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An unconditionally numerically stable super-implicit ice-sheet model incorporating membrane stresses

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While numerical solutions of linear time-dependent equations can generally be rendered unconditionally stable by using implicit marching schemes, this is not generally the case for non-linear equations. In the case of ice-sheet models using the SIA mechanics, time-step limits required by stability considerations are generally around one year for grid sizes of a few kilometres for semi-implicit schemes. Hindmarsh (2001) showed that super-implicit schemes, with implicit weighting factors greater than or equal to $n/2$, where n is the Glen index, are unconditionally stable.

Hindmarsh (2009) used a related super-implicit scheme to solve the evolution equations for an ice-sheet with higher-order (membrane stress approximation) mechanics. This scheme is described here. It requires a particular form of the continuity equation, which simplifies to the usual SIA form for small membrane stress contributions. Again the scheme is unconditionally stable provided the non-linear elliptic membrane stress equations converge. The implicit weighting factor must now be n or more. Time-steps of 100a are practicable for small grid sizes.

Super-implicit schemes are unusual, but provide approximations consistent with the corresponding partial differential equations as the time-step goes to zero. They are generally under-damped, but the resulting numerical oscillations are not large, and can be reduced by reducing the time-step. The paper also discusses the use of super-implicit schemes in the context of enhanced modelling of grounding line areas, either by locally high-order spatial schemes, or by use of flux parameterisations. The ability of these computationally efficient methods to solve more general ice-sheet configurations is assessed.

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