Geophysical Research Abstracts, Vol. 9, 00834, 2007
SRef-ID: 1607-7962/gra/EGU2007-A-00834


# A robust 2D higher-order ice-flow model for inverse applications

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When inverting glacier surface velocity observations for basal parameters, a shallow-ice approximation model is of limited use and a higher-order ice-flow model is better suited. This is because surface velocity observations carry the smoothing effect of longitudinal stress gradients on local variations in sliding, bed elevation and surface elevation.

We present a robust 2D time-independent isothermal higher-order ice-flow model. The physical model is based on Pattyn (2002). The numerical model is based on finite elements. We use triangular elements and linear base functions to build a piecewise linear approximation of the velocity solution. This leads to a set of equations that is very similar to a finite difference discretisation on a staggered grid. As compared to Pattyn's finite difference discretisation on a regular grid, our dicretisation results in a significantly better stability in the non-linear iteration. This allows for a robust inversion of basal parameters. A second improvement is a simpler and more efficient relaxation scheme for the non-linear iteration. An adapted preconditioned conjugate gradient solver assures a fast solution of the ice velocity for each iteration.

We give ample evidence for the validity of the model. A first test is the so-called parallel-sided slab setup, for which our results match the analytic solution. A second series of experiments consists of simple variations on the parallel-sided slab setup and tests the performance of the model in the case of bed, surface and sliding variations. The results match physical intuition. A third series of validation experiments follows the ISMIP-HOM benchmarks. Model consistency is proven for all experiments.