THE INFLUENCE OF LANDSCAPE EVOLUTION ON SCANDINAVIAN ICE SHEET DYNAMICS AND EXTENT

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Ice sheets have shaped the Scandinavian landscape during numerous glacial periods throughout the Quaternary, but little is known about the effects of a changing landscape on the Scandinavian ice sheets in return. Here, we use a higher-order ice-sheet model (iSOSIA) to investigate how past morphological changes in the Scandinavian landscape may have affected ice-sheet extent and dynamics. Our preliminary results indicate that the Scandinavian ice sheet would have extended further south before the formation of the Norwegian Channel, which is believed to have been formed by glacial erosion during recent glacial periods (since ~0.5 Ma). This suggests that landscape changes should be considered in addition to varying climate conditions, when exploring changes in ice-sheet dynamics and extent between glacial periods.

INTRODUCTION

The erosive power of glaciers and ice sheets has shaped the landscape in many parts of the world. Scandinavia has been covered by ice 10 times during the past 1 Ma and repeated glaciations have been present since the onset of the Quaternary 2.6 Ma ago. In this study we investigate how large scale glacial morphological changes on-and-offshore influence the extent and dynamics of the SIS using a numerical ice sheet model by simulating the SIS on different morphological settings (**FIG 1**). By analyzing the differences between our simulations in volume, extent, and sliding dynamics we can quantify how past ice sheets are influenced by large scale glacial morphological changes and better understand how we should interpret Quaternary climate history.

METHODS

We use the integrated second-order shallow ice sheet approximation model (iSOSIA, Egholm et al. (2011)) to simulate ice sheet evolution through a glacial cycle. The model domain is limited to the Scandinavian section of the Fennoscandian Ice sheet complex and the reference "last glacial period" experiment is simulated on a present day topography. Mass balance is calculated using a PDD model and temperature, temperature amplitude and precipitation are based on reanalysis and climate model outputs for present day and last glacial maximum as "interglacial" and "glacial maximum" states and scaled with the d18O-stack in between. The other experiments are carried out on modified landscapes representing two different time periods:

- Quasi-Mid-Pleistocene-Transition (**MPT,** 1 Ma) is simulated on a landscape with offshore glacial morphological features filled in (**FIG 2**, **1A**).
- Quasi-pre-Quaternary (**PRE-Q**, ≈ 2.6 Ma) we reconstruct a pre-glacial offshore morphology using offshore seismic interpretations of the base Quaternary deposits in the North Sea and the base of the NAUST formation (2.8 Ma) in the Norwegian Sea. (**FIG 3, 1B,C,E**). Onshore erosion is assessed using methods described in Pedersen et al. (2021).

