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Reconstruction of past equilibrium line altitude using ice extent data

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With the end of the Last Glacial Maximum (LGM), about 20 000 years ago, ended the most recent long-lasting cold phase in Earth's history. This last glacial advance 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 itself reflects past temperature and precipitation conditions. Here we present an inverse approach, based on a Tikhonov regularization, we have recently developed to reconstruct the LGM mass balance from observed ice extent data. The ice flow model is developed using the shallow ice approximation and solved explicitly using Graphical Processing Units (GPU). The mass balance field, b, is the constrained variable defined by the ice surface S, balance rate β and the spatially variable equilibrium line altitude field (ELA):

$$b = \min(\beta \cdot (S(x, y) - ELA(x, y)), c). \qquad (1)$$

where c is a maximum accumulation rate. We show that such a mass balance, and thus the spatially variable ELA field, can be inferred from the observed past ice extent and ice thickness at high resolution and very efficiently. The GPU implementation allows us solve one 1024x1024 grid points forward model run under 0.5s, which significantly reduces the time needed for our inverse method to converge. We start with synthetic test to demonstrate the method. We then apply the method to LGM ice extents of South Island of New Zealand, the Patagonian Andes, where we can see a clear influence of Westerlies on the ELA, and the European Alps. 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.