Dynamics and climate sensitivity of Hans Tausen Iskappe (Greenland)

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Opening new horizons
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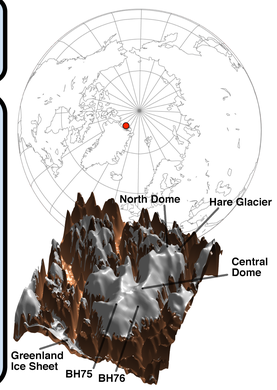
Where?

Peary Land (North Greenland): world's northernmost ice cap (82-83°N, 36-42°W)



Why?

Why detailed ice cap model?

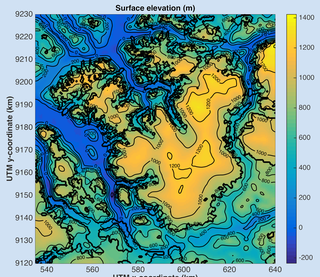
- Ice caps: important sea-level contribution
- Understand climate sensitivity and thresholds in system
- Improve parameterization global GIC (glaciers and ice caps) models: few models on individual ice caps exist

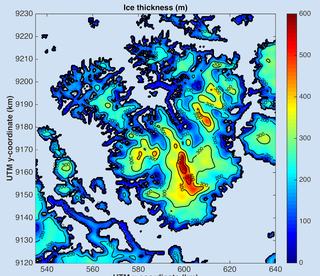
Why Hans Tausen Iskappe?

- Information about mass balance, surface velocities, meteorology, thermodynamics and geometry
- Region of extreme warming in future climate projections
- Interesting Holocene evolution: disappeared during Holocene Thermal Maximum!

Geometry

- 1995 surface and bedrock DEM from Starzer and Reeh (2001)
- Area of ca. 4000 km² ⟶ ca. 4-5% of Greenland total GIC area
- Ice volume: around 770 km³ ⟶ 10x volume of all Swiss glaciers!





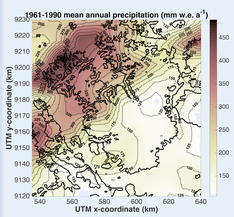
How? (the models)

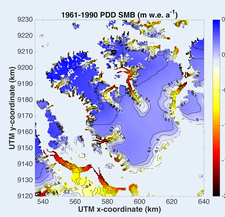
Ice flow and thermodynamics

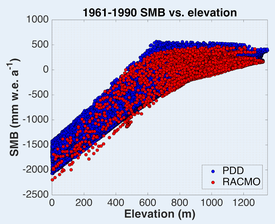
- 3-D higher-order ice-flow model (Fürst et al., 2011). Successfully used for ice flow modelling of:
  - Morteratsch glacier complex (Switzerland) (Zekollari et al., 2013, 2014; Zekollari and Huybrechts, 2015)
  - Greenland ice sheet (e.g. Fürst et al., 2015)
- Thermodynamics (Huybrechts, 2002): advection, diffusion, geothermal heating.
  - In ablation zone: additional heat source

Surface mass balance (SMB)

- Precipitation: downscaled precipitation from RACMO2.3 model run (11-km), agrees well with field measurements
- Runoff:
  - Positive degree-day (PDD) approach with meltwater retention in snowpack (Janssens and Huybrechts, 2000).
  - Model Parameters and temperature parameterizations derived from field and Greenland measurements
- Good agreement between modelled SMB and observations 1994-95:
  - Hare glacier: frontal ablation (200 m) of -1.5 m w.e. a^{-1}, ELA around 750 m, SMB 1300 m): 0.3 m w.e. a^{-1}





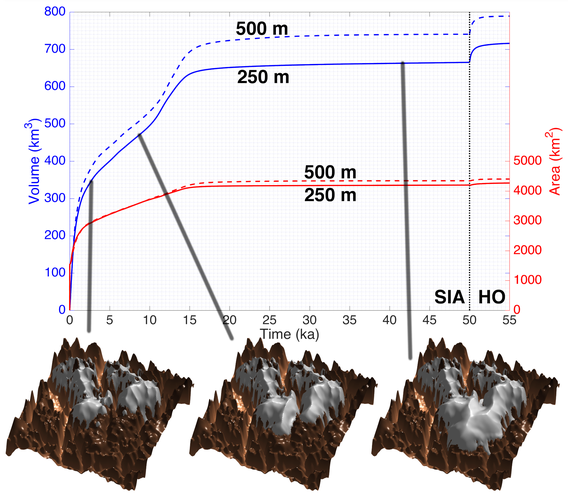


Good agreement between RACMO and PDD SMB fields
→ couple PDD model to ice flow model to investigate dynamics and climate sensitivity of Hans Tausen Iskappe

Ice cap under 1961-1990 conditions

A few words about the simulations

- Start from ice-free surface. Ice can only start to build up where present-day ice cap is. From there on: can freely expand
- Spin-up with Shallow Ice Approximation (SIA). After 50 ka: switch to higher-order (HO) solution



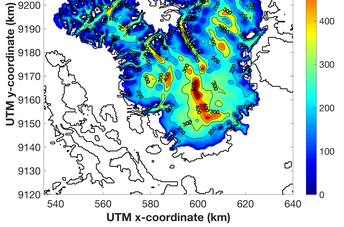
Ice cap build-up and evolution to steady state

