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Regional-scale glacier melt modelling with dynamically downscaled climate fields: surface energy balance model versus temperature-index model

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Current projections of glacier mass loss on regional and global scales are based on semi-empirical temperature-index models whose parameters are poorly constrained in the absence of mass balance observations. To narrow the uncertainty in projected glacier melt on these scales, we aim to develop a modelling approach that incorporates surface energy balance (SEB) models forced with coupled dynamical and statistical downscaling. A first step towards this goal, addressed in this study, is to evaluate the performance of a SEB model forced with dynamically downscaled fields at three glaciers in the interior of British Columbia (BC) that were the subject of multi-year observations by automated weather stations (AWS). Our second goal is to compare the performance of a temperature-index model with the SEB model, when both are forced with downscaled fields, for all mountain glaciers in the interior BC over four summer seasons. With the use of Weather Research and Forecasting (WRF) model we downscale meteorological variables and energy fluxes at spatial resolution computationally attainable for a regional scale (e.g. western Canada) and relatively long periods (e.g. a decade). The WRF model, nested within the ERA-Interim global reanalysis, produced hourly output fields at 2.5 km grid for all three glaciers, as well as 850 m grid for one of the glaciers. We find that with in situ measurements of all fluxes, the SEB model simulates daily mean melt rate within 5% error over the whole melt season. Forcing the SEB model with the downscaled instead of measured fluxes, yields up to 20% difference in simulated seasonal melt. The difference between downscaled and AWS-derived values, however, can be large for individual SEB components (up to 80% difference), revealing a cancellation of biases in the estimated total melt energy. A positive bias in seasonal incoming shortwave radiation in WRF is compensated by a negative bias in the incoming longwave radiation, and by an underestimation of sensible and latent heat fluxes. The temperature-index model, with individually calibrated melt factors for each glacier site and each season, simulates in situ seasonal melt within 15% difference from the SEB model. The melt factors are found to substantially vary spatially (e.g., two locations 200 m apart on the same glacier) and temporally (same location over two melt seasons). This variability in melt factors (4.1-7.6 mm w.e. $^{\circ}C^{-1}$ day^{-1}) is partly explained by the variability in mean seasonal albedo (0.20-0.35 for ice surface, 0.67 for firn/snow surface). When the mean melt-factor value (6.3 mm w.e. $^{\circ}C^{-1}$ day^{-1}) is assigned to all glaciers in the region, the temperature-index model underestimates seasonal regional melt by 1 m w.e. relative to the SEB model. The negative bias remains even when the largest melt-factor value from the calibration sample is used for all glaciers. The results highlight the limitations in the regional-scale melt modelling in the absence of glacier-specific melt factors for each glacier in the region.