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Reconstructing neoglacial ice advance on Signy Island, Maritime Antarctica, from moss burial ages

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ABSTRACT

Late Holocene glacial dynamics in Maritime Antarctica are relatively poorly understood due to limited data availability. Here, we present a reconstruction of neoglacial ice advance on Signy Island (South Orkney Islands, 60°S 45°W) based on radiocarbon-dated moss burial ages. The results showed that mosses were buried by neoglacial ice advance starting from an oldest age of approximately 218 CE (Common Era), with a peak in burial dates between 1000 and 1400 CE. The timing of advance is in line with regional temperature reconstructions, and moves former local ice advance reconstructions back by several centuries. Map and satellite image comparisons over the past 50 years confirm that the island's ice cap is now retreating (horizontally) at increasing rates, from a mean of approximately 8 m/yr over the past 50 years to 20 m/yr in the period 2020-2023. Compared to the reconstructed average advance rate between 1300 and 1600 CE based on current and past recorded moss burial dates, the ice cap is currently retreating about six times faster than it previously advanced. Reconstructing periods of past glacial advance and retreat, as in our study, is important to determine the sensitivity of low altitude ice caps to the ongoing temperature increases predicted across the sub- and Maritime Antarctic.

1. Introduction

Antarctica's ice comprises the largest freshwater reserve on Earth, and areas of recent rapid melting have raised concerns about its future contribution to sea level rise, altered ocean circulation and ecosystem functioning (Chown et al., 2022; Constable et al., 2022). Reconstructing past ice sheet configurations under different temperature regimes can help understand current trends and potential future responses, but data availability is limited. On a continental scale, in most Antarctic regions mean air temperatures declined over the last 2000 years, until the start of increasing atmospheric CO_2 levels with the onset of the industrial age (Stenni et al., 2017). The first half of this period was relatively warm (300-1000 CE, Common Era), and the coldest intervals occurred 1200-1900 CE (Stenni et al., 2017). This pattern has stimulated a discussion about whether Northern Hemisphere (NH) climate anomalies, such as the relatively warm Medieval Climate Anomaly (MCA) and the cold Little Ice Age (LIA), are reflected in Southern Hemisphere (SH) palaeoclimate records (e.g. Bentley et al., 2009; Lüning et al., 2019; Simms et al., 2021), or whether Antarctica has a distinct climate history (Ahmed et al., 2013; Stenni et al., 2017). Various ice core and moss bank records show that, after 1900, steep warming trends have been apparent throughout the Maritime Antarctic (e.g. Mulvaney et al., 2012; Stenni et al., 2017; Charman et al., 2018). These are already resulting in the loss of ice caps on low lying sub-Antarctic islands (Gordon et al., 2008; Cook et al., 2014) and, with ongoing warming, this may increasingly influence Maritime Antarctic regions at higher southern latitudes. Uncovering when and where the Antarctic has previously experienced glacial advances and retreats is important to understanding whether

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analogous cooling and warming periods were experienced in both Hemispheres. Reconstructions of past ice sheet responses to these climate changes can also improve models projecting future ice loss (Davies et al., 2014). From an ecological standpoint, it can provide additional insights into vegetation dynamics by identifying the spatial extent of ice cover-free areas for biological colonization, and periods when these areas have been buried under snow and ice (Smith, 1990).

The South Orkney Islands in the Maritime Antarctic, including Signy Island, are unique because the archipelago is the only landmass close to the latitude of 60° in the Southern Ocean. It is strongly exposed to the Antarctic Circumpolar Current and lies in the Southern Hemisphere westerly wind zone, likely experiencing greater climate fluctuations than comparable locations further south in the Antarctic (Smith, 2005). These fluctuations have a large impact on the island's terrestrial ecosystems, which are dominated by diverse mosses and lichens. These generally die when buried for extended periods under snow or ice, and (re)colonize newly-exposed ground after subsequent ice retreat from refugia (Smith, 1990, 1995; Convey and Hughes, 2023).

Multi proxy analyses of Signy Island lake sediment cores obtained in 1991 have indicated a period of greater biological productivity, likely as a result of warmer and possibly wetter conditions that began prior to the Common Era and persisted until approximately 700–900 CE, followed by cooler conditions from ~1000 until 1900 CE (Jones et al., 2000; Noon et al., 2003). Other past climate interpretations have been derived from a handful of radiocarbon dated moss remains, which were exposed around 1975 by the retreat of the main ice cap on the island (Fenton, 1982; Smith, 1990). Radiocarbon dating (C-14) such re-exposed mosses reveals the timing of burial by glacial advance, i.e. the time at which the moss became ice-covered and stopped photosynthesis and growth. This procedure can therefore be used to indicate minimum ages for the onset of neoglacial advance, although earlier onsets are still possible if fluctuations in the advancing ice margin resulted in alternating periods of photosynthesis and burial (La Farge et al., 2013; Roads et al., 2014). Burial dates of the mosses reported by Fenton (1982) and Smith (1990) were mostly between 1400 and 1700 CE. Today, the island's ice cap has retreated considerably further, by horizontal distances of up to 800 m compared to 1975, providing a unique opportunity to obtain dates from mosses that were potentially buried closer to the onset of the glacial advance identified by Fenton (1982) and Smith (1990).

