Journal of Glaciology

Article

Cite this article: Stringer CD *et al*. (2025) Accelerated glacier changes on the James Ross Archipelago, Antarctica, from 2010 to 2023. *Journal of Glaciology* **71**, e102, 1–15. https://doi.org/10.1017/jog.2025.10075

Received: 10 August 2023
Revised: 14 July 2025
Accepted: 22 July 2025

Keywords:
Antarctic glaciology; Glacier surges; Climate change; Melt - surface

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Accelerated glacier changes on the James Ross Archipelago, Antarctica, from 2010 to 2023

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Abstract

Accelerated glacier mass loss across the Antarctic Peninsula has consequences for sea level rise and local ecology. However, there are few direct glaciological observations available from this region. Here, we reveal glacier changes on the James Ross Archipelago between 2010 and 2023. The median rate of glacier area loss (remote-sensing derived) increased over the study period, with the most significant changes observed in smaller glaciers. In situ measurements show that ablation has prevailed since 2019/20 with the most negative point surface mass balance change measured as −1.39 ± 0.12 m water equivalent at Davies Dome and Lookalike Glacier in 2022/23 (200–300 m a.s.l.). We identified a tripling of the frontal velocity of Kotick Glacier in 2015, which, combined with terminus surface elevation gains (bulging), suggests that this is the first surge-type glacier identified in Antarctica from velocity and surface elevation change observations. We contend that the glacier recession rate has increased due to increased air temperatures (0.24 ± 0.08°C yr^{-1}, 2010–23), decreased albedo and glacier elevation change feedbacks. These processes could decrease glacier longevity on the archipelago. Future research should prioritise monitoring albedo and rising equilibrium-line altitudes and identify glaciers most vulnerable to rapid future mass loss.

1. Introduction

Small glaciers and ice caps (hereafter referred to as glaciers) cover ∼133 400 km^2 around the periphery of Antarctica and represent 18% of global glacier area, excluding the major ice sheets, of which ∼77 600 km^2 are found around the periphery of the Antarctic Peninsula (Pfeffer and others, 2014; RGI 7.0 Consortium, 2023). However, despite such a large glacierised area, few glaciological data are available for land-terminating glaciers in Antarctica compared to other world regions. Antarctic Peninsula glaciers receded at accelerating rates until the end of the 20th century (Davies and others, 2012), and several ice shelves collapsed (Cook and Vaughan, 2010), coincident with air temperatures warming among the most rapidly of any place on Earth (Vaughan and others, 2003). Glacier recession rates then slowed down during the early 21st century, coincident with decreased air temperatures (Oliva and others, 2017). Nonetheless, following an increase in air temperatures since the mid-2010s (Carrasco and others, 2021), Antarctic Peninsula glaciers are once again receding at an enhanced rate (Engel and others, 2023). Furthermore, recent extreme warming across the Antarctic Peninsula has led to exceptional melt rates in some places (Siegert and others, 2023), most notably on the George VI and Larsen C ice shelves (Bevan and others, 2020; Banwell and others, 2021; Xu and others, 2021).

Exceptional melt events release large volumes of freshwater, as well as sediments and solutes, into proglacial streams, lakes and the Southern Ocean (Carrivick and Tweed, 2021; Kavan and others, 2023; Stringer and others, 2024). More generally, the loss of glacier mass can increase meltwater flux and the availability of sediment (Carrivick and Rushmer, 2009). This affects both water temperature (Carrivick and others, 2012a) and water quality, and thus the fragile marine and lacustrine ecosystems of Antarctica (Nedbalová and others, 2013; Gonçalves and others, 2022), as well as contributing to glacier flow accelerations (Bell and others, 2018; Tuckett and others, 2019).

Recently recorded mass losses from the peripheral glaciers of Antarctica (2000–19: −20 Gt yr^{-1}) are the fifth greatest of any world region, but small in comparison with other glacierised world regions when considered per unit glacierised area (−1.5 × 10^{-4} Gt yr^{-1} km^{-2} compared to

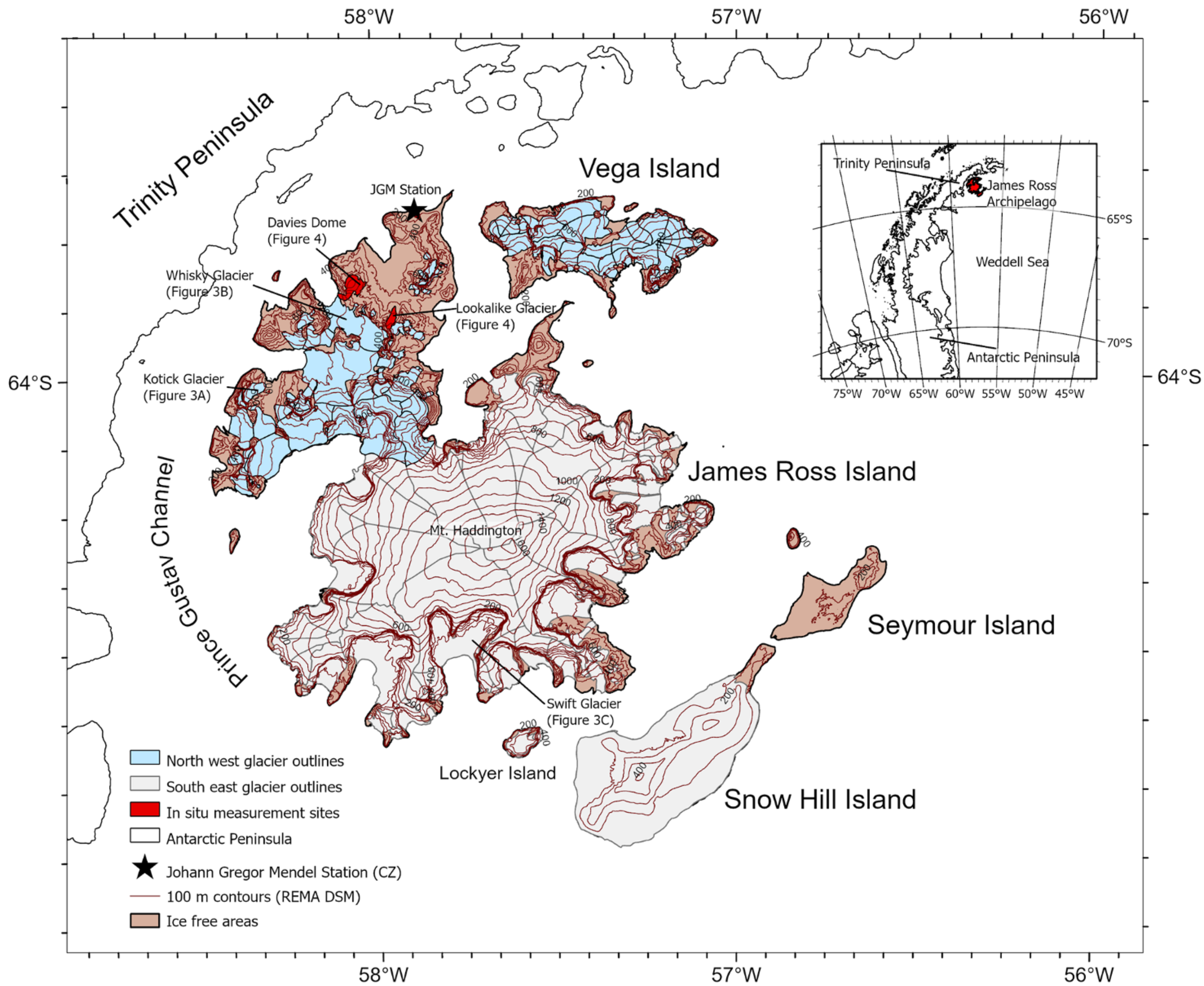

Figure 1. Map of glacier outlines derived from the GLIMS dataset. Glaciers in the north-western sector of the island are in pale blue, with those in the south-eastern sector in white. Those glaciers with in situ measurements (Lookalike Glacier and Davies Dome) are coloured in red; these have GLIMS IDs of G301945E63889S and G302049E63932S, respectively. We have also labelled glaciers that have experienced remarkable changes: Whisky Glacier (G301946E63935S), Kotick Glacier (G301659E64016S) and Swift Glacier (G302228E64270S). The inset shows the location of James Ross Archipelago with respect to the AP (highlighted red).

