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Reconstructing spatially variable mass balances from past ice extents

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The Last Glacial Maximum (LGM), which ended about 20 000 years ago, left a strong observable imprint on the landscape, such as abandoned moraines, trimlines and other glacial geomorphic features. These features provide a valuable record of past continental climate. In particular, terminal moraines reflect the extent of glaciers and ice-caps, which in turn reflect past temperature and precipitation conditions. Here we present an inversion method and its application to reconstruct the LGM mass balances, including a spatially variable equilibrium line altitude (ELA). The method is based on a Tikhonov regularization and enables to invert past ice extent data at the scale of a mountain range. We show that the method only requires the computation of an ice flow model, to solve the ice thickness equation, and the Laplacian of the ELA field. The ice flow model is developed using the shallow ice approximation, with a MUSCL flux limiter, and is solved explicitly using Graphical Processing Unit (GPU) to significantly reduce the calculation time needed. It also includes the effects of flexural isostasy. The developed inversion method could be used with any other higher order ice flow model.

We apply the method to LGM ice extents of the European Alps and South Island of New Zealand. In New Zealand, the ELA spatial pattern shows a W-E and a N-S change in the altitude of the ELA. The lower ELAs in the west compared to the east reflect the effects of the Westerlies on precipitation. The N-S change is the result of the temperature change because of the latitudinal difference. In the Alps, we observe lower ELAs on the southern flanks than on its on northern flanks. Analyzing changes in the ELA spatial patterns from LGM to present can give us more insight in the changes of precipitation, wind and temperature patterns through time. These examples show that the method is capable of constraining spatial variations in mass balance at the scale of a mountain range and provide us with information on past continental climate.