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Glaciers on Svalbard survived the Holocene thermal optimum

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Highlights

- Largest ice caps on Svalbard survived the Early Holocene warming.
- Many cirque and valley glaciers re-formed 5500 years ago.
- Regrowth of glaciers caused transgression in NW Svalbard last 2000 years.
- Best Earth model has a thin lithosphere and low-viscosity asthenosphere.

Abstract

About 60% of Svalbard is covered by glaciers today, but many of these glaciers were much reduced in size or gone in the Early Holocene. High resolution modeling of the glacial isostatic rebound reveals that the largest glaciers in Nordaustlandet and eastern Spitsbergen survived the Early Holocene warming, while the smaller, more peripheral glaciers, especially in the northwest, started to form about 5,500 years ago, and reached 3/4 of their current size about 600 years ago. Relative sea level has been rising during the last few millennia in the north and western parts of Spitsbergen, while land still emerges in the remaining part of Svalbard. Here we show that this sea level rise in the northwest is caused by the regrowth of glaciers in the Mid- to Late Holocene that slowed down, and even reversed, the post-glacial isostatic uplift and caused the crust to subside over large areas of Spitsbergen.

Introduction

Today there are more than 2000 glaciers on Svalbard (Liestøl, 1993), but during the exceptional warm climatic optimum in the Early Holocene on Svalbard (Mangerud and Svendsen, 2018), it has been assumed that many of these glaciers were completely deglaciated or much reduced in size (e.g. Hughes et al., 2016). However, it is not known to what extent the glaciers on Svalbard were absent or smaller than today in the Early- and Mid-Holocene. In this paper, we try to find that answer by modeling the isostatic response due to the decay and regrowth of the Holocene glaciers on Svalbard. We compare the output of the modeling to the observed sea level curves, and test different scenarios for the Holocene ice growth against these observations. By this approach, we are able to show that the largest glaciers must have survived the climatic optimum and that the regrowth of glaciers reversed the isostatic uplift and caused the crust to subside over a large part of Spitsbergen (Fig. 1).

A clear sign of this subsidence is the recent rise in relative sea level in the northwestern corner of Spitsbergen (Fig. 1). Here, cultural remains are found closer to sea than when they were built. Coastal erosion of cultural remains from the 17th century has been reported from Amsterdamøya (Vogt, 1932), Ebeltofthamna in western Spitsbergen (Forman et al., 1987) and at Kapp Wijk in Isfjorden (Feyling-Hanssen, 1955); cf. Fig. 1 for locations. Also in Nordaustlandet, at the island Nordre Russøya in Murchinsonfjorden (Fig. 1), the location of a Russian hunting station built in the late 1700, was levelled at only 0.8 m above the highest tide in 1958, and suggests a sea level rise since the settlement was built (Blake, 1961). Stratigraphic evidence for this transgression includes thousand-year-old driftwood anchored in sediments about 1 m below mean tide level at the head of Bockfjorden (Salvigsen and Høgvard, 2005), and present-day beach gravel found on top of 2000-yr-old peat (Fig. 1) (Forman, 1990). The observations of the transgression in northwestern Spitsbergen were published many years ago, and were explained by Vogt (1927, 1932) as a result of isostatic subsidence due to the Late Holocene growth of the glaciers.

Farther east and south on Svalbard the situation is the opposite; the sea level curves show emergence over the last 2000 yr. Sea level curves from both Hopen and Kongsøya in eastern Svalbard (Fig. 1) show a recent relative uplift of 3 and 4.5 mm/yr, respectively (cf. Table 2). Hoppe et al. (1969) observed that in a zone between 2.5 and 4.4 m above the local driftwood limit on Hopen the stranded driftwood had saw-cut logs obviously made by humans. In this zone they also identified logs belonging to wooden Russian ships (“Lodjas” type) probably used for hunting on Svalbard some 300–500 years ago. This change in behavior from east to west excludes eustasy as the driving mechanism, and is evidently caused by movements of the solid earth.

