Improvements to Simulations of Canopy Longwave Radiation in Boreal Forests and their Impact on Seasonal Snow Cover

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Introduction and study sites

Northern boreal forests cover a large fraction of snow covered area, and **enhance downwelling longwave radiation (LWE)** that impacts the surface energy balance and snowmelt. We analyse seven forest stands with available measurements of sub-canopy longwave radiation (LWR), and necessary forcing variables and parameters. These sites span a wide range of vegetation types and structures, and diverse meteorological conditions (**Fig. 1**). Vegetation is evergreen at **Alptal** and **Seehornwald** (spruce/fir) and **Sodankyla** (pine). The deciduous sites are **Abisko** (birch), **Cherskiy** and **Yakutsk** (larch), while **Borden** is a mixed forest (maple, pine). At each site we compare the parameterization of sub-canopy LWR in the Community Land Model version 4.5 (**CLM4.5**; Oleseon et al. 2013) with that of **SNOWPACK** (Gouttevin et al. 2015) **during spring snowmelt** .

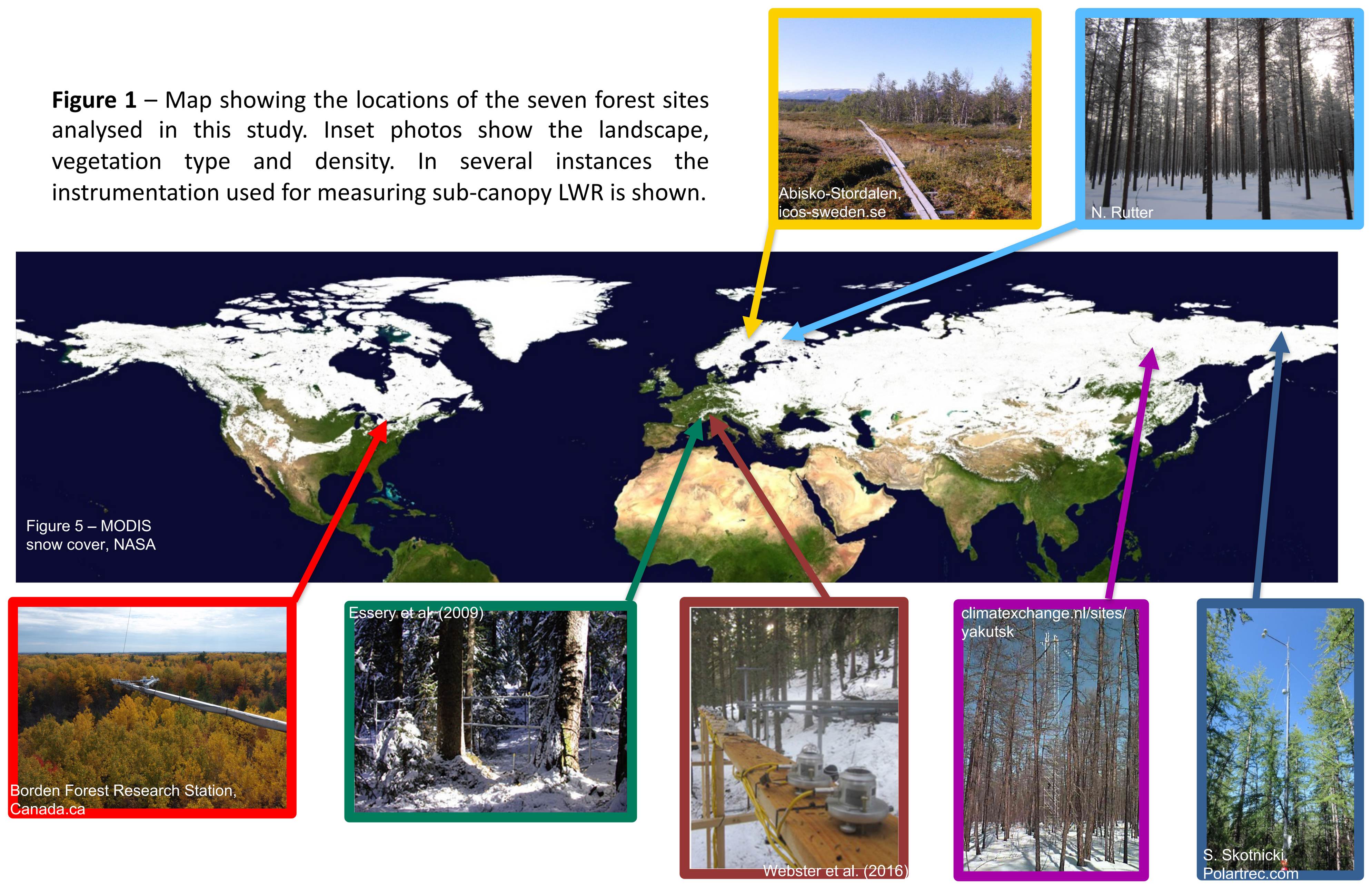

Figure 1 – Map showing the locations of the seven forest sites analysed in this study. Inset photos show the landscape, vegetation type and density. In several instances the instrumentation used for measuring sub-canopy LWR is shown.

