Improved parameterization of marine ice dynamics and flow instabilities for simulation of the Austfonna ice cap using a large-scale ice sheet model

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Background

- dome-shaped and of compact size
- annual extent: 8120 km²
- max surface elevation: 800m
- mean/max ice thickness: 310/580
- 28% of Austfonna grounded below sea level - up to 57% in case of three known surge-type basins
- applicable case study for numerical simulation of marine ice sheets

Motivation

- observed thickening in the interior and thinning at the margins
- change in accumulation-ablation pattern or a build up towards renewed surge activity
- address surface processes and glacier dynamics by combining ongoing glacier observation with numerical modelling

Austfonna

- surf velocity measurements recently restricted to winter snapshots of mid 1999/2000
- slope move ice cap (<10 m/a) interpreted by fast flow units (>100 m/a)
- new stake networks on Basin-3 and Duvebreen
- 5 stakes each, along central flow line
- equipped with GPS receivers (IWU, Utrecht) for continuous positioning at 1h interval

Simulation Code for Polythermal Ice Sheets³

- shallow-ice approximation
- finite-difference method on a regular grid
- accounts for cold and temperate ice

Model input

- bedrock topography (present & elevated)
- surface topography
- precipitation field
- surface air temperature
- geothermal heat flux
- sea level

Model output

- ice extent & thickness
- velocity field
- temperature field
- water content (temp ice)
- snow load
- age of ice
- rebound of lithosphere

Marine ice margin

- balance of inflow and ice loss determines whether ice allows (re) advance of marine margins
- fast flow occurs despite the lack of considerable temperate ice volumes

DICPOLIS & model input

- real marine ice margin has a vertical calving front. Position may be described using empirical formulae based on the flotation criterion
- works well for retreating margins, but prohibits marine advance
- (margin must move in one step (0.1 - 1 yr) to next grid point (1.2 km) while overcoming the flotation criterion)

Marine ice margin

- underwater (ice) η®
  - submarine ice allowed to form
  - cumulative mechanism accounts for sub-grid position changes
  - negative sm2 (low elevation) and calving Qp proportional to local water depth Dp and ice thickness H to a certain power

\[ Q = k D^2 H \]

- balance of inflow and ice loss determines whether the local ice thickness exceeds or falls below flotation thickness

- post-processing may cut off unice for realistic extent of marine ice margin

Results – steady fast flow versus surge behavior

- surf velocity measurements currently restricted to winter snapshots of mid 1999/2000
- slope move ice cap (<10 m/a) interpreted by fast flow units (>100 m/a)
- new stake networks on Basin-3 and Duvebreen
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Dynamic regime

- steady fast flow versus surge behavior in conjunction with marine ice dynamics strongly affect the steady-state geometry of Austfonna

Sliding (enhanced for marine grounded ice)

- activated when temperate base develops during build-up phase (increased insoluation)
- required to produce coincident present-day ice cap and areal extent
- increased draw-down of ice thickness during active phase (enables surge behavior at present ice thickness)
- rigorous flow enhancement leads to drastic surges of regional occurrence

- uw ice allows (re-) advance of marine margins
- fast flow occurs despite the lack of considerable temperate ice volumes

Thermal regime

- low-frequency GPR (20 MHz)
  - internal reflection horizons down to 200 m
  - absence of reflections below 200 m along most meltwater pathways

- exception: lower reaches of Duvebreen

- crevasse route surface meltwater into glacier (direct warming and latent heat release)

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Observations