a global average of -3.7×10^{-4} Gt yr^{-1} km^{-2}; Hugonnet and others, 2021; RGI 7.0 Consortium, 2023). Projected increased melt rates across the Antarctic Peninsula are uncertain. Some models indicate mean annual surface melt will increase in the northern Antarctic Peninsula by >2 m water equivalent (w.e.) yr^{-1} (Garbe and others, 2023), though other projections show this may be offset by increased snowfall accumulation under high-emission scenarios (Edwards and others, 2021). Therefore, there is a pressing need to understand how recent air temperature increases, changes in precipitation (Carrasco and Cordero, 2020) and an increase in extreme warm events affect Antarctic Peninsula glaciers.

This study presents and evaluates glacier changes in the James Ross Archipelago in response to recent and ongoing extreme air temperature warming recorded at the Johann Gregor Mendel (JGM) Czech Antarctic Station (57.9°W, 63.8°S). Specifically, we provide satellite-derived data on changes in glacier area (Landsat-7, Landsat-8 and Landsat-9) and albedo (MODIS) for the James Ross Archipelago since 2010. Additionally, we present coincident in situ measurements of ablation and accumulation for Lookalike Glacier and Davies Dome on the Ulu Peninsula, James Ross Island, collected as part of a long-term study in the region (Engel and others, 2024).

1.1. Study site

The James Ross Archipelago is situated off the northeast coast of the Antarctic Peninsula, across the Prince Gustav Channel and 10 km eastwards from Trinity Peninsula (Fig. 1). The largest islands of the archipelago are James Ross Island, Vega Island, Snow Hill Island and Seymour Island, and they are home to 156 glaciers (Fig. 1, Table 1). The bedrock across the archipelago is primarily composed of Cretaceous to Paleogene mudstones and sandstones, with upland regions of Neogene basalts, hyaloclastite breccias and tuffs (Smellie, 2013; Mlčoch and others, 2019). The archipelago has a semi-arid polar continental climate, with a mean annual air temperature of −7°C at JGM Station (10 m a.s.l.) (Kaplan Pastíriková and others, 2023) and a mean lapse rate of 0.43°C 100 m^{-1} measured over glacierised sites (270–540 m a.s.l. between 2013 and 2016) (Ambrozova and others, 2019). Mean annual precipitation

Table 1. Total number of glaciers analysed by island. Glacier outlines were derived from the GLIMS dataset, with some erroneous ones excluded. Areas are those presented in the results section for 2023. See the Methods for further details

Island	Number of glaciers	Total area (km^2)
James Ross Island	124	1742.4
Snow Hill Island	1	300.0
Vega Island	30	158.2
Lockyer Island	1	10.4
Sum	156	2211.1

is estimated at between 400 mm and 700 mm w.e. (Palerme and others, 2017), although high wind speeds mean the effective precipitation is lower than this (Nývlt and others, 2016; Hrbáček and others, 2021). To consider the regional variability in climatic conditions (Morris and Vaughan, 2003), we split the glaciers into two groups: those closer to the considerably warmer Ulu Peninsula (north western sector) and those closer to the ice-bound Weddell Sea (south east).

Since the Last Glacial Maximum, when ice from the Antarctic Peninsula coalesced with James Ross Island (Glasser and others, 2014), the most prominent ice mass on James Ross Island is the Mount Haddington ice cap (Fig. 1), which is estimated to be between 200 and 300 m thick and drains over steep cliffs to outlet glaciers that are predominantly marine-terminating (Skvarca and others, 1995). Numerous small valley and cirque glaciers also exist beneath near-vertical bedrock cliffs on the Ulu Peninsula of James Ross Island and have changed in thermal regime but relatively little in geometry during the late Holocene (Carrivick and others, 2012b). Vega Island is largely covered by two plateaux ice caps that feed small tidewater glaciers (Davies and others, 2012). Seymour Island is free of glacier cover. In contrast, Snow Hill Island is almost entirely covered by a marine-terminating ice cap (Davies and others, 2012).

In this study, we present data for Lookalike Glacier (a land terminating glacier) and Whisky Glacier (marine terminating), among others. In previous studies, Lookalike Glacier has also been referred to as 'Whisky Glacier' or 'IJR-45', causing confusion. Therefore, we use the name Lookalike Glacier to refer to the small land-terminating glacier on the Ulu Peninsula, while Whisky Glacier refers to the larger marine-terminating glacier that terminates in Whisky Bay, as suggested by the Antarctic Place Names Committee in 2015.

2. Methods

2.1. *In situ measurements*

2.1.1. *Air temperature*

We used air temperature data collected for each glaciological year (defined as beginning of March to end of February; Engel and others, 2024; note that this is shifted by 1 month with respect to the standard glaciological year of the southern hemisphere, which runs from the beginning of April to the end of March) between 2009/10 and 2022/23 from the automatic weather station located near JGM Station (10 m a.s.l.). Air temperature was measured using a Minikin TH datalogger and EMS33H probe (EMS Brno, Czech Republic) with an accuracy of ±0.15°C, installed at 2 m above the ground in a multi-plate radiation screen. From the hourly air temperature observations, we have calculated the annual sum of positive degree days at JGM Station (Hock, 2003). We conducted a linear regression to calculate the average annual change in temperature and report the standard error of the slope of the regression line (similar to other studies, e.g. Carrasco and others, 2021).

2.1.2. *Glaciological measurements*

Glacier ablation and accumulation was measured using stakes placed on Davies Dome Glacier and Lookalike Glacier, which form part of a long-term measurement study (Engel and others, 2018, 2024). These data have mostly been previously published (Engel and others, 2024), although this study examines the individual point data in greater detail. The ablation stakes are representatively distributed across the surface of the glaciers except for the crevassed sea-terminating outlet of Davies Dome. In the case of Davies Dome, we have selected to report measurements from ablation stakes along a W-E transect because they are less affected by snowdrifts and enhanced accumulation at the northeastern slope of the dome. We have split these ablation measurements into 100 m altitude bins.

