EGU2020-7604
https://doi.org/10.5194/egusphere-egu2020-7604
EGU General Assembly 2020

A new strictly mass conserving surface gradient calculation scheme for SIA-based ice flow models

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Ice flow models based on the Shallow Ice Approximation (SIA) are among the most broadly used type of ice flow model thanks to their simplicity and low computational costs. One key problem of SIA-based models are the mass conservation issues that emerge within steep terrain. In more detail, at some grid cells more ice can removed within one time step than there is present leading to negative ice thicknesses. This issue becomes increasingly problematic with topographical steepness and model resolution. As high resolutions become more accessible with faster computers, mass conservation errors might become increasingly important in the future.

Here we present a new scheme for SIA models that are integrated explicitly forward-in-time centred-in-space, one of the most common implementation. We show that mass conservation can be restored by capping surface differences with the upstream ice thickness in the computation of surface gradients, given a time step is used that maintains numerical stability. This new scheme is simple, strictly mass conserving, and can be implemented vectorially resulting in compact and efficient codes. We demonstrate the functionality of our new scheme and show some practical applications.