Toy model results (Fig. 2)

We perform stand-scale experiments to assess the parameterization of sub-canopy LWR and LWE. A toy model is developed to **quantify the impact on LWE** that is due to the parameterization alone.

- Errors in sub-canopy LWR in CLM4.5 show a systematic **daytime overestimation** and **night time underestimation** (**Fig. 2**, left column).
- Errors in simulated LWE **increase under clearer skies** (decreasing ε_{sky}): higher insolation and lower atmospheric LWR (**Fig. 2**, centre column).
- The range of LWE is **determined by ε_{sky} and vegetation density**.

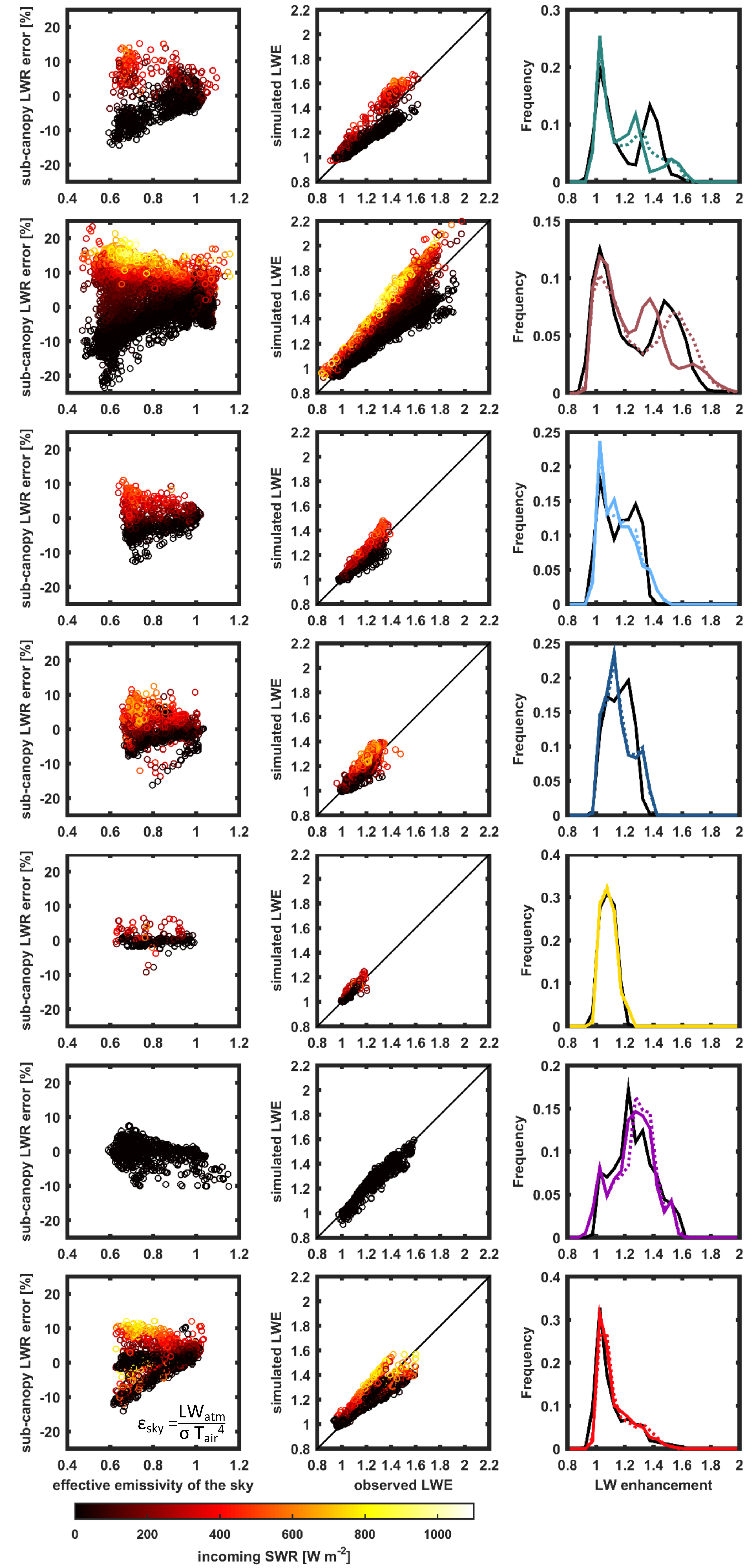

Figure 2 – Errors in sub-canopy LWR simulated by CLM4.5 (left column), comparison of simulated and observed LWE (centre column), and PDFs of LWE for observations (black), CLM4.5 (colour, solid), and CLM4.5 including biomass heat storage (colour, dashed).