The height of the stakes above the glacier surface was measured with an accuracy of ±0.01 m using a standard tape measure during the austral summer, typically in early February. Although the accuracy of our measurements was taken to be ±0.01 m, this does not account for uncertainty that may arise from melt at the base of the stake or possible compaction of snow/firn/ice at the base of the stake, or variability in snowpack density (Thibert and others, 2008). We converted the ablation stake values in the ablation and accumulation zones to mass changes using densities of 900 and 500 ± 90 kg m^{-3}, respectively (Engel and others, 2018). Huss and others (2009) estimate point surface mass balance data to have an uncertainty of ±0.1 m w.e. in the ablation area and ±0.3 m w.e. in the accumulation zone. For simplicity, we therefore assume a central estimate of 0.2 m w.e. as our uncertainty. For elevation bins with two measurements, we propagate the uncertainty using Equation (1):

$$\frac{\sqrt{0.2^2 + 0.2^2}}{2} = 0.12 \qquad (1)$$

2.2. *Glacier area*

Glacier outlines for years 2011, 2017 and 2023 were delimited by manually editing GLIMS glacier outlines (Raup and others, 2007) to digitise glacier extent visible in Landsat images (see Table 2). We used glacier outlines produced between 2005 and 2014 available from the GLIMS dataset but found it necessary to manually remove some erroneous polygons that seemed to correspond to frozen lakes, snow-filled surface depressions, shadows and a few spurious digitising/topology errors. The years 2011, 2017 and 2023 were chosen for image clarity (lack of clouds and overall snow cover). We then quantified area change for each period (2011–17 and 2017–23) and converted this into a percentage change relative to the initial glacier area. Error in glacier outline position is assumed to be ±15 m, or half the size of one Landsat pixel (Paul and others, 2017). Our conservative estimate of the uncertainty in glacier area, assessed by creating a ±15 m buffer on each glacier and calculating the standard deviation in those areas, produces a mean uncertainty (1σ) in a glacier area of ±0.13 km^2, or 7% of the glacier area, which is comparable to previous studies (Malmros and others, 2016;

Table 2. List of satellite (Landsat) images used to delimit glacier outlines. The specific image date is coded into the image ID

Month-year	Sensor	Image IDs
February/March-2011	Landsat-7 ETM +	20110219-LE0720110307-LE07
February-2017	Landsat-8 OLI	20170204-LC08
February-2023	Landsat-9 OLI-2	20230204-LC09

Taylor and others, 2022). Other sources of errors can be introduced by misidentifying debris cover or snow-covered nunataks/headwalls, which we consider to be negligible and therefore accounted for within our conservative approach.

2.3. Albedo

We used the MODIS Snow Cover Daily Global product (MOD10A1 V6.1, 500 m resolution) to extract albedo values for all of the study glaciers with an area of > 2 km^2 ($n = 99$), using Google Earth Engine. This product has been widely used in previous studies (e.g. Dumont and others, 2012). Mean albedo was calculated for each glacier for every day of January and February (i.e. the austral summer) between 2010 and 2023. These daily values were then averaged to give a single annual albedo value per glacier (mean standard deviation, σ, of each glacier over the study period of 0.16). The analysed glaciers were then separated into northwest (mean $\sigma = 0.18$) and southeast sectors (mean $\sigma = 0.14$) (Fig. 1), and a median annual value calculated to represent each sector.

While not specifically assessed in this study, previous work has shown the root mean squared error between in situ and satellite measurements of albedo to be small (e.g. 0.026, Traversa and others, 2021). However, given this study focuses on interannual comparisons of albedo, relative changes in albedo are more important than true values. Uncertainties typically stem from saturation problems over snow-covered areas, although this is difficult to quantify and is assumed to be negligible (Naegeli and others, 2019).

3. Results

3.1. Temperature and albedo changes

Both mean annual air temperature and the sum of positive degree days have increased during the study period (Fig. 2a). The lowest annual temperature in the period was in 2009/10, at −8.59 ± 0.15°C, and the highest of −3.61 ± 0.15°C in 2022/23. The average warming trend was 0.24 ± 0.08°C yr^{-1} ($r^2 = 0.44$, p = 0.01). The sum of positive degree days have also increased over the study period, with an average rate of increase of 15.0 ± 3.8 K d yr^{-1} ($r^2 = 0.56$, $p < 0.01$). This trend is most clear from 2018/19 when the sum of positive degree days increased from 213 K d to 406 K d in 2021/22. Despite a slight decrease in the sum of positive degree days in 2022/23 relative to the previous year, with a value of 391 K d, it had the second highest value in our study period. The lowest sum of positive degree days was in 2009/10, at 127 K d.

The rate of glacier area change (decline) increased in absolute terms in the period from 2017 to 2023 compared to between 2011 and 2017 (Fig. 2b). The median rate of glacier area loss between 2011 and 2017 was 0.06% yr^{-1}, but then increased to 0.38% yr^{-1} between 2017 and 2023. While the upper quartile value for area change was maintained at 0.00% yr^{-1}, the lower quartile rose from an area loss of 0.39% yr^{-1} to 0.94% yr^{-1}. The largest changes in area are typically associated with smaller ice masses (see Supplementary Figure SI 3). Given an uncertainty in the glacier area of 1.2% yr^{-1}, 23 glaciers receded by a magnitude greater than the uncertainty between 2011 and 2017, compared to 38 glaciers between 2017 and 2023. All of these statistically significant glacier recessions were in glaciers smaller than 6 km^2 in area.

Our data suggest that median albedo has decreased through the study period (Fig. 2c) at an average rate (linear regression) of −0.07 ± 0.02 decade^{-1} (south eastern sector, $R^2 = 0.47$, p = 0.01) and −0.07 ± 0.03 decade^{-1} (north western sector, $R^2 = 0.27$, p = 0.06), and this decline is most pronounced since 2019. This general negative trend is punctuated by pronounced minima in 2012 (SE = 0.72, NW = 0.62), 2016 (0.60, 0.69) and 2023 (0.66, 0.59); these minima are most pronounced for the north-western sector (Fig. 2c).

3.2. Glacier area changes

While most glaciers have decreased in surface area during the period 2011–23 (Fig. 2b), there have been some notable exceptions. Two glaciers have gained in areal extent: Whisky Glacier (Figs 1 and 3b) and Kotick Glacier (Figs 1 and 3a). Whisky Glacier slightly reduced in area, from 28.7 ± 0.4 km^2 to 28.2 ± 0.4 km^2 (a loss of 1.8%) between 2011 and 2017 before the terminus advanced by ~800 m, increasing its area to 29.5 ± 0.4 km^2 (an increase of 4.7%). Kotick Glacier advanced by >800 m during the period between 2011 and 2017 when it increased in area from 5.0 ± 0.1 km^2 to 5.5 ± 0.1 km^2 (an increase of 11.0%). Since 2017, the terminus position of Kotick Glacier has remained approximately stable, although the glacier as a whole decreased in size to 5.2 ± 0.1 km^2 (a loss of 6.0% of its area), with that area loss occurring primarily close to its headwall. In contrast, Swift Glacier's eastern terminus position receded by 4.2 km (Figs 1 and 3c), 3.3 km of which occurred since 2017. Swift Glacier, which has its accumulation area on Mount Haddington ice cap according to the GLIMS outlines (Raup and others, 2007, Fig. 1), decreased in size from 178.4 ± 0.6 km^2 in 2011 to 175.9 ± 0.6 km^2 in 2017 (a loss of 1.3% of its area) and was further reduced to 161.0 ± 0.6 km^2 in 2023 (a loss of 8.5% of its area).

3.3. Site-specific albedo and glacier stake data

Across the entire archipelago, there has been a reduction in albedo through time (Figs 2c and 4a). On Davies Dome and Lookalike Glacier (Fig. 4a), albedo has followed the same trend as the rest of the island, with a broadly negative trend (Davies Dome = −0.05 ± 0.04 decade^{-1}, Lookalike = −0.06 ± 0.03 decade^{-1}) punctuated by minima in 2012, 2015, 2016 and 2023. Minima in albedo correspond with measurement of negative changes in stake height. While the relationship (Pearson's test) between albedo and point surface mass balance is not statistically significant ($p > 0.05$), albedo has a closer relationship with point surface mass balance at 200–300 m (p = 0.08), compared at higher elevation (p = 0.26).

