ($S_{tot}$)**, **aerodynamic resistance ($r_a$)** and **bulk surface resistance to evapotranspiration ($r_s$)**. Also, **SEB imbalance ($I$)** was explicitly accounted for.
- We propose a novel modification to a widely used attribution methodology obtaining much improved model accuracy.

**The mire surface was cooler on the annual level (–0.4 ± 0.2 °C):**

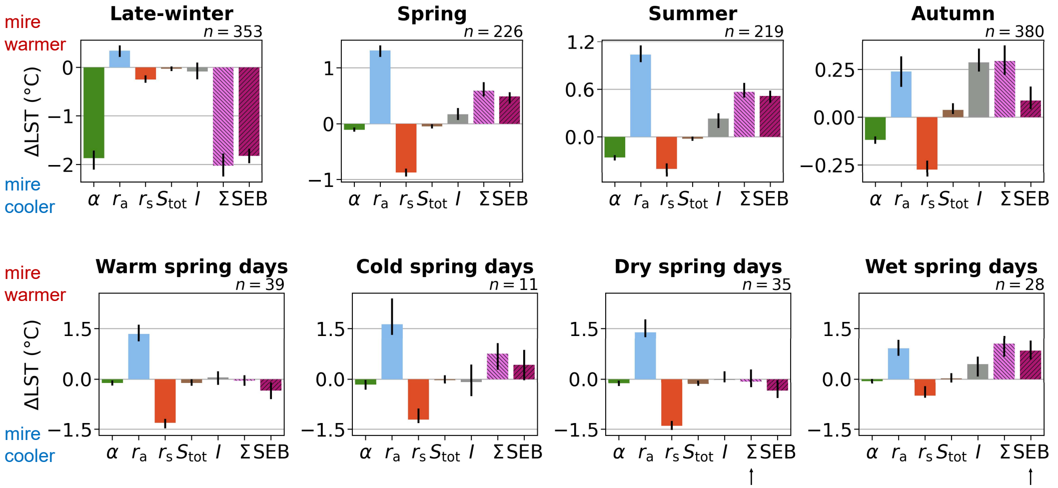
- Higher albedo ($\alpha$)
- Reduced turbulent mixing (higher $r_a$)
- Higher potential for evaporative cooling (lower $r_s$)

**…but a more extreme environment:**

- Colder during winter (higher $\alpha$)
- Warmer during summer (higher $r_a$)
- Pronounced diel temperature range (heat storages, $r_a$)

**Important differences from previous comparisons between low-vegetation and forest ecosystems:**

- Annually, a considerable cooling effect from the lower albedo due to long snow-covered period in the northern boreal zone
- Larger relative importance of difference in evaporation potential than in e.g. grassland–forest comparisons
- In the daily scale, LST difference not affected by differences in energy storages, when using actual measurements of soil heat flux

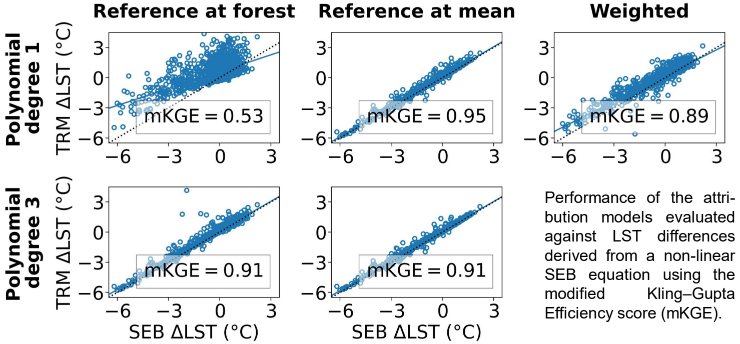



Σ = total attribution

SEB = ΔLST based on measurements

**The novel attribution re-formulation performed best**

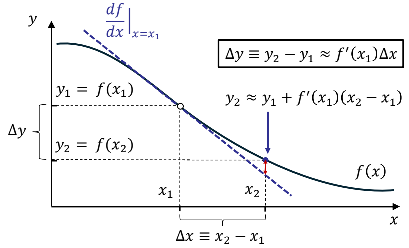
- Setting the Taylor series reference to **the mean surface state** alleviates large model errors.
- Results indicate low impact of variable auto- and cross correlation.
- Based on an analytic approach instead of empirical adjustment of LST sensitivities.




Performance of the attribution models evaluated against LST differences derived from a non-linear SEB equation using the modified Kling–Gupta Efficiency score (mKGE).

**Attribution is based on a Taylor series of the linearised LST equation**

$$f(x) = f(a) + \frac{f'(a)}{1!}(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \cdots$$




**Two-resistance mechanism attribution framework (TRM, Rigden & Li, 2018)**

In constant background forcing, the surface temperature can be expressed as a linearised function of the surface properties state $\boldsymbol{x} = (\alpha, G, r_a, r_s)$:

$$\mathrm{LST} = f(\boldsymbol{x}),$$

and the difference in LST between two surface property states using sensitivities and differences in the properties:

$$\Delta\mathrm{LST} \approx f'(\boldsymbol{x}^*)\boldsymbol{\Delta x}$$

$$= \frac{\partial \mathrm{LST}}{\partial \alpha}\bigg|_{\alpha^*}\Delta\alpha + \frac{\partial \mathrm{LST}}{\partial G}\bigg|_{G^*}\Delta G + \frac{\partial \mathrm{LST}}{\partial r_a}\bigg|_{r_a^*}\Delta r_a + \frac{\partial \mathrm{LST}}{\partial r_s}\bigg|_{r_s^*}\Delta r_s,$$

where $\boldsymbol{x}^*$ is a reference state.

**Previous approaches for reducing the model error:**

Liao et al. (2018) used weighted average of the partial derivatives at the both states:

$$f'\big((\boldsymbol{x}_1, \boldsymbol{x}_2)\big) \equiv m \times f'(\boldsymbol{x}_1) + (1-m) \times f'(\boldsymbol{x}_2),$$

with $m$ optimised against measured LST differences.

Chen et al. (2020) suggested increasing the polynomial degree to account for variable auto- and cross-correlations.

**A new formulation based on the mean state**

By choosing $\boldsymbol{x}^* \equiv \boldsymbol{x}_1 + \frac{1}{2}\Delta\boldsymbol{x}$, we get

$$\Delta\mathrm{LST} = f'(\boldsymbol{x}^*)\Delta\boldsymbol{x} + \frac{1}{24}f'''(\boldsymbol{x}^*)(\Delta\boldsymbol{x})^3 + \cdots,$$

which has a smaller series residual.

**Literature**

Rigden, A.J., Li, D., 2017. ‘Attribution of surface temperature anomalies induced by land use and land cover changes’. doi:10.1002/2017GL073811.
Liao, W., Rigden, A.J., Li, D., 2018. ‘Attribution of Local Temperature Response to Deforestation’. doi:10.1029/2018JG004401.
Chen, C., Wang, L., Myneni, R.B., Li, D., 2020. ‘Attribution of Land-Use/Land-Cover Change Induced Surface Temperature Anomaly: How Accurate Is the First-Order Taylor Series Expansion?’ doi:10.1029/2020JG005787