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Strong altitudinal control on the response of local glaciers to Holocene climate change in southwest Greenland

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ABSTRACT

Accelerating ice loss during recent years has made the Greenland Ice Sheet one of the largest single contributors to global sea level rise, accounting for 0.5 of the total 3.2 mm yr^{-1}. This loss is predicted to continue and will most likely increase in the future as a consequence of global warming. However, the sensitivity of glaciers and ice caps (GICs) in Greenland to prolonged warm periods is less well constrained and geological records documenting the long-term glacial history are needed to put recent observations into a broader perspective. Here we report the results from three proglacial lakes where fluctuations in local glaciers located at different altitudes in Kobbefjord, southwest Greenland have been recorded. Our results show that the lakes received meltwater from the initial deglaciation of the area ~9.2 cal. ka BP until ~8.7–7.9 cal. ka BP when the meltwater input ceased as the glaciers most likely disappeared. Regrowth of glaciers began again at ~5.5 cal. ka BP at ~1370 m a.s.l., ~3.6 cal. ka at ~1170 m a.s.l., and ~1.6 cal. ka BP at ~1000 m a.s.l., clearly reflecting strong altitudinal control of the GIC response to Neoglacial cooling. Our results highlight that GICs in Kobbefjord, southwest Greenland are primarily influenced by changes in summer air temperatures and winter precipitation and that they are facing a rapid decay that most likely will result in their disappearance within the next centuries as a consequence of global warming. If current 21st Century retreat rates continue, the GICs in the study area will be completely gone in ~30–90 years, with the smallest GICs disappearing first.

1. Introduction

Recent worldwide observations show that local glaciers and ice caps (GICs) are responsible for ~25% of the total global mean sea level rise (1993–2010), equivalent to 0.86 mm yr^{-1} (Church et al., 2013). The current contribution from the GICs in Greenland is 0.08 ± 0.03 mm yr^{-1} (Bolch et al., 2013). Projections of future mass loss from Greenland GICs range between 2116 ± 129 and 3907 ± 108 Gt by 2098 C.E. for conservative mid-range scenarios, which amounts to a mean global sea level rise between 5.80 ± 0.4 to 11.2 ± 0.3 mm (Machguth et al., 2013). The main driver of the observed changes in glacier mass balance has been shown to be increased summer temperatures; whereas winter precipitation contributed less significantly (Bolch et al., 2013; Machguth et al., 2013). Longer time series based on aerial photographs and other historical records also demonstrate a strong correlation between glacier fluctuations and changes in summer air temperature (Weidick, 1959, 1963, 1968; Gordon, 1981; Bjørk et al., 2012; Leclercq et al., 2012; Weidick et al., 2012).

On a decadal to millennial time scale, little is known about the GICs fluctuations in Greenland (Kelly and Lowell, 2009). Most information about long-term GIC fluctuations is derived from radiocarbon dating of reworked organic remains such as molluscs or plant macrofossils in historical moraines, radiocarbon dating of dead vegetation melting out of glaciers, or ice core data showing that the ice extent prior to the Little Ice Age (LIA) was smaller than

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at present (Weidick, 1963, 1968; Sudgen, 1972; Kelly, 1980; Ingolfsson et al., 1990; Hjort, 1997; Landvik et al., 2001; Madsen and Thorsteinsson, 2001; Knudsen et al., 2008; Möller et al., 2010; Lowell et al., 2013; Schweinsberg et al., 2017). However, knowledge remains sparse of GICs fluctuations in Greenland and whether they survived past warmer conditions than today, e.g. the Holocene Thermal Maximum (HTM) ~8-5 cal. ka BP and the Medieval Climate Anomaly (MCA) ~1200-950 C.E. Only a few available studies have provided continuous records of Holocene glacier fluctuations in east Greenland (Lowell et al., 2013; Levy et al., 2014; Balascio et al., 2015) and west Greenland (Schweinsberg et al., 2017). These records show that local GICs were significantly reduced and most likely completely absent during the HTM. The number of well constrained mountain glacier records is extremely low compared to the total number of 20,281 GICs (~90.000 km^2) in Greenland (Rastner et al., 2012) and is in sharp contrast to the long tradition of recording past mountain glacier fluctuations and climate change in, for example, Iceland (Larsen et al., 2011a; Striberger et al., 2012; Schomacker et al., 2016), Scandinavia (Karlen, 1981; Nesje et al., 2000; Bakke et al., 2010), the European Alps (Ivy-Ochs et al., 2009), and North America (Menounos and Clague, 2008; Barclay et al., 2009; Briner et al., 2009).

In this study, we use sediment cores from three proglacial lakes to track upvalley Holocene glacier fluctuations in Kobbefjord, southwest Greenland and investigate whether surface summer temperatures and winter precipitation variability are synchronous with the observed changes at centennial scale.