In the years 2020/21, 2021/22 and 2022/23, negative changes in point surface mass balance were measured at all altitudes of both glaciers. Since 2009/10, this was observed only in 2011/12 and 2015/16. There has been consistent ablation measured below

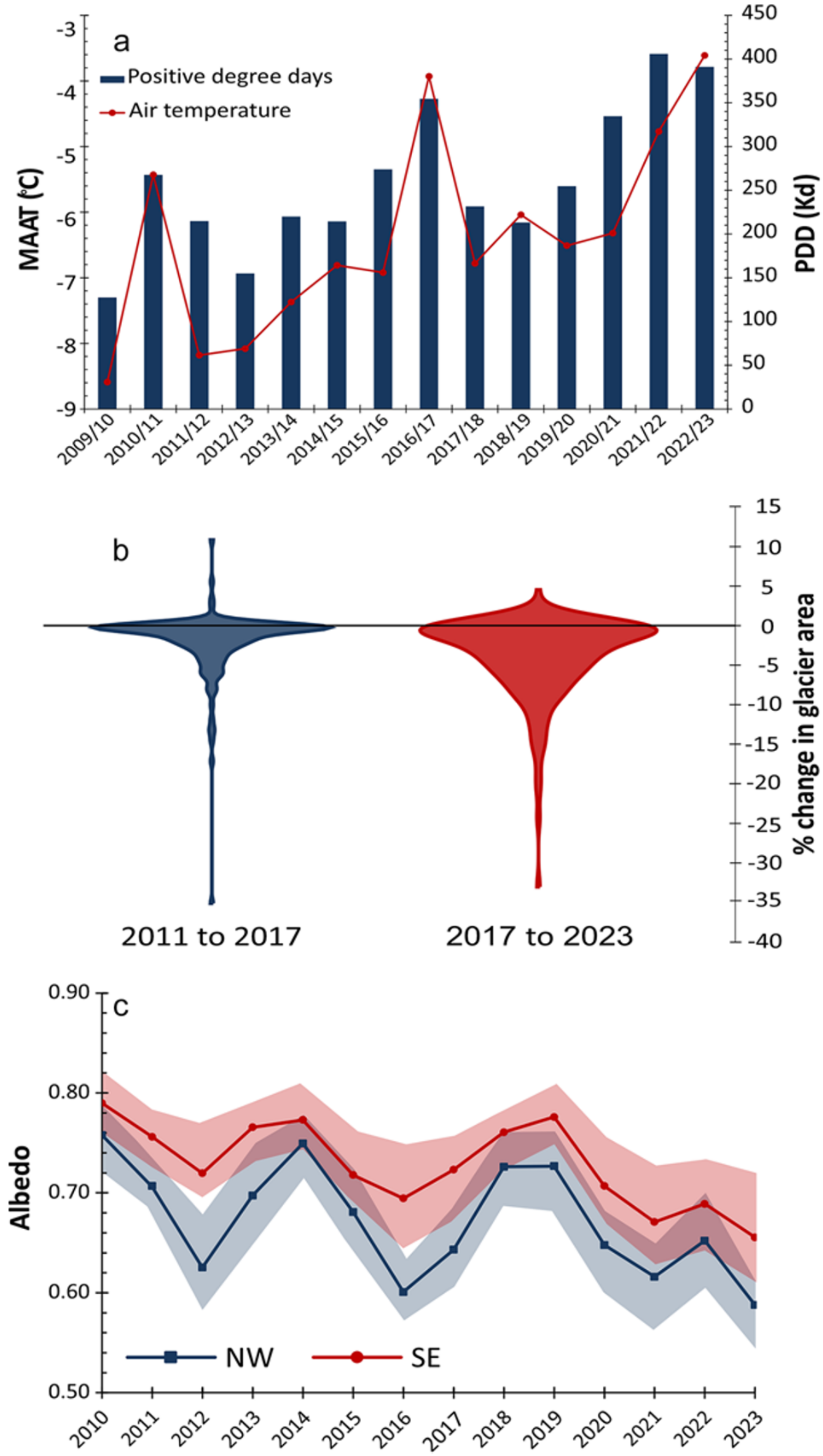

Figure 2. (a) Mean annual air temperature (MAAT) and annual sum of positive degree days (PDD), measured at JGM; (b) violin plot of % glacier area change 2011–17 and 2017–23, NB: the width of the plots is proportional to the number of glaciers ($n = 156$); (c) change in albedo for the north west (NW) and southeast (SE) glaciers, NB: shaded area shows inter-quartile range.

300 m altitude since 2012/13, except for 2018/19 when some stakes showed positive mass balance, and in the 40–500 m bin since 2019/20. Since 2009/10, only 2 years have seen positive changes at all altitudes (2010/11 and 2012/13). The greatest change in point surface mass balance at every altitude was in 2022/23, which was recorded as −1.39 ± 0.12 m w.e. below 300 m, −0.83 ± 0.12 m w.e. at 300–400 m, −1.01 ± 0.20 m w.e. at 400–500 m and −0.60 ± 0.20 m w.e. above 500 m.

4. Discussion

4.1. Observations from other studies

In addition to the data collected in this study, we present datasets of surface mass balance, accumulation area ratio and equilibrium-line altitude data collected in other recent studies that cover our study period (2010–23), specifically for Lookalike Glacier, Davies Dome and Glaciar Bahia del Diablo (Engel and others, 2018, 2024;