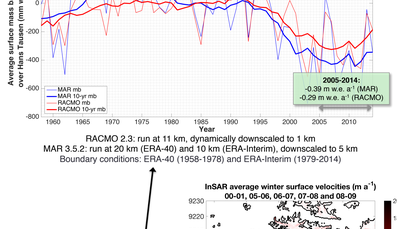
- Ice builds up in northern part
- Ice flow from northern to southern part
- Ice cap starts to grow in southern part (under impulse of SMB-elevation feedback)

Scan QR code to see 3-D animation of ice cap build-up

Impact model resolution and complexity

- **Resolution**: need high resolution to solve ice flow narrow outlet glaciers.
- **Complexity**: higher-order is non-local solution (longitudinal stresses): smoothing velocity field → slower velocities outlet glaciers → thicker compared to Shallow Ice Approximation (SIA)

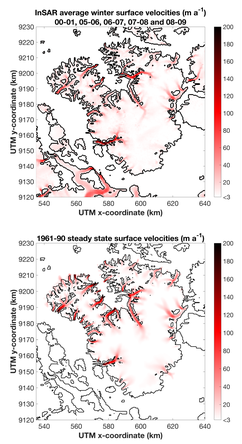




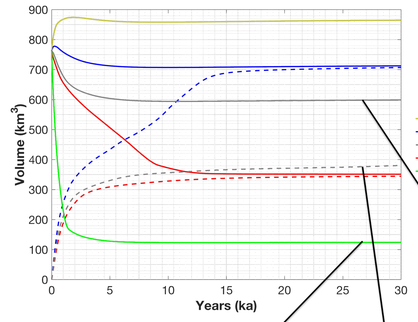
RACMO 2.3: run at 11 km, dynamically downscaled to 1 km
MAR 3.5.2: run at 20 km (ERA-40) and 10 km (ERA-Interim), downscaled to 5 km
Boundary conditions: ERA-40 (1958-1978) and ERA-Interim (1979-2014)

1961-1990 steady state vs. observations

- **Extent and ice thickness:**
  - Similar extent and ice thickness patterns. In line with RCMs SMB
  - Steady state outlet glaciers overall slightly thicker
- **Thermodynamics:**
  - Temperature profile at Central Dome (top -21°C, bottom at 16°C) can closely be reproduced
  - Temperature profile Hare glacier: cannot reproduce very high basal temperature (-1°C!) without additional heat source ablation area (cf. role of meltwater and refreezing, supported by field evidence). With this additional heat source:
    Δ steady state – observed thickness outlet glaciers more limited
- **Surface velocities (compared to InSAR velocities from Joughin et al. (2010, 2015)):**
  - Spatial patterns closely reproduced
  - Velocities outlet glaciers slightly faster for steady state ice cap



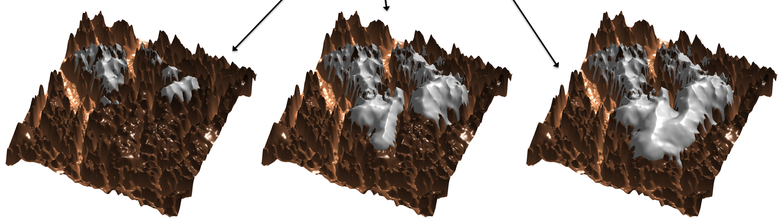
Ice cap stability and climate sensitivity

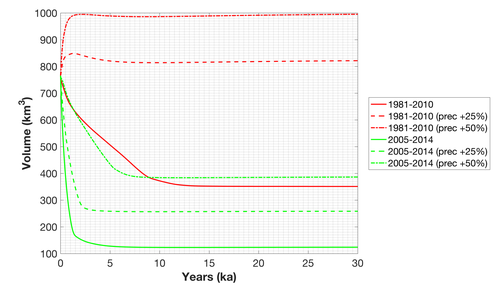


CASE I
Evolution to same steady state: no small ice cap instability (SMB southern part allows ice cap growth, which can be initiated by ice flow from North to South)

CASE II
Small ice cap instability, does not grow to same steady state (southern part instability)

CASE III
Evolution to same steady state: without ice in the South (SMB locally too negative and ice flow from North to South is too limited to initiate growth)





In case of warming and (partial) disappearance sea-ice: precipitation could be much higher (cf. mid-Holocene where precipitation was up to twice as high as present-day's values) → could (partly) compensate for mass loss

Findings

- Need high resolution (250 m) and higher-order model to resolve ice flow properly
- 1961-1990 climatic conditions: changes in geometry are limited, as expected from RCMs. Good agreement with velocity, temperature, extent, ice thickness observations/measurements
- Very sensitive: small change in climatic forcing can cause large change in geometry: is especially the case for the southern part of the ice cap! Importance SMB – elevation feedback
- Small ice cap instability exists under certain conditions
- In a warmer climate: loss of the permanent sea-ice could lead to an increased precipitation, which will compensate for a (part) of the mass loss

Work in progress / Future work

- Parameterization ice cap collapse
- Holocene evolution
  - Temperature reconstruction from Agassiz Ice Cap (summer temperature from melt layers)
  - Precipitation: different scenarios
  - Sea-level change and isostasy need to be taken into account
  - Parameterization ice cap collapse
- Future evolution: need Holocene evolution + RCP scenarios

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Information, questions, remarks, suggestions?

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