Here, we present moss burial ages from re-exposed mosses around the current, rapidly retreating, edge of the ice cap on Signy Island, to further constrain the timing of neoglacial ice advance on Signy Island. We compare the rates of neoglacial advance (based on radiocarbon data) with the rates of ice retreat (based on available satellite images), and compare these with similar records in the wider region. We thereby provide a unique contribution to understanding the sensitivity of this low altitude island ice cap to late Holocene environmental changes, which is essential to assess current and future glacial dynamics. Finally, we discuss the ecological implications of the extensive re-exposure of ice cover-free ground by the recent rapid melting of the Signy Island ice cap.

2. Methods

2.1. *Location and sampling*

Signy Island (60°43′S 45°36′W) is part of the South Orkney Islands archipelago located in the northern Maritime Antarctic region, approximately 700 km north-east of the Antarctic Peninsula and 800 km south-west of South Georgia (Fig. 1a). It has a surface area of ~20 km^2, of which currently ~25% is covered by permanent snow and ice, with ice cover-free ground colonised by extensive moss and lichen communities (Smith, 1972, 1990). The climate, as typical of the Maritime Antarctic, is milder and moister than that of the Continental Antarctic, with a mean annual temperature of −3.9 °C and 400 mm precipitation per year (Convey et al., 2018). The island is fully snow-covered in winter, when mean monthly air temperatures remain below zero, although short thaw periods are possible in any month (Convey et al., 2018). The island's ice cap feeds the McLeod Glacier extending towards the southern beaches and the near-extinct Orwell Glacier extending to the shallow Cemetery Bay in the east, as well as steep snow and ice slopes terminating on land on the west side of the island. Its highest point is 278 m above sea level at Tioga Hill, which protrudes from the western part of the ice cap (Fig. 1b).

During the 2022/23 austral summer, we collected apparently moribund or dead moss samples (n = 41) from re-exposed moss banks and superficial moss remains around the current edges of the ice cap for radiocarbon dating analyses, to determine when they had initially been

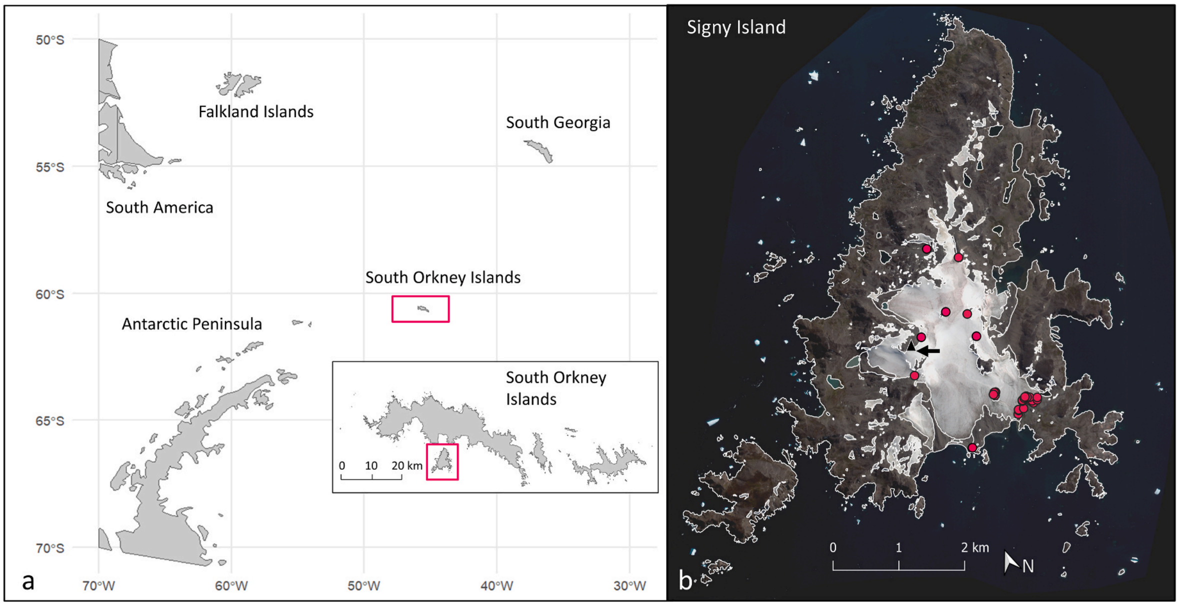

Fig. 1. **a)** Location of Signy Island, part of the South Orkney Islands, in the broader region, **b)** map of the island in summer (background WorldView-2 satellite image © 2025 Vantor), including the sampling points of the re-exposed mosses collected in 2023 and Tioga Hill (black arrow), the highest point on the island (278 m). The sampling points within the ice cap are located on re-exposed nunataks.