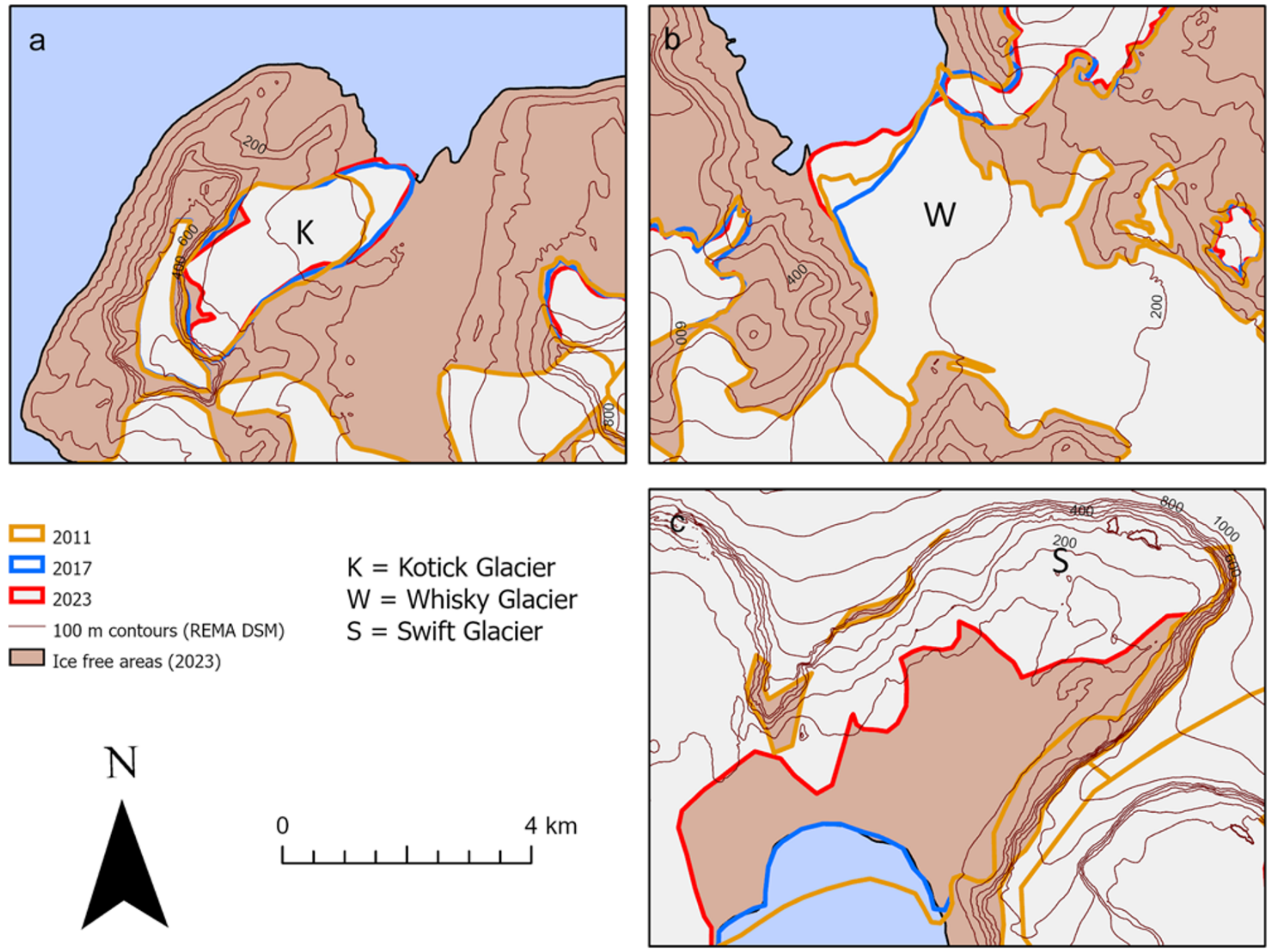

Figure 3. Area changes in glaciers on James Ross Island, including the advance of Kotick Glacier (a), Whisky Glacier (b) and the remarkable loss of area of Swift Glaciers (c). GIFS of these changes are available in the Supplementary material.

WGMS, 2023). The studies by Engel and others (2018, 2024) calculated annual surface mass balance using the glaciological method between January and mid-February for Lookalike Glacier and Davies Dome. The change in height of stakes was measured and converted to m w.e. (using densities for ablation and accumulation of 900 and 500 ± 90 kg m^{-3}, respectively, and then interpolated using the nearest-neighbour technique to create a set of surface mass balance isolines). The results from Vega Island are also calculated using the glaciological method, but interpolations were conducted using a linear approach (Marinsek and Ermolin, 2015; WGMS, 2023). Equilibrium line altitude and accumulation area ratio were then derived from the surface mass balance isolines.

These datasets from other studies support the patterns of change identified in this study (Fig. 4b). For example, glaciological changes at Lookalike Glacier, Davies Dome and Glaciar Bahia del Diablo all demonstrate a negative trend in surface mass balance and accumulation area ratio, and an increase in equilibrium line altitude (Fig. 5). Equilibrium line altitude has increased at an average rate of 12.9 ± 3.8 m yr^{-1}. Mean glacier-wide surface mass balance has decreased at an average rate of −0.06 ± 0.02 m w.e. yr^{-1} between 2010 and 2023, with accumulation area ratio also decreasing at an average rate of −3.6 ± 1.3% yr^{-1}. The highest surface mass balance values observed at Lookalike Glacier and Davies Dome, within the 301–400 m elevation band (Fig. 4b), confirm the spatial pattern of surface mass balance described by Engel and others (2018). The increased accumulation in the NE section of Davies Dome was attributed to the removal of snow from the flat top of the dome and its redistribution by wind onto the leeward slope. At Lookalike Glacier, the zone of enhanced accumulation extends from the flat upper part along the eastern glacier margin down to lower elevations, influenced by snowdrifts. Decreased accumulation at the highest section of this glacier may be attributed to its steep slopes below the ice divide and snowdrift from the divide to the adjacent glacier.

4.2. Drivers of recent melt

The mean annual air temperature increase of 0.24 ± 0.08°C yr^{-1} recorded at JGM Station (using the glaciological year March to February) during the study period (2010–23) and an increase in the sum of positive degree days of 15.0 ± 3.8 K d yr^{-1} are exceptional, both by Antarctic standards (Supplementary Figure SI 1; see Turner and others (2020) and their table 3) and in a global context, where temperatures have been rising rapidly since 1971 (up to 0.05°C yr^{-1}) (Fan and others, 2020; Osborn and others, 2021). Temperature records from other Antarctic stations in the region indicate that the long-term (1953/54–2023/24) increase in temperature has been a magnitude smaller than those recently recorded

