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A robust strategy to calibrate a coupled ice-flow, mass balance and debris cover evolution model

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The aerial extent of supraglacial debris cover is increasing on mountain glaciers as a result of recent climatic warming. A thicker debris cover tends to shield the glacier surface from melting, with important consequences for glacier dynamics and evolution. However, only a few studies have tried to model the impact of a changing supraglacial debris cover on glacier evolution at a regional scale. For nearly all of the existing models, it is difficult to calibrate the individual unknown model parameters, such as the degree-day factors, temperature and precipitation biases, debris supply rate and englacial debris concentration, because of the strong interdependencies between mass balance, ice-flow and debris cover and thickness evolution. In the case of regional scale modelling of glacier evolution, almost all of these unknown model parameters are tuned with respect to a small set of selected glaciers. As a result, the level of uncertainty in the calculated model outputs varies for those glaciers that are outside the set of glaciers that were used during calibration. On top of that, due to process-based complexities, many of these models have parameterised the evolution of spatial distribution of debris thickness rather than using process-based models. Therefore, we propose using Bayesian inference to calibrate the coupled ice-flow and debris evolution model. Bayesian inference presents a unique way to calibrate the model parameters while taking into account the uncertainty in the observed data. The stochastic calibration of model parameters through Bayesian inference enables a robust uncertainty analysis of the model results. Using Bayesian inference, helps decouple the intertwined complex process that renders model calibration easy.

To demonstrate the above, as a first step, we present a strategy to effectively decouple and separately calibrate the mass-balance and debris cover evolution modules. We first calibrate the unknown parameters of the mass balance model, namely the degree day factor and the temperature and precipitation biases. We use Bayesian inference for calibrating the mass balance model against geodetic mass balance and satellite-derived, maximum annual snowline altitude. Next, we calibrate a debris cover evolution model using the calibrated mass balance model. We first test this approach at the Oberaletsch Glacier in the Swiss Alps. The mass balance model is forced by reanalysis temperature and precipitation, using a degree-day model modified for debris melt effects. Using our strategy, we simulate the 20-year averaged glacier-wide mass balance within 10% uncertainty as compared to existing geodetic mass balance data. In addition, we simulate the evolution of supraglacial debris-cover for every 10 m elevation band within a mean

uncertainty of ~11% as compared to satellite-derived debris cover data. In the future, in addition to the mass balance and debris evolution, we also aim to use this strategy to calibrate the ice-flow module. Once calibrated, the coupled model will be used to estimate the future evolution of glaciers located in the Swiss Alps.