covered by ice. Most samples were obtained near the retreating edge of the ice cap, with some taken further from the ice edge where no other material was present. In addition, some samples were taken from ground recently exposed by the melting of formerly persistent snow fields, and from newly-exposed rock protruding from the glacier (nunataks) (Fig. 1b). Along the south-eastern edge of the retreating ice (Gourlay Snowfield) extensive moss banks have been re-exposed (Fig. 2), providing the majority of samples (n = 27) collected. Samples of the top 10 mm of the surface of the exposed moss banks were taken by hand with nitrile gloves, transferred into plastic sample bags and stored at −20 °C immediately on return to Signy Research Station (2-4 h). They were kept at −20 °C throughout return transport to the British Antarctic Survey (Cambridge, UK) and onwards to VU Amsterdam (NL), before subsampling for radiocarbon dating. Where recognizable, the moribund mosses were identified before dating. Samples included the genera *Andreaea* and *Chorisodontium.* The bank-forming *Chorisodontium aciphyllum* is the only species of the genus to occur in the Maritime Antarctic region, while three species representing *Andreaea* are known to occur on Signy Island (Ochyra et al., 2008).

2.2. Analyses

Subsamples of 30-50 g were taken from the 41 collected moss surface samples and processed for radiocarbon dating following Groningen guidelines (Dee et al., 2020). Three samples failed to yield sufficient carbon. The radiocarbon ages of the remaining samples were calibrated using the SHCal20 Southern Hemisphere calibration curve (Hogg et al., 2020), resulting in a total of 38 dates with mean standard deviations of ~25 y. All dates were processed using OxCal v4.4.4 software (Bronk Ramsey, 1995). Samples dated in the modern era (post-1950) (n = 6) were not used further, as they were all taken further away from the ice edge and, therefore, modern regrowth and moss kill by human presence cannot be excluded. On Signy Island, mosses can also be killed by seal trampling, which could have happened before the modern era, but the seals are unlikely to have occurred as far inland as the locations where most of our samples were collected (Convey and Hughes, 2023). Therefore, a total of 32 dated moss samples form the basis of this study.

The changing extent of Signy Island's ice cap in the instrumental period was derived from satellite images obtained in 2010 (Quickbird-2), 2020 (Worldview-2) (Maxar imagery © 2025 Maxar Technologies) (Gerrish and Ireland, 2024), and 2023 (Worldview-2 image © 2025 Vantor), and a 1975 map from the British Antarctic Survey archive (The Directorate of Overseas Surveys © Crown Copyright, 1975). All images were taken in summer (January-March) without recent snowfall, representing the minimum summer extent of the ice cap. The images from 2020 to 2023 were taken on the same day of the month (February 10), marking the height of the summer period. The outlines of the ice cap from the 1975 map and the different satellite images were manually digitised in QGIS and used to overlay the 2023 image to visualise the retreat between the specified years. It should be noted that the 1975 outline is error-prone due to limited mapping accuracy at the time and that, while being as precise as possible and using very high resolution satellite imagery, small spatial errors cannot be excluded for the 2010 and 2020 outlines (Gerrish and Ireland, 2024). The retreat rates from 1975 to 2023 and 2020 to 2023 were calculated by dividing the horizontal distance re-exposed by the duration in years. We also estimated an average past advance rate based on our burial dates from the 2023 ice cap outline and the dates reported by Fenton (1982) and Smith (1990) for the 1975 outline, dividing the average difference in years between the dates by the average difference in distance between the 2023 and 1975 outlines. Due to the unavailability of the raw radiocarbon data from 1975, those dates were not recalibrated. In addition, written records and personal observations referring to Manhaul Rock, a large protruding nunatak on the south-eastern part of the McCleod Glacier, were used to discuss potential thinning rates over time.

3. Results

The majority (27/32) of the radiocarbon-dates showed moss burial dates of between 1000 and 1400 CE (Table S1; Fig. 3). All these 27 samples were located on the east side of the ice cap, mostly concentrated around the Gourlay Snowfield in the south-east (Fig. 4). Four further samples were buried before 1000 CE, with the oldest burial date being 218 – 517 CE. These samples were all obtained on the west side and on exposed rock close to the top of the ice cap (Fig. 4a). The youngest burial date was 1712-1924 CE (Fig. 3), in a sample originating from the southern beach (Fig. 4a).