2. The Kobbefjord area

2.1. Geographical setting

Kobbefjord (Danish name), or Kangerluarsunnguaq (Greenlandic name) is located ~20 km from the capital Nuuk in southwest Greenland (Fig. 1). The fjord is ~17 km long, 0.8–2.0 km wide, and is part of the Godthåbsfjord system (Mikkelsen et al., 2008). The climate in Kobbefjord is classified as low Arctic with a mean annual air temperature of 0.7 °C (2008–2010), ranging from 10.7 °C in (July) to −30 °C (January). The total annual precipitation is 838–1127 mm (2008–2010), and an average of 25–50% of the total annual precipitation falls as snow during the winter period (Jonasson et al., 2000). The most typical vegetation types are characteristic of a low-Arctic ecosystem such as copse, fen, dwarf-shrub heaths and fell fields (Søndergaard et al., 2012).

The topography of the Kobbefjord region rises to more than 1400 m a.s.l. with bedrock composed of Archaean tonalitic to granodioritic gneiss, and Qorqût granite (Hollis et al., 2005). Small valley glaciers and snowfields are present at high elevation between 530 and 1370 m a.s.l. mainly on the north side of slopes (Fig. 2). In the glacially carved valley floors several large proglacial lakes are found including Qassi Sø, Langesø and Badesø (Fig. 2). These lakes are connected by streams that join before entering Badesø – the last lake before the meltwater reaches Kobbefjord.

The study area is located in a sparsely glaciated region of Greenland. The local glaciation in the Godthåbsfjord region is comprised of ~100 smaller GICs, amounting to a total of ~40 km^2. None of the GICs reach the sea, as the lower glacial limit is 530 m.a.s.l. The median elevation of the regional glaciation is ~1000 m.a.s.l. (Rastner et al., 2012). Approximately 40–60 km south of the Godthåbsfjord region, a larger (~850 km^2) glaciated region with similar topographical characteristics is found.

2.2. Glaciation history

The glacial history from the Last Glacial Maximum (LGM) to present is generally well known for southwest Greenland (Winsor et al., 2015a, 2015b). During the LGM, the ice margin was located on the shelf edge c. 20–40 km offshore from the present coastline (Funder et al., 2011) and Kobbefjord and the mountain peaks in the region were most likely ice covered then (Larsen et al., 2014). Radiocarbon ages of molluscs and ^{10}Be ages of boulders south of Nuuk indicate that the ice margin retreated onto land between ~10.1 and 10.7 ka and that the entrance of the Godthåbsfjord was deglaciated ~10.7 cal. ka BP (Larsen et al., 2014). Between the coast

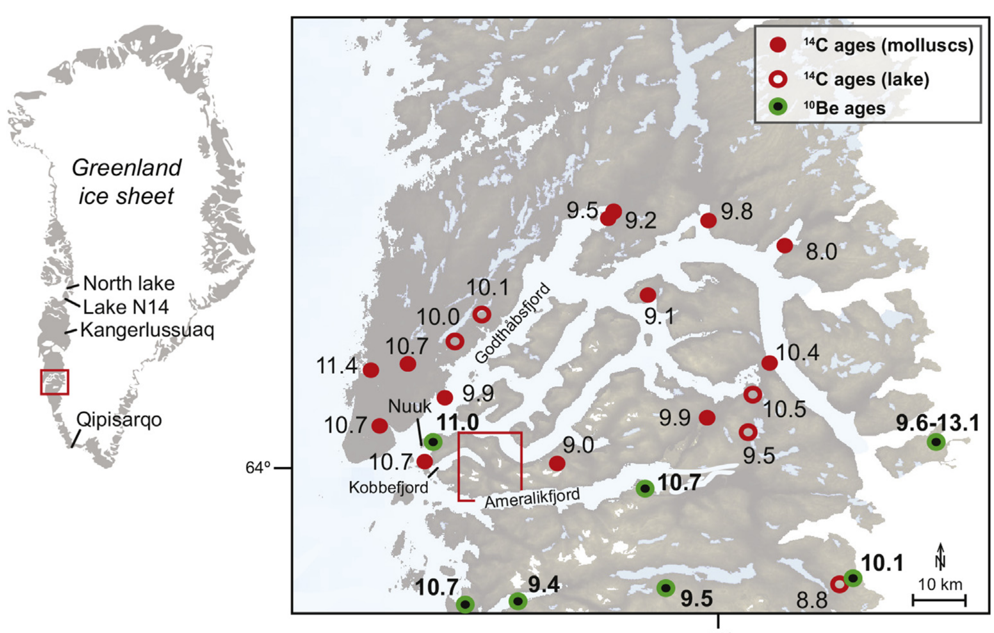

Fig. 1. The Godthåbsfjord system in southwest Greenland (Larsen et al., 2014; Winsor et al., 2015a). The inserted map shows the Kobbefjord study area. Red box displays the field study area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)