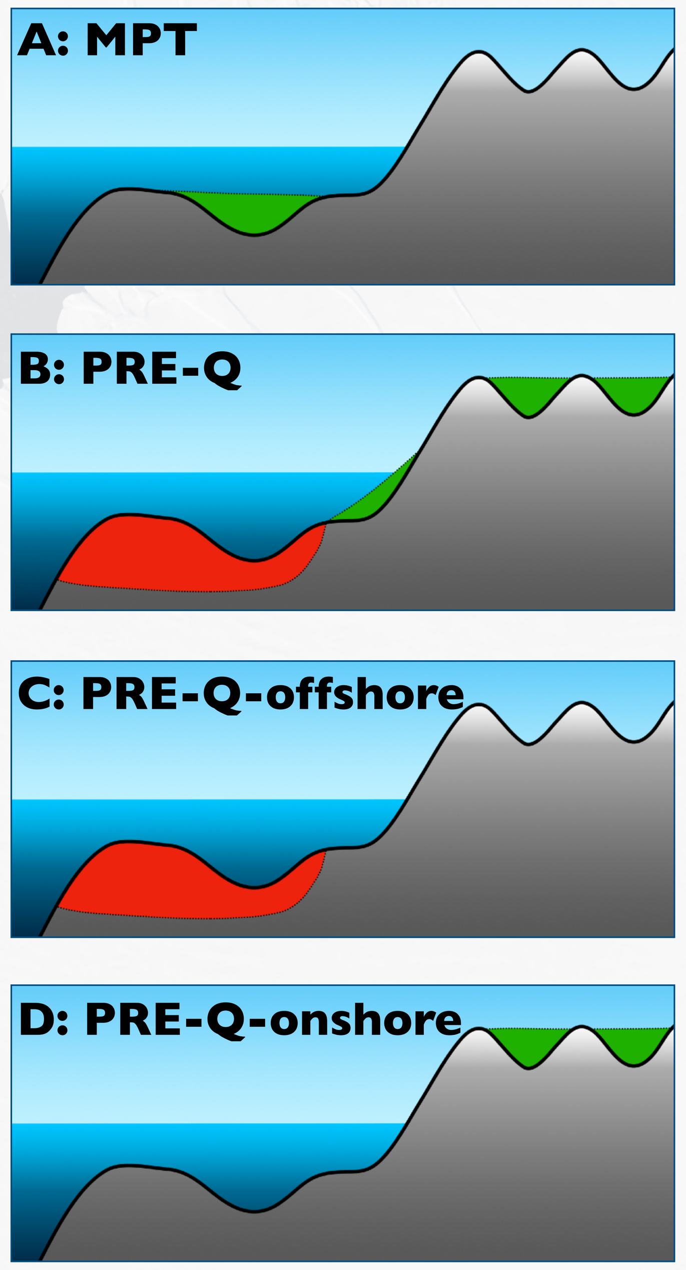


FIG 1: Schematic sections illustrating the change in topography and bathymetry for the 5 different experiments. Green is added material, red is removed. Black line is reference model.

