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Dimension analysis as a tool to explain numerical inaccuracies in ice sheet modelling

J. van den Berg (1), R.S.W. van de Wal (1) and J. Oerlemans (1)

(1) Institute for Marine and Atmospheric research Utrecht, Utrecht University, Princetonplein 5, 3584CC Utrecht, The Netherlands (J.vandenBerg@phys.uu.nl)

We assessed the effects of varying spatial discretisations through a series of experiments with simplified geometries in one-dimensional and two-dimensional vertically integrated ice flow models based on the shallow ice approximation. An essential modelling element is the mass balance parameterisation as a function of altitude, since numerical errors can grow nonlinearly over time due to this feedback mechanism. The mass balance feedback with height and associated numerical problems are especially important for research which deals with ice sheet inception, where the integration periods of model runs are very long.

We found that the model's numerical behaviour is very sensitive to the precise initial conditions, local geometry and climate. The cause of this behaviour is the sensitivity to the discretisation of the ice margin. For a fine grid, the ice flux at the ice margin is large enough to overcome the negative mass balance at the next grid point in the model. The ice sheet will grow and continue to the next grid point and so forth. However, for a coarse grid, the same ice flux may not be large enough to overcome the more negative mass balance of the next grid point much farther away. Hence ice growth in the model will stop. Because of the height-mass balance feedback this seemingly small error can grow rapidly over time. As a result, ice sheets calculated with too coarse grids can be grossly underestimated.

We show that dimension analysis can not only explain the modelled results, but is also able to predict under which conditions numerical inaccuracies have a potential influence. We show that valley glaciers do not suffer from the above mentioned numerical problems, whereas large ice sheets need to be treated more carefully.