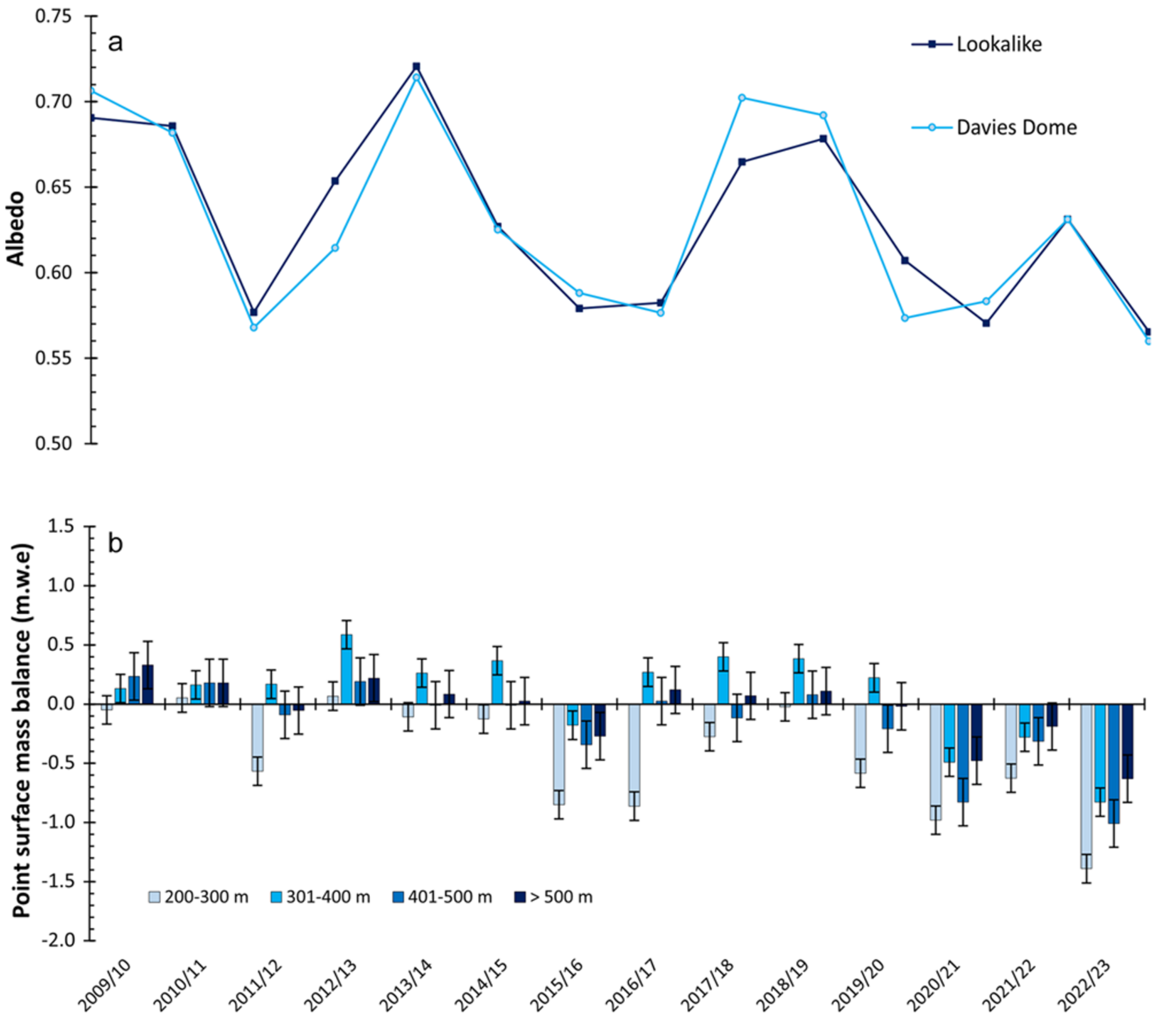

Figure 4. (a) Mean albedo for Lookalike Glacier and Davies Dome; (b) changes in point surface mass balance at Lookalike Glacier and Davies Dome glaciers at different altitudes (error bars show uncertainty).

for James Ross Island, with Turner and others (2020) reporting warming of 0.03°C yr^{-1} and 0.02°C yr^{-1} at the nearby Marambio and Esperanza bases, respectively. When compared directly to data acquired Esperanza Station (~60 km NE of JGM) from the BAS Met READER dataset (Colwell, 2013), we find that mean annual air temperature (measured over the glaciological year of March to February) has been rising at an average rate of 0.19 ± 0.06°C yr^{-1} between 2009/10 and 2023/24, indicating the temperature rises observed at JGM Station are representative of the wider region. Indeed, the temperature increases and subsequent lengthening of the melt season recorded at JGM Station are in excess of observed rapid changes in the Arctic (0.1°C yr^{-1} on Svalbard), which is said to have undergone the Earth's fastest rate of warming (Adakudlu and others, 2019; Arndt and others, 2019; England and others, 2021).

Our data show that albedo varies interannually (Fig. 2c), likely dependent on the combined effects of snowfall (accumulation), aeolian transport of dust, as well as possible debris sourcing from surrounding rocks (Naegeli and Huss, 2017; Johnson and Rupper, 2020; Davies and others, 2024). Although a rise in air temperature (Fig. 2a) would be expected to increase the rate of glacial melt, a decrease in albedo would further exacerbate melt rates (Naegeli and Huss, 2017; Johnson and Rupper, 2020; Davies and others, 2024). Changes in albedo induce a positive feedback, whereby dust and other debris lower glacier albedo, leading to melt and thinning which reveals more debris, which acts to keep albedo low (Naegeli and Huss, 2017). We interpret the difference in albedo between the north west and south east sectors of the archipelago to highlight the importance of the Ulu Peninsula: a large glacier-free region, a source of dust that, upon aeolian deposition, lowers albedo because large dust storms are observed frequently (Kavan and Nývlt, 2018). Dust deposits have been observed to have accumulated on Triangular Glacier (Kavan and others, 2020; Engel and others, 2023) and Lookalike Glacier (Kavan and others, 2020) on the Ulu Peninsula.

More broadly, the James Ross Archipelago is home to several large proglacial areas which are abundant in fine dust (Davies and others, 2012), which is likely to contribute to darkening

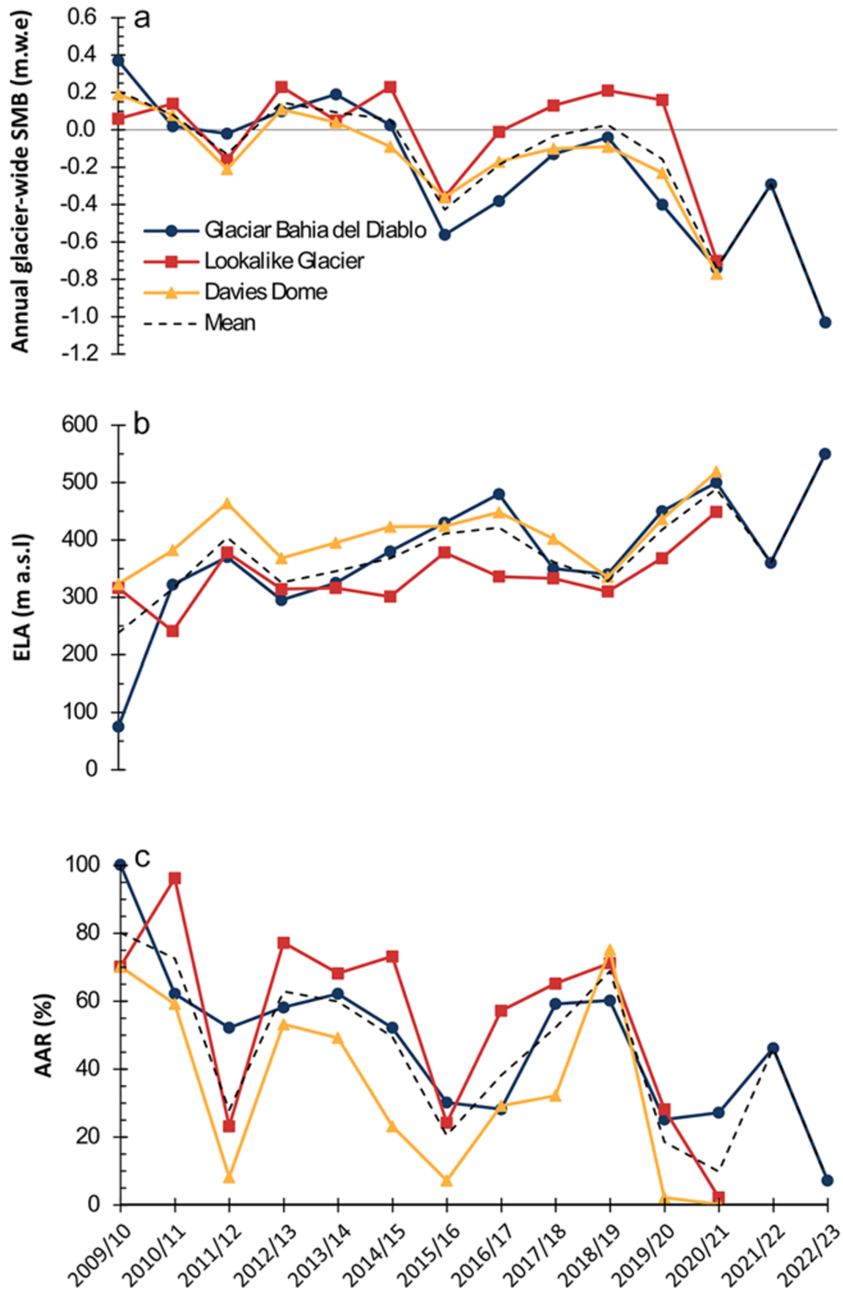

Figure 5. Glaciological datasets for Glaciar Bahia del Diablo (WGMS, 2023), Lookalike Glacier (Engel and others, 2018, 2024) and Davies Dome (Engel and others, 2018, 2024). These depict: (a) annual glacier-wide surface mass balance (SMB); (b) equilibrium-line altitude (ELA) and (c) accumulation area ratio (AAR).