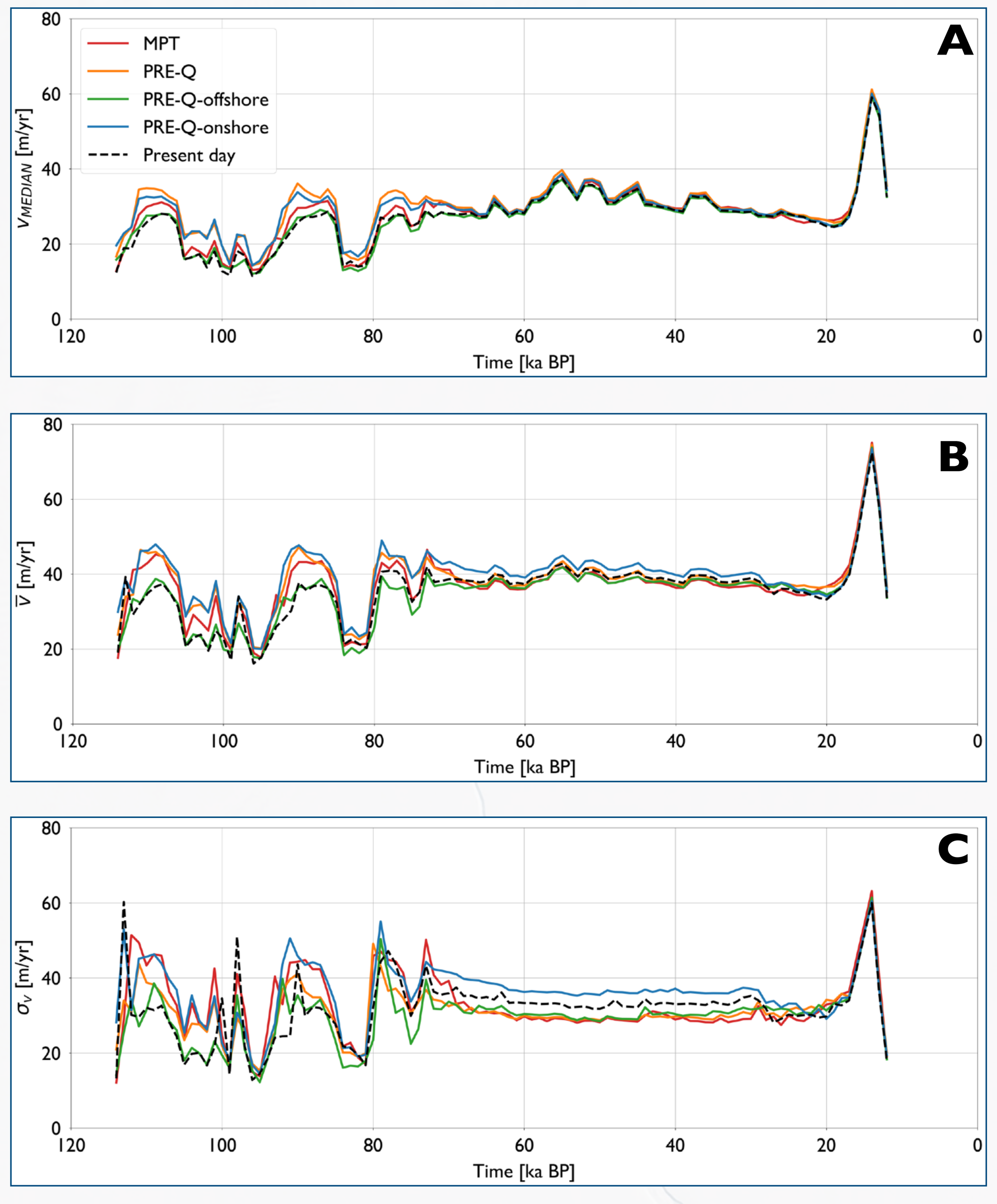


FIG 7: Median, mean and standard deviation of ice sliding velocities for all experiments

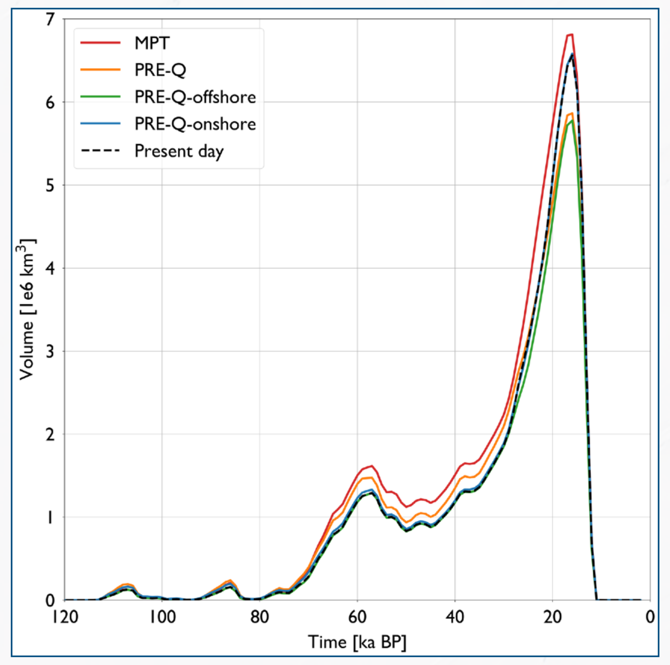


FIG 4: Ice volume over one glacial period for different experiments

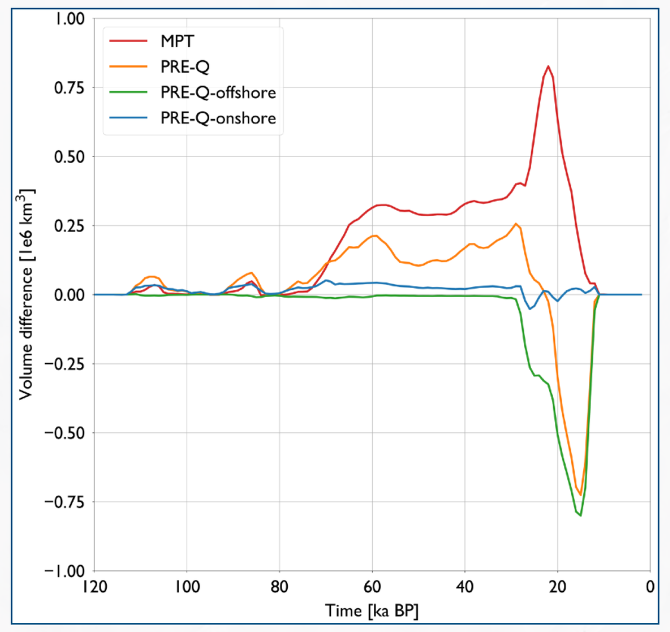


FIG 5: Difference in ice volume compared to reference model over one glacial period for different experiments