References

Gouttevin, I., M. Lehning, T. Jonas, D. Gustafsson, and M. Mölder (2015), A two-layer canopy model with thermal inertia for an improved snowpack energy balance below needleleaf forest (model SNOWPACK, version 3.2.1, revision 741), Geoscientific Model Development, 8, 2379–2398, doi:10.5194/gmd-8-2379-2015.

Oleson, K., D. Lawrence, G. Bonan, B. Drewniak, M. Huang, C. Koven, S. Levis, F. Li, W. Riley, Z. Subin, S. Swenson, P. Thornton, A. Bozbiyik, R. Fisher, E. Kluzek, J.-F. Lamarque, P. Lawrence, L. Leung, W. Lipscomb, S. Muszala, D. Ricciuto, W. Sacks, Y. Sun, J. Tang, and Z.-L. Yang (2013), Technical Description of version 4.5 of the Community Land Model (CLM), Tech. rep., National Center for Atmospheric Research, doi:10.5065/D6RR1W7M.

Impacts on LWR and snow in CLM4.5 (Figs. 3 and 4)

Adding a **biomass heat storage term** from SNOWPACK has only a small impact on the errors in CLM4.5, except at sites with the densest vegetation (**Fig.2**, right column). Therefore, a more substantive correction is applied to CLM4.5 based on a multiple regression derived from Fig. 2 (left column), which mimics the effects of a **second canopy layer** in SNOWPACK.

- **The correction reduces the diurnal range of LWR** by 20-25%, while also maintaining the correct diurnal cycle, which suggests an improved simulation of LWE (**Fig. 3**).
- Output from global simulations of CLM4.5 shows the same behaviour.
- Observed diurnal variability in LWR is 2x larger at **Sodankyla** than **Alptal** due to vegetation density, but in CLM4.5 the variability is similar because **the model prescribes similar LAI**.

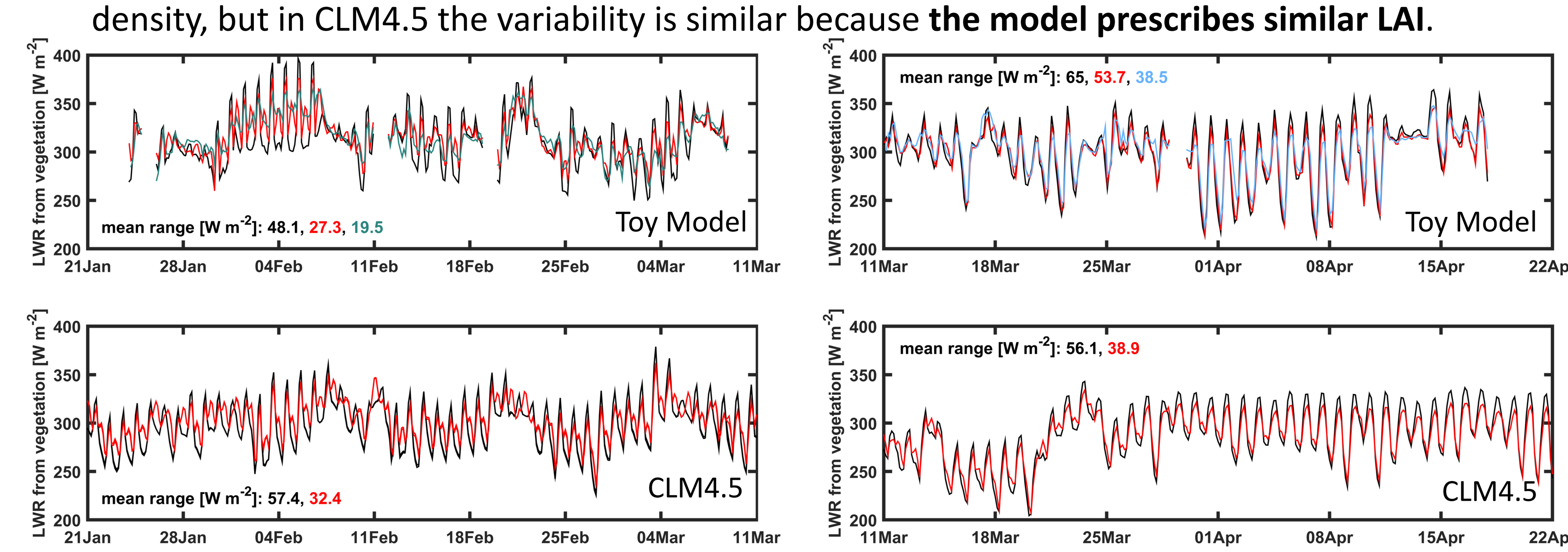

Figure 3 – Top row shows LWR emitted from vegetation before (black) and after (red) applying a correction factor for Alptal (left) and Sodankylä (right). Bottom row shows output from an offline global simulation with CLM4.5 for an arbitrary model year. The blue line in the top panels shows LWR from vegetation inferred from measurements of sub-canopy LWR.