glacier surfaces in the north-west sector, lowering albedo and thus increasing melt rates, particularly in years with less snowfall (Fassnacht and others, 2015; Kavan and others, 2020). We contend that the combination of rising temperature, culminating in very high temperatures in 2022/23 and low surface albedo (Fig. 2c), is likely the cause of enhanced glacier area loss and the exceptional glacier ablation (Figs 2b and 5b) in recent years. This is consistent with modelling work, which has shown that glaciers in the northern Antarctic Peninsula region are highly sensitive to relatively small changes in air temperature, especially during periods when air temperature fluctuates around 0°C (Jonsell and others, 2012). This sensitivity has been observed across the Antarctic Peninsula (Costi and others, 2018). This loss of glacier mass is acutely shown by in situ stake data (Fig. 4c), which records consistent ablation for 3 years. Similarly, there was a consistent thinning in both periods on Snow Hill Island and to the east of Vega Island, as well as around the periphery of James Ross Island, particularly on its southern coast (Fig. 4b). Furthermore, consistent warming since the 1950s (Supplementary Figure SI 1), means that short-term extreme weather events are likely to have been compounded by decades of warming, which in turn is likely to further decrease glacier longevity in the future (Zekollari and others, 2020)

4.3. Drivers of glacier area change

While most glaciers on the archipelago have undergone moderate decreases in their area since 2011 (median values of 0.06% yr^{-1} 2011–17 and 0.38% yr^{-1} since 2017), three glaciers have shown large aerial changes (Fig. 2b). Swift Glacier receded from a marine-terminating environment to a land-terminating setting between

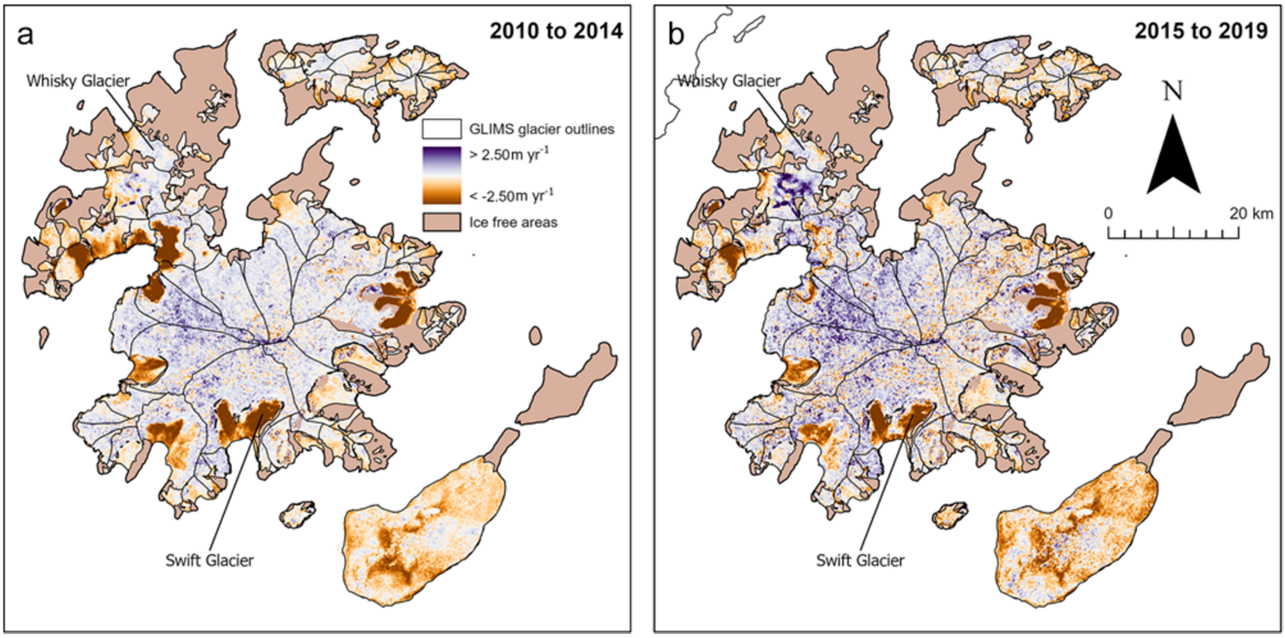

Figure 6. Rate of surface elevation change for (a) 2010–14 and (b) 2015–19 (Hugonnet an others 2021).

2011 and 2023. This will likely mean that the region experiences a decrease in the supply of sediment (nutrients into the sea), as well as a reduction in ocean mixing and a decrease in albedo (Chu and others, 2009; Riihelä and others, 2021; Meire and others, 2023).

Successive years of summer Landsat images (available as GIF images in the Supplementary material) reveal that the rate of Swift Glacier's terminus recession was non-linear, with the majority (3.3 km) of this 4.2 km recession occurring in the austral summer of years 2018/19. This rate of recession is comparable to the highest rates (∼5 km yr^{-1}) recorded for large tidewater glaciers in the Antarctic Peninsula region (Wallis and others, 2023). It is two orders of magnitude higher than most glacier recession rates recorded in the Arctic, which are typically between 10 and 35 m yr^{-1} (Rachlewicz and others, 2007; Kavan and Strzelecki, 2023); specifically, it is one order of magnitude greater than the highest recession rates observed on Svalbard and other glaciers in the Barent's Sea region (∼300 m yr^{-1}, Błaszczyk and others, 2021; Carr and others, 2023), and more akin to exceptional retreat rates observed in northern Greenland (>1 km yr^{-1}, Carr and others, 2017). We propose that this frontal recession of the Swift Glacier ablation tongue could be due to a combination of warming air and ocean temperatures (Cook and others, 2016), and record low sea ice extent in the Weddell Sea in the 2018/19 season (Jena and others, 2022). In addition to this, rising equilibrium line altitudes (Fig. 5b) indicate that the equilibrium line altitude of Swift Glacier is likely to regularly be high enough to intersect with the glacier head wall. This would result in most of Swift Glacier's area being in the ablation area, with any snowfall it receives completely melted by the end of the season. Swift Glacier's topographic setting, flowing from the Mount Haddington Ice Cap into a lower elevation cirque (Fig. 1), means it is vulnerable to disconnection from the Mount Haddington Ice Cap (Rippin and others, 2020; Davies and others, 2022, 2024), although without any direct observations of avalanching it is not possible to say with certainty that this has occurred. A sudden decrease in nourishment to the glacier tongue, brought on by a disconnection of the outlet glacier from its ice cap, has previously been observed to cause the rapid recession of glaciers in North America (Davies and others, 2024), and we interpret the cause of Swift Glacier's recession to be mechanistically similar. This loss of ice flow through to the glacier tongue has resulted in substantial thinning (as highlighted by data from Hugonnet and others (2021); Fig. 6a, b). Consequent lowering of the terminus has revealed exposed bedrock and thermokarst features (see Supplementary Figure SI 2) that are characteristic of stagnant, degrading ice masses elsewhere (e.g. Schomacker and Kjær, 2008; Błaszkiewicz and others, 2023). While this has been interpreted as a substantial recession, disconnected ice masses often experience increased debris cover due to the diminished influx of new ice and the resulting ice stagnation (Davies and others, 2022) and further research should focus on collating velocity data to verify this interpretation.

Whisky Glacier and Kotick Glacier are both unusual due to experiencing large advances in their terminus positions. Having receded between 2011 and 2017, the Whisky Glacier terminus appears to have advanced slightly (∼200 m) between 2017 and 2022, followed by a 400 m advance in a single year between 2022 and 2023. While this terminus advance may represent a surge event, in the absence of surface elevation and velocity data it is difficult to make this interpretation with any certainty. This advance occurred despite calving (visible in satellite images) and thinning occurring at the terminus of the glacier (Fig. 6). Further attention should be given to Whisky Glacier in the future to determine the cause of the advance.