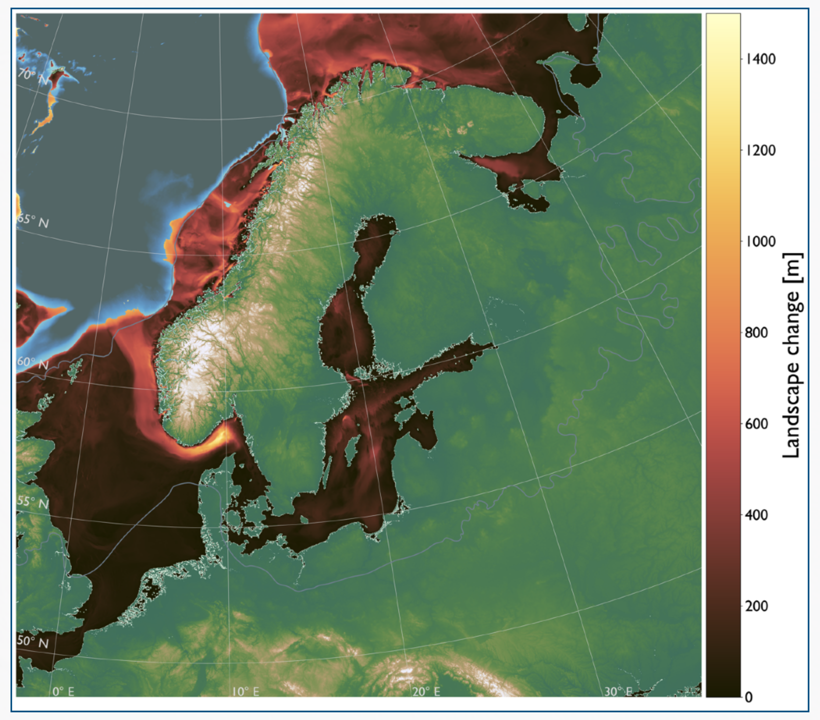


FIG 2: Landscape for MPT

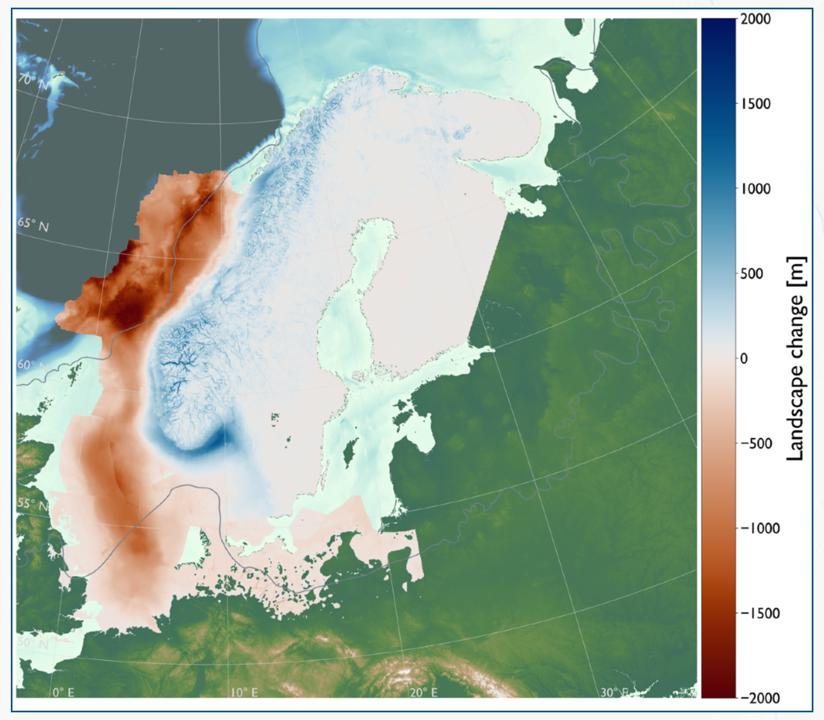


FIG 3: Landscape for PRE-Q

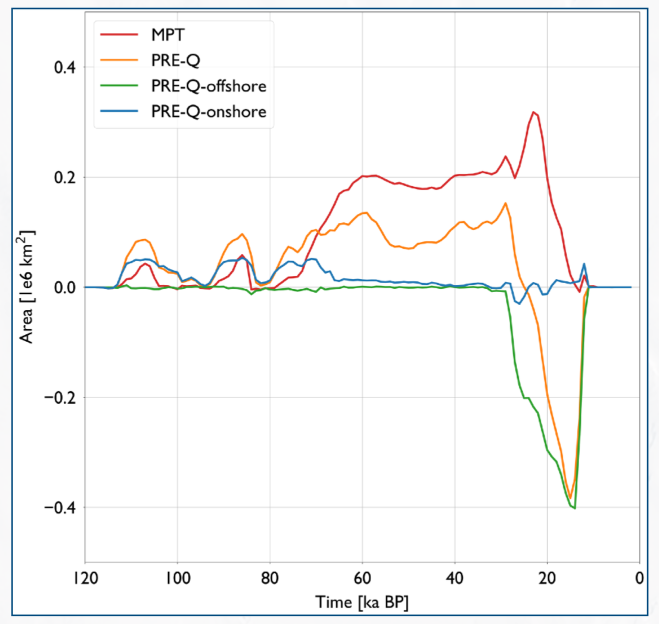


FIG 6: Difference in ice area over one glacial period for different experiments

FIG 8: Glacial maximum ice thickness difference for the quasi-Mid-Pleistocene-Transition experiment compared to reference model at glacial maximum. Blue colors