Tracking the recent retreat of the ice cap outline showed that, since 1975, it has retreated by 150-800 m horizontal distance, depending on location. The western side of the ice cap has experienced the largest retreat of up to 800 m (Fig. 4a). On the southern and south-eastern margins, retreats of 300-400 m have taken place while, on the steeper north and north-eastern margins, retreat appears to be more variable and difficult to determine due to the irregular ice margins in these areas

Fig. 2. Re-exposed moss banks close to the Gourlay Snowfield, the south-eastern edge of the retreating ice cap on Signy Island (February 2023).

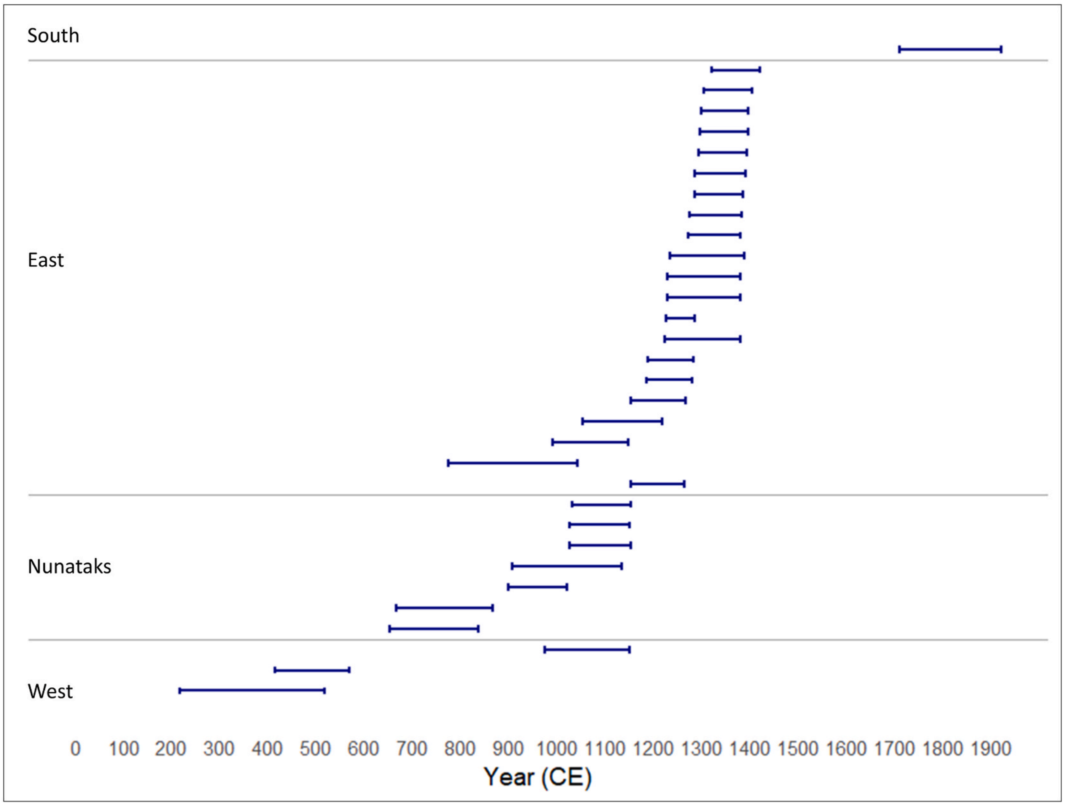

Fig. 3. Radiocarbon dates (95% probability intervals) in calibrated years CE (Common Era), reflecting the burial dates of re-exposed moss samples taken around the edges of the ice cap, from nunataks and along the margins of permanent snowfields on Signy Island. The topographical origin of the samples is indicated on the left.

(Fig. 4a and b). The mean retreat rate in the south-eastern area was 8 m/y over the past 50 years. However, comparison of satellite imagery over the past 15 years confirms that retreat rates are rapidly increasing and have almost doubled between 2020 and 2023 compared to 2010-2020 (Fig. 5), being on average 20 m/y in the most recent period (2020-2023). Comparison of Manhaul Rock's protrusion heights above the ice revealed a vertical ice thinning rate of 0.5 m/yr for the southern part of the ice cap.

