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Improved representation of forest snow processes in coarse-resolution models: lessons learnt from upscaling hyper-resolution simulations

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Forest snow cover dynamics affect hydrological regimes, ecosystem processes, and climate feedbacks, and thus need to be captured by model applications that operate across a wide range of spatial scales. At large scales and coarse model resolutions, high spatial variability of the processes shaping forest snow cover evolution creates a major modelling challenge. Variability of canopy-snow interactions is determined by heterogeneous canopy structure and can only be explicitly resolved with hyper-resolution models (<5m).

Here, we address this challenge with model upscaling experiments with the forest snow model FSM2, using hyper-resolution simulations as intermediary between experimental data and coarse-resolution simulations. When run at 2-m resolution, FSM2 is shown to capture the spatial variability of forest snow dynamics with a high level of detail: Its accurate performance is verified at the level of individual energy balance components based on extensive, spatially distributed sub-canopy measurements of micrometeorological and snow variables, obtained with mobile multi-sensor platforms. Results from hyper-resolution simulations over a 150,000 m^2 domain are then compared to spatially lumped, coarse-resolution runs, where 50m x 50m grid cells are represented by one model run only. For the spatially lumped simulations, we evaluate alternative upscaling strategies, aiming to explore the representation of forest snow processes at model resolutions coarser than the spatial scales at which these processes vary and interact.

Different upscaling strategies exhibited large discrepancies in simulated (1) distribution of snow water equivalent at peak of winter, and (2) timing of snow disappearance. Our results indicate that detailed canopy structure metrics, as included in hyper-resolution runs, are necessary to capture the spatial variability of forest snow processes even at coarser resolutions. They further demonstrate the relevance of accounting for unresolved sub-grid variability in snowmelt calculations even at relatively small spatial aggregation scales. By identifying important model features, which allow coarse-resolution simulations to approximate spatially averaged results of corresponding hyper-resolution simulations, this work provides recommendations for modelling forest snow processes in medium- to large-scale applications.