indicate more and red less ice in the quasi-Mid-Pleistocene-Transition. Solid purple indicate areas where the quasi-Mid-Pleistocene-Transition experiment extends further than reference and orange less. Black line indicates reference extent, red quasi-Mid-Pleistocene-Transition extent and grey indicate maximum estimated LGM extent (DATED-1)

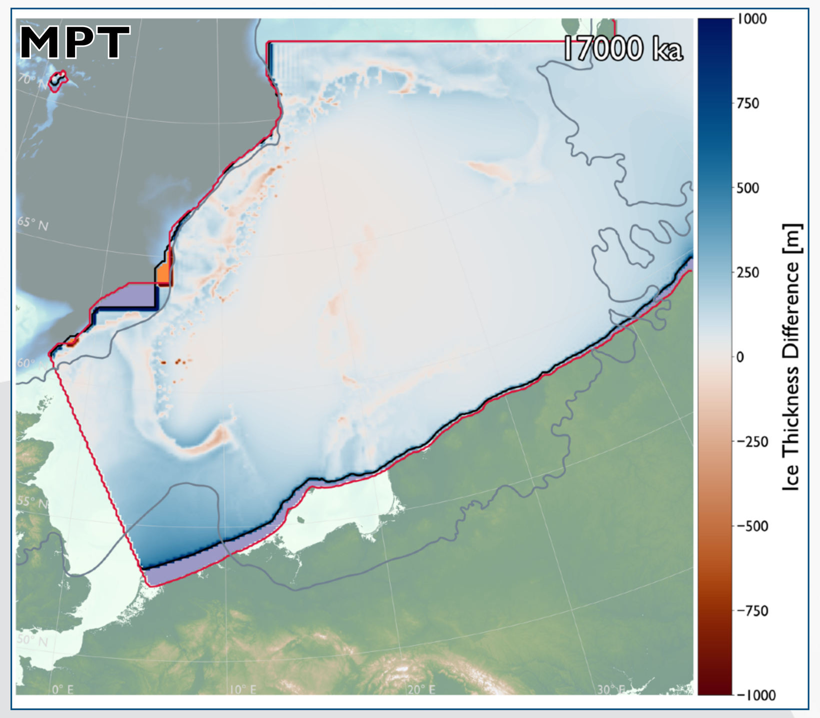
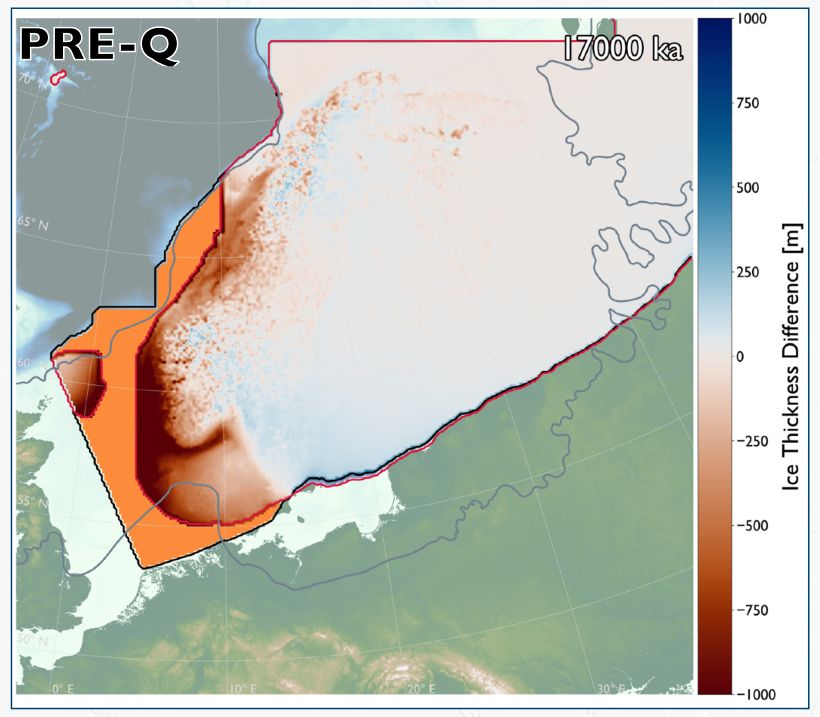