4. Discussion

4.1. Onset of the last neoglacial ice advance

The recent rapid retreat of Signy Island's ice cap has provided a unique opportunity to obtain minimum ages for the onset and progression of the neoglacial ice advance. The data from the central and western parts showed that the minimum age for the onset of ice advance was 218 CE (Figs. 3 and 4), while dates from the south-eastern parts of the ice cap showed ongoing ice expansion between 1000 and 1400 CE. In comparison, most dates obtained close to the then-existing ice margin sampled in 1975 ranged from 1400 to 1700 CE (Fenton, 1982; Smith, 1990), 300-400 years later. These findings are consistent with our hypothesis that the retreat that has taken place between 1975 and 2023 has re-exposed mosses that were still buried in 1975. The dates obtained in this study combined with those sampled at the 1975 ice margin indicate that neoglacial ice advance on Signy Island, whether or not continuous, occurred from at least ~200 CE and continued until ~1700 CE.

The timespan of this neoglacial advance is broadly in line with previous local paleoenvironmental reconstructions, although the onset precedes the evidence of cooling identified in those studies. Jones et al. (2000) identified a general cooling period from lake sediment core proxies on Signy Island starting around 750 CE and lasting until ~1950 and (Hodgson and Convey (2005)) reported reductions in abundance of mite species and macrofossils in lake sediment records commencing ~550-750 CE, associated with cooling after a warm period lasting several thousand years. The period of ice advance inferred from our moss burial dates on the south-east side (1000-1400 CE) follows the steepest decline in dry mass accumulation rates in sediment cores from two different lakes shortly after 1000 CE, including the disappearance of some biological macrofossils (Jones et al., 2000) and cooling inferred from isotopic d^{18}O carbonate signatures (Noon et al., 2003), all suggested to be indicators of glacial advance associated with local or regional cooling.

Not all proxies capture the onset of neoglacial advance in a similar way: radiocarbon dates from ice, lake and marine records likely detect the direct onset of cooling (after reservoir corrections, where applicable), whereas moss burial ages only reflect minimum ages until the point at which no further moss is being exposed by the modern ice retreat, and assuming no regeneration has occurred during ice margin fluctuations. Regeneration has been demonstrated elsewhere in mosses that had been ice-covered for up to 600 years (La Farge et al., 2013; Cannone et al., 2017), and from 1 m deep shoots obtained within the permafrost layer in a 1500 year old moss bank on Signy Island (Roads et al., 2014). However, while some biological activity was reported directly from the field (La Farge et al., 2013), the mosses in these studies were grown at 15-20 °C, which is far above field temperatures, and the species re-exposed from under the ice did not belong to the genera identified in our samples, reducing the likelihood of our dates reflecting regrowth associated with ice margin fluctuations within the neoglacial period. In addition, the lag time of glacial response to climate cooling can delay estimates derived from moss burial dates, yet regional studies have suggested high glacial sensitivity to temperature change (Davies et al., 2014). On Signy Island, the evidence for cooling from ~750 CE derived from lake sediments predates the main period of moss burial (1000-1400 CE) by approximately 250 years (Jones et al., 2000; Hodgson and Convey, 2005). However, moss burial ages have the

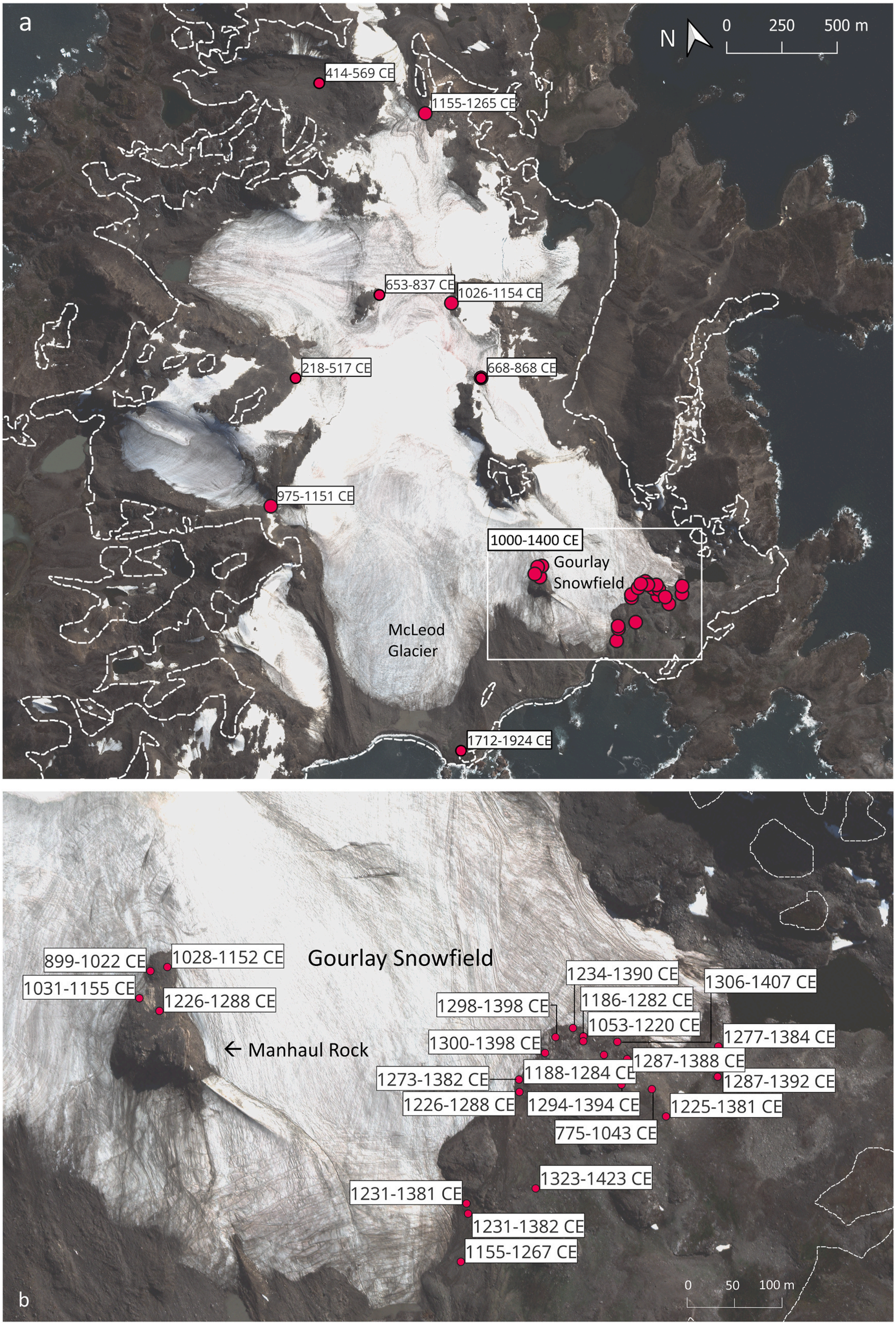

Fig. 4. **a)** Satellite image (WorldView-2) of Signy Island from February 2023 (© 2025 Vantor), including an outline of the ice cap in 1975 (white dashed line), with the sample locations and radiocarbon dates in CE (Common Era) of burial dates obtained from re-exposed moss samples collected in 2023. **b)** Zoomed in view of the south-eastern part of the ice cap (Gourlay Snowfield), illustrating individual sample locations and dates around the Manhaul Rock nunatak and the south-eastern ice margin.

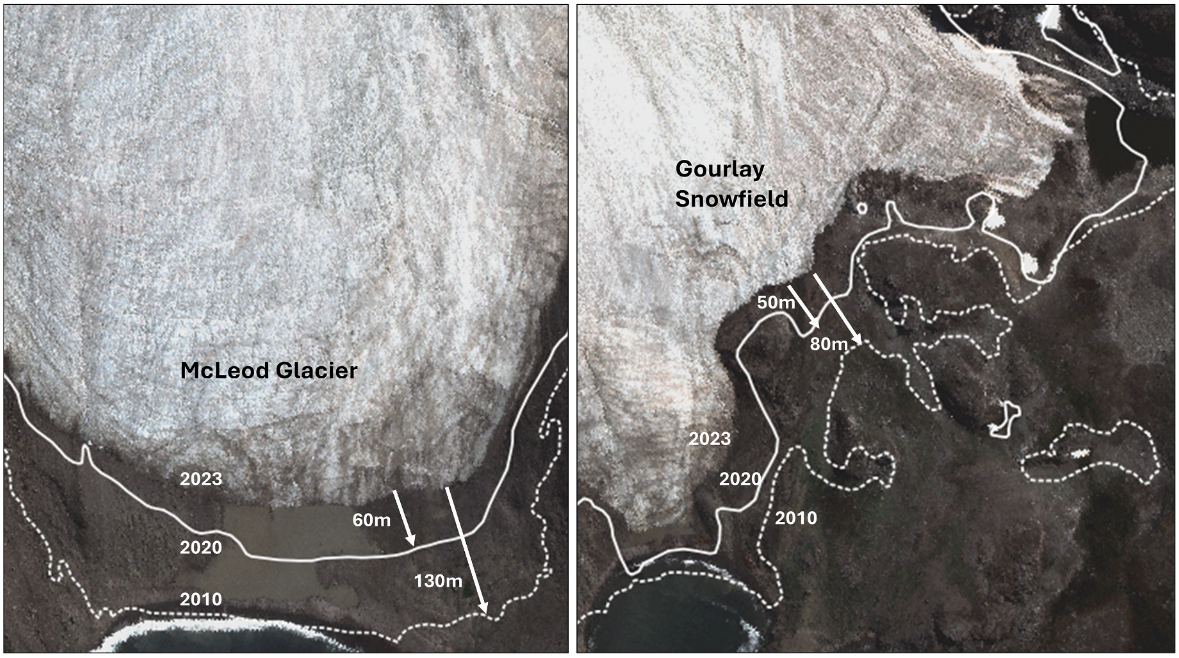

Fig. 5. Retreat of the ice cap on Signy Island along its south (McLeod Glacier) and south-eastern margins (Gourlay Snowfield) between 2010 (dotted line), 2020 (solid line) (derived from Maxar imagery © 2025 Maxar Technologies) and 2023 (ice edge on WorldView-2 satellite image © 2025 Vantor).

advantage that advance rates can be calculated through spatial sampling in relation to current or past known ice extent (see section 4.2).