Evidence of decreased or absent glaciers comes from two sources: sediments in lakes downslope of present-day glaciers, and beaches and other sediments containing marine shells or vegetation that were overrun by advancing glaciers in the Late Holocene. At the coast of western Spitsbergen the sediments in proglacial lakes revealed the total disappearance of glaciers in their catchments between ca. 9,000-3,000 cal yr BP. See Fig. 1 for locations (Linnébreen; Svendsen and Mangerud, 1997; Karlbreen; Røthe et al., 2015; Annabreen; de Wet et al., 2017). Glacially overridden vegetation and beaches are known from both Spitsbergen (*e.g.* Humlum et al., 2005; Salvigsen and Høgvard, 2005) and eastern Svalbard (*e.g.* Jonsson, 1983; Ronnert and Landvik, 1993; Blake, 1989). Most glaciers on Svalbard reached their maximum Holocene extent by the termination of the Little Ice Age in the beginning of the 1920s (Hagen et al., 2003). Today the largest glaciers can in places exceed a thickness of 500 m (Dowdeswell et al., 1986).

The modeling takes into account the entire glaciation history, from the Last Glacial Maximum (LGM, 20,000 cal yrs BP) of the Svalbard-Barents Sea and Scandinavian ice sheets (the Eurasian ice sheet) until today. We compare the output of the glacial isostatic modeling to the observed sea level at 2,000 yr and 6,000 cal yr BP, and test different scenarios for ice growth in the Holocene against these observations. We have used an Earth model with a low viscosity asthenosphere and a weak elastic lithosphere, but other Earth models are also tested and compared to the sea level observations.

Section snippets

Late- and post-glacial ice sheet model

Our deglaciation model of the Eurasian ice sheet follows the spatial reconstructions of Hughes et al. (2016) from 20,000 to 12,000 cal yr BP. This was not subject to any change in this study. Ice thicknesses were calculated independently from the glacial isostastic modeling, and based on the Glen-Nye flow law and a long term balance ratio between ablation and accumulation gradients (for more details about the model cf. Appendix). Fig. A1 shows the extent and thickness of the modeled Eurasian

Results and discussion

The modeled isostasy of the 'Young glaciers' scenario is in considerable conflict with the sea level observations. The modeling shows that the entire Spitsbergen and Nordaustlandet would be from 3 to 9 m below present sea level 2,000 years ago, in disagreement with the observed emergence at Nordaustlandet, Barentsøya and southeast Spitsbergen (Fig. 5A). The reason for this large subsidence in the model is the late formation and growth of the glaciers that took place after 3,000 cal yr BP in the

Conclusions

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  A significant portion of the ice caps on Nordaustlandet and in the east and south on Spitsbergen survived the Holocene thermal optimum, while the smaller glaciers in the north and west on Spitsbergen did not outlive the warm period. The glaciers grew significantly between 7,500 and 5,500 cal yr BP, while the more peripheral glaciers, including those in the northern Spitsbergen, started to form 5,500 years ago. All glaciers reached their maximum Holocene extent by the termination of the Little

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  Generally, it is believed Late Holocene relative sea level was regressive around Svalbard (Bondevik et al., 1995; Forman et al., 2004; Sessford et al., 2015). It is unknown to what extent Neoglacial glacier expansion influenced relative sea level in Svalbard during the Late Holocene as eustatic sea level is suggested to have out-paced relative land uplift along Spitsbergen’s western coast (Forman et al., 2004; Fjeldskaar et al., 2018). Radiocarbon ages of driftwood make up roughly 10 % of the SVALHOLA database and 35 % of the terrestrial ages.
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  Interestingly, the differences between the authigenic and detrital values (△εNd) at these two sites display similar variability over time (Fig. 7). Neodymium isotopic decoupling was enhanced (i.e., leading to more positive △εNd values) since the mid-Holocene, when new glaciers formed (Fjeldskaar et al., 2018; Svendsen and Mangerud, 1997; van der Bilt et al., 2015) (growth curve of valley glacier in Fig. 7) and/or existing glaciers on Svalbard readvanced ~4.5 ka (Baeten et al., 2010; Forwick et al., 2010) (growth curve of ice cap in Fig. 7). Decoupling is even more markedly enhanced during the transition period and main phase of LIA, when most glaciers on Svalbard reached their maximum extent (e.g., Martín-Moreno et al., 2017; Svendsen and Mangerud, 1997) (Fig. 7).

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