The terminus advance of Kotick Glacier coincides with a period for which there is ice surface velocity data (NASA MEaSUREs ITS_LIVE project data (Gardner and others, 2018) and surface elevation data (Hugonnet and others, 2021)). The terminus of Kotick Glacier advanced by 350 m in 2014/15 and 300 m in 2015/16 (Fig. 3a) and this corresponds to an ice surface velocity increase from 41 ± 29 (1σ) m yr^{-1} to 130 ± 29 m yr^{-1} (Fig. 7a). This suggests that Kotick Glacier may be a surging glacier. This interpretation is further supported by the pronounced surface elevation

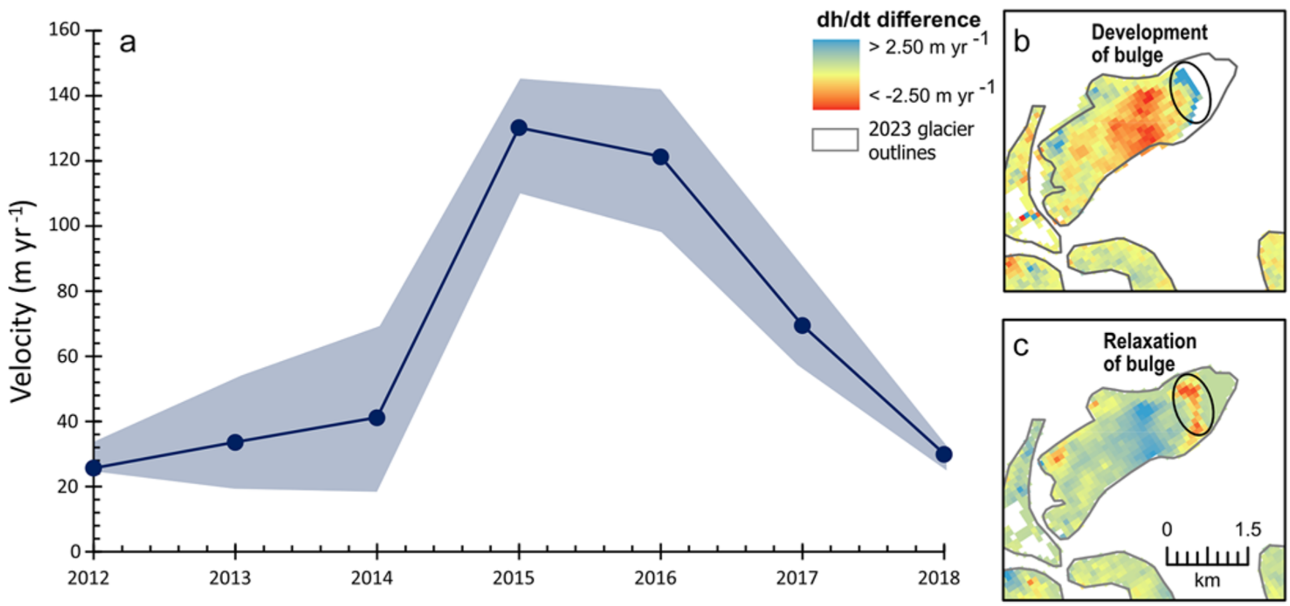

Figure 7. (a) Velocity is described by the median value on the bulge evident at the front of the glacier, with the shading showing the standard deviation. Insets show the difference in the average annual surface elevation change between (Hugonnet and others, 2021) tiles for (b) 2005–09 (median uncertainty ±1.89 m) and 2010–14 (±2.31 m) and (c) 20–14 (±2.31 m) and 2015–19 (±5.90 m).

gain (often referred to as 'bulging') present at the glacier terminus (Fig. 7b), which is shown by an increase in the rate of glacier thickening at the glacier terminus, although it should be noted that these elevation changes are associated with relatively large uncertainties (Hugonnet and others, 2021, Fig. 7). This phenomenon is frequently observed as glaciers reach the active phase of a surge cycle (Clarke and Blake, 1991). This occurred prior to the terminus advance and coincided with a reduced rate of thinning upstream of the bulge. Following the terminus advance in 2015, the rate of thinning on the bulge increased (Fig. 7c). These changes occurred coincidentally with a decrease in glacier velocity in 2016 to 121 ± 33 m yr^{-1} and more obviously to 70 ± 22 m yr^{-1} in 2017 as it relaxed back into a state of relative quiescence. Therefore, to our knowledge, this is the first surge-type glacier to have been identified in Antarctica from velocity and surface elevation change. We note that many glaciers in the Antarctic Peninsula region have been observed to suddenly increase in velocity (De Angelis and Skvarca, 2003; Glasser and others, 2011); however, these events were associated with the collapse of the Larsen A, Larsen B and Prince Gustav Ice shelves and are likely to be the consequence of de-buttressing on the glaciers (Rignot and others, 2004; Joughin and others, 2021). Previous work (Sevestre and Benn, 2015) has highlighted that glacier geometry, in particular glacier length, is correlated with surging behaviour. With a length of 4 km, a mean annual air temperature measured at the nearby JGM of −7°C and a mean annual precipitation of up to 700 mm yr^{-1}, the geometry of Kotick Glacier and the 'climatic window' are suitable for surging to occur (Sevestre and Benn, 2015; Benn and others, 2019). Indeed, Carrivick and others (2012b) commented that, considering the environment, it was surprising that no surge-type glaciers had been observed on James Ross Island.

While the velocity and surface elevation data, as well as the glacier's climatic setting and geometry, make it likely that this is a surge-type glacier, we are mindful that we have not observed any cyclicity due to an absence of velocity data for this region before 2012 and the low availability of satellite images from before 1990. It is feasible that recent temperature increases in the region may have made this surge event more likely by delivering more meltwater to the bed (Tuckett and others, 2019; Benn, 2021), although other glaciers in the region maintained a positive mass balance in 2015 when this surge event occurred (Engel and others, 2018). Possible geomorphological evidence for surging has previously been described on the Antarctic Peninsula, but never directly observed (Nichols, 1973; Wellman, 1982), and further research looking for geomorphological evidence for surging around Kotick Glacier may be useful to determine if there is evidence of cyclicity.

4.4. Outlook

Although the recession rates revealed in this study are lower than those documented in the paleo record (Batchelor and others, 2023), it is clear that some of the glacier changes observed on James Ross Island have been rapid. Given that glacier mass loss is projected to increase in the coming years (DeConto and Pollard, 2016), we find it instructive to consider the longevity of the James Ross Archipelago glaciers to future melt by using annual equilibrium line altitude data (Fig. 5b) in relation to glacier hypsometry.

Parts of glaciers below the minimum mean equilibrium line altitude recorded over our study period (238 ± 115 m a.s.l., $n = 3$) are vulnerable to future melting (Fig. 8) and include large proportions of Snow Hill Island, the southern coast of Vega Island and the periphery of James Ross Island (which have already experienced thinning in recent years, Fig. 6). While many of these regions will remain dynamically active, those to the southeast of James Ross Island are in danger of markedly accelerated recession and thinning, much like Swift Glacier (Fig. 3c). Given that equilibrium line altitudes intersect the ice cap plateau edges, and in some places sit on the plateau itself, further disconnections are very likely as ice fluxes to the glacier tongues in the lower elevation cirques reduce. As areas at the foot of the steep headwall become increasingly