The minimum age for the onset of neoglacial ice advance on Signy Island in our study is consistent with the long term regional cooling trend for Antarctica from 0 to 1900 CE reported by Stenni et al. (2017), with the start of the coldest interval in their reconstruction (1200-1900 CE) corresponding to the period when most of the mosses in our study were buried by the ongoing ice advance (1000 – 1400 CE). This cooling peak reflected in our dates falls within the time-frame for which many records report an onset of cooling around the Antarctic Peninsula, i.e. between ±1000-1600 CE (Simms et al., 2021; Çiner et al., 2025). This timing has raised discussion about a potential relationship with the Northern Hemisphere Little Ice Age (NH LIA) (e.g. Bentley et al., 2009; Simms et al., 2021; Çiner et al., 2025), which commenced between ~1250 and 1500 CE at different locations around the North Atlantic (Grove, 2001).

When comparing regional records, the peak in our data matches inferred cooling conditions from multiple proxy records from South Georgia (54°S, 36°W, ±800 km north-east of Signy Island) (Oppedal et al., 2018) and from various locations around the Antarctic Peninsula, including the South Shetland Islands (Simms et al., 2021), Palmer Deep (Domack et al., 2001; Shevenell and Kennett, 2002; Shevenell et al., 2011), Bilari Bay (Christ et al., 2015) and Marguerite Bay (Simms et al., 2021). However, other studies report later onsets of cooling ~1400-1800 CE (Simms et al., 2021; Çiner et al., 2025), more consistent with the peak of the NH LIA, as well as multiple cooling periods leading up to this time (Groff et al., 2023). Conversely, earlier, more continuous, cooling has been inferred from ~0 to 500 CE onward (e.g. Davies et al., 2014; Ćejka et al., 2020), which is consistent with the earliest dates obtained in our study. Whether our dates reflect continuous or intermittent glacial advance cannot be assessed from our dataset, but future retreat may provide further re-exposed material and data. On a regional scale, more records from different proxies will be needed to fully understand the neoglacial ice advance and how it relates to Northern Hemisphere dynamics in the Maritime and sub-Antarctic.

4.2. *Recent rapid retreat rates*

The oldest ice advance dates obtained in this study indicate that the Signy Island ice cap is continuing to deglaciate towards a minimum ice configuration last seen ~1800 years ago (218 CE) on the west side of the island. The high recent retreat rates apparent from the satellite image comparison show a maximum horizontal retreat of up to 800 m over the past 50 years on the west side of the island (Fig. 4a). In the south and east of the island, retreat over the same period was ~400 m (Fig. 4b), potentially due to protection from warm air and rain which predominantly arrives from the west (Holdgate, 1997; Lu et al., 2023). Signy Island also experiences occasional short-term warm temperature spikes associated with atmospheric rivers and from föhn winds originating from the larger and higher altitude Coronation Island to the north, which have increased the number of warm events per year over the instrumental period (since 1947), increasing the melting of snow and ice (Lu et al., 2023). Some of the earliest burial ages (i.e. from before 1000 CE) were obtained from nunataks protruding through the island's ice cap (Figs. 3 and 4), showing that these were likely the first areas to experience neoglacial advances through increases in snow and ice accumulation on the highest parts of the island. Conversely, these are also areas that have experienced high thinning rates during the observational period, such as Manhaul Rock, which was fully ice covered in the 1960s, protruded by 8 m in 1988 and is currently (2026) at 30 m above the ice (Purvis et al., 2013; D. Fox personal observation March 2026). This suggests that low altitude ice caps in the Maritime Antarctic are highly sensitive to even small changes in climate. Future comprehensive sampling as the ice cap continues to retreat may reveal an earlier onset of the neoglacial advance as more buried mosses become exposed. Regarding the ending of the neoglacial advance period, our youngest burial date of suggests that ice advance was still occurring until at least 1712-1924 CE on the island's southern coast (Figs. 3 and 4). The advance likely continued until rising temperatures from ~1945 CE (Colwell, 2013; Lu et al., 2023) initiated the current period of ice retreat.