FIG 9: Glacial maximum ice thickness difference for the quasi-pre-Quaternary experiment compared to reference model at glacial maximum. Blue colors indicate more and red less ice in the quasi-pre-Quaternary. Solid purple indicate areas where the quasi-pre-Quaternary experiment extends further than reference and orange less. Black line indicates reference extent, red quasi-pre-Quaternary extent and grey indicate maximum estimated LGM extent (DATED-1)



RESULTS

The maximum ice volume reaches $6.5 \cdot 10^6$ km² for the reference model and vary up to ± 12 % for MPT and PRE-Q-offshore respectively (**FIG 4, 5,** same for area in **FIG 6**). Mean and median ice sliding velocity predating 60 ka are higher in experiments MPT, PRE-Q and PRE-Q-onshore (**FIG. 7A, 7B**), and in the last 60 ka they are higher in PRE-Q-onshore (**FIG 7C**). Ice can extend further south in MPT compared to reference (**FIG 8**) and ice from the SIS cannot bridge over the North Sea in PRE-Q during glacial maximum (**FIG 9**).

DISCUSSION

- MPT have more than 12 % more ice than the reference simulation at glacial maximum - filling in the glacial-morphological features in the bathymetry allows the ice to more easily ground itself of the shelf and in the North Sea. This allows for relatively large ice sheets during the mid-Pleistocene-Transition.
- PRE-Q has a higher ice volume compared to the reference after 60 ka due to a coastal sediment wedge again allowing for ice build-up offshore followed by a sharp decrease in ice volume when approaching glacial maximum. The deep North Sea and missing Norwegian shelf prevents ice grounding and build-up offshore.
- Ice sliding velocities is an indicator of ice sheet dynamics and erosive potential. We observe that mean and median ice sliding velocities before 60 ka is higher for MPT AND PRE-Q because the ice builds more easily offshore (**FIG 7A, 7B**).
- In MPT, ice builds further south because of lower relief in the North Sea and the Danish region (**FIG 8**).
- In PRE-Q, ice cannot bridge the North Sea (**FIG 9**) in the early Quaternary.

CONCLUSION

In this study, we observe up to ± 12 % glacial maximum ice volume difference compared to a reference last glacial period ice sheet simulation within the same climatic conditions by reconstructing possible earlier bathymetric and topographic setting (≈1 Ma and ≈2.6 Ma). The results indicate that a mid Quaternary SIS could have had better conditions for southward growth given the same climatic conditions as the last glacial period. The size and volume of glaciations in the early Quaternary would have been limited by a deep North Sea and the absence of the Norwegian shelf. Our results indicate that glacial-morphological changes are important to account for when interpreting ice volume proxies of the past.

Egholm, David L., Mads F. Knudsen, Chris D. Clark, and Jerome E. Lesemann. 2011. "Modeling the Flow of Glaciers in Steep Terrains: The Integrated Second-Order Shallow Ice Approximation (ISOSIA)." Journal of Geophysical Research: Earth Surface 116 (2): 1–16.

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