Simulating Subglacial Sediment Transport using a Semi–Lagrangian Method

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Introduction

Temperate ice sheets have the capacity to erode, transport and deposit large quantities of sediments. These products of past ice sheet activity can be observed in the geological record. Simulating the sediment record, therefore, helps constrain reconstructions of past ice sheets.

Two methods of sediment transport are considered here:

- sediments can be transported in a thin basal ice layer
- transport can occur within a deforming layer of sediments below the ice bed.

The amount of sediments transported within these layers depends on their rheology and the thermal conditions at the ice base.

A three-dimensional, thermo-mechanically coupled ice sheet model using the shallow ice approximation is used. The model employs a simple binary sliding law. Basal decollement only occurs when the ice base has reached the pressure melting point of ice. Basal velocities are assumed to be proportional to the gravitational driving stress

\[ \frac{\partial \langle \mathbf{v} \rangle}{\partial t} + \nabla \cdot (\langle \mathbf{v} \rangle \langle \mathbf{u} \rangle) = \dot{S} \]

where \( \langle \mathbf{v} \rangle \) is the basal velocity, \( \langle \mathbf{u} \rangle \) is the transport velocity and \( \dot{S} \) is the sediment erosion/deposition.

Numerical problems can be avoided by using a semi–Lagrangian approach to solving the advection equation. The approach taken here is outlined in the Figure below.

Theory

The sediment transport problem reduces to solving the advection equation

The new sediment distribution \( s_{n+1} \) at time \( t = n + 1 \) is sought given the velocity field \( \mathbf{v} \) and the present sediment distribution \( s_n \). In one dimension (left panel), \( s_{n+1} \) is found by tracing back particles injected at the cell edges and integrating the old sediment distribution between \( x_{n} \) and \( x_{n+1} \) and dividing by \( \Delta x \).

Results

The output produced by the model outlined above is phenomenologically rich. The following plots demonstrate output of the same simulation of the Fennoscandian ice sheet during the last glacial cycle.

The ice sheet pushes sediments quickly to the margin where they accumulate. These ridges are then partly eroded during subsequent ice readvances.