The difference in burial ages of ±300 years on average between our data and those from 1975 in the south-east of the island (Fenton, 1982; Smith, 1990) show that glacial retreat over the past 50 years has exposed the same area of ground that was covered by 300 years of glacial advance. This indicates that the ice cap is currently retreating roughly six times faster than it previously advanced: assuming continuous advance and retreat, the advance rate during the period ~1300-1600 CE was 1.3 m/yr, while the average retreat rate over the past 50 years has been 8 m/yr. We acknowledge that his retreat rate calculation is dependent on the accuracy of the 1975 map, but this should be minor relative to the overall retreat distance. Additionally, we note that continuous, linear, advance is unlikely over the course of 300 years, and that direct comparison with the short-term retreat rates derived from maps/satellite imagery should be interpreted with caution. However, the derived average advance rate of 1.3 m/yr between 1300 and 1600 CE is broadly consistent with those reported by Groff et al. (2023) for two locations on Anvers Island (64°S) (~1100-1300 CE), of 0.3 and 2 m/yr. They also reported much higher subsequent retreat rates, with averages of 8.7 and 4 m/yr between 2004 and 2019. On the southern part of the ice cap, the exposure measurements at Manhaul Rock indicate an ice thinning rate of 0.5 m/yr over the past 50-60 years.

Satellite images of Signy Island obtained over the past 15 years show increasingly rapid ice retreat rates. At the southern and south-eastern margins of the ice cap (McLeod Glacier and Gourlay Snowfield), characterized by extensive, gently sloping snow and ice fields, horizontal retreat rates almost doubled between 2020 and 2023 compared to 2010-2020 (Fig. 5), reaching up to 20 m/yr. Along other margins of the ice cap the retreat rates were more variable across this time period, but still broadly comparable to those in the south-east. These increased retreat rates coincide with continued warming patterns and the occurrence of extreme weather events across Antarctica, with impacts on both the cryo- and biosphere (Robinson et al., 2020; Lu et al., 2023; Siegert et al., 2023). With ongoing warming predicted in the region (Bracegirdle et al., 2020), Signy Island's now remnant ice cap is likely to continue retreating and thinning at similar or even faster rates. If it reaches a point when no more moss emerges from under the retreating ice, the ice cap will have exceeded its previous minimum Holocene configuration.

4.3. Ecological implications

The earliest burial ages obtained here indicate that before ~200 CE, there must have been an ice cover-free area on the island long enough for mosses to establish. It can take several decades for mosses to establish on bare ground following ice retreat in the Antarctic (Ruiz-Fernández et al., 2017), and to form banks as substantial as those sampled on the south-eastern margins of the ice-cap at Gourlay Snowfield would likely have taken centuries (cf. Lindsay, 1978; Fenton, 1980). Deep moss banks on the northern and western slopes of Signy have shown continuous growth over the last 1500 to 5000 years (Fenton, 1980; Royles et al., 2012; Roads et al., 2014), suggesting that, while glacial expansion between ~200 and 1700 CE clearly reduced the area of terrestrial habitat, the ice did not expand over these areas and the bryoflora diversity was likely still comparable to that of the present day. The current rapid re-exposure of bare ground provides an opportunity for (re)colonisation both by regeneration of the re-exposed moss banks and establishment of new mosses (Smith, 1982, 1995; La Farge et al., 2013). In combination with enhanced water supply from melt streams around the ice cap, this will likely lead to an increase in vegetation on Signy Island in the coming decades.

5. Conclusions

The rapidly retreating ice cap on Signy Island provides a unique opportunity to derive minimum ages for the last neoglacial ice advance from moss burial dates. These suggest an earliest onset of ice advance ~218 CE and a peak between 1000 and 1400 CE, particularly along the southern and south-eastern margins of the ice cap. These dates predate the former estimates of neoglacial ice advance (1400-1700 CE) obtained from the 1975 ice margin by several hundred years, aligning it more closely with Antarctic Peninsula ice core temperature compilations. Further ice retreat will likely expose more mosses from which earlier minimum ages for ice advance could potentially be derived. Accurately constraining such periods is important to better link glacial advance and retreat rates to current and past environmental conditions in the Maritime and sub-Antarctic, in particular, to determine the climate sensitivity of the lower altitude ice caps. Comparisons of satellite images obtained over the last five decades confirm that retreat rates are rapidly increasing, with 8 m/yr in the past 50 years and 20 m/yr in the most recent years (2020-2023). As regional temperatures are predicted to keep rising, more bare ground and potentially previously buried moss will be re-exposed, likely leading to (re)colonisation by mosses and lichens and expansion of their communities on the island.

Data availability statement

The data that support the findings of this study are available in the Supporting Information of this article.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quascirev.2026.110145.

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