The correction to CLM4.5's sub-canopy LWR also impacts the **seasonal cycle of snow mass** at the study sites (**Fig. 4**), but the **magnitude depends on vegetation density**.

- At **Sodankyla** (sparse vegetation), the correction has very little impact.
- At **Alptal** (dense vegetation), the corrected model melts about 50% more snow during Feb-Mar.
- Next steps are to refine the correction, and to further investigate its impact on snow.

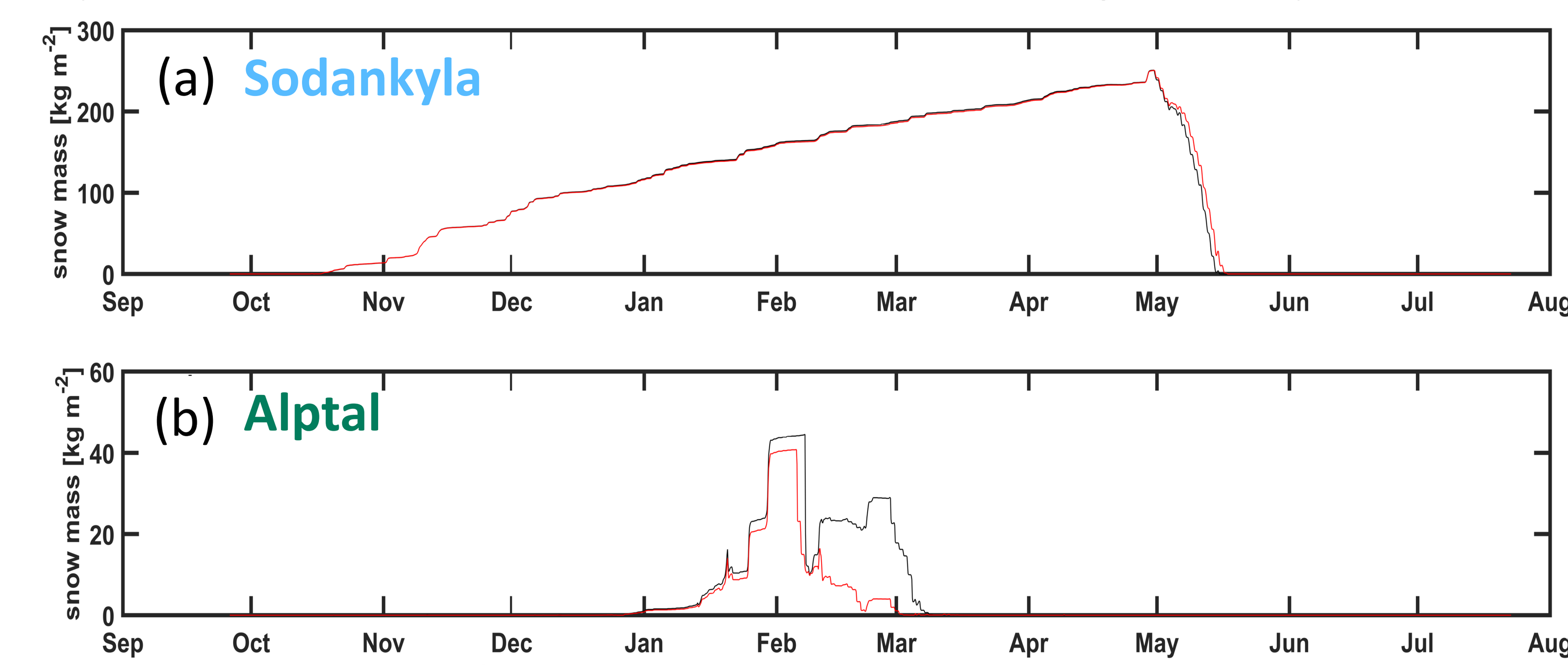

Figure 4 – Simulated snow mass (kg/m²) from offline simulations of CLM4.5 during a single year at (a) Sodankylä, and (b) Alptal. The black line shows the output from the unperturbed control simulation, while the red line shows the output from the simulation including the correction to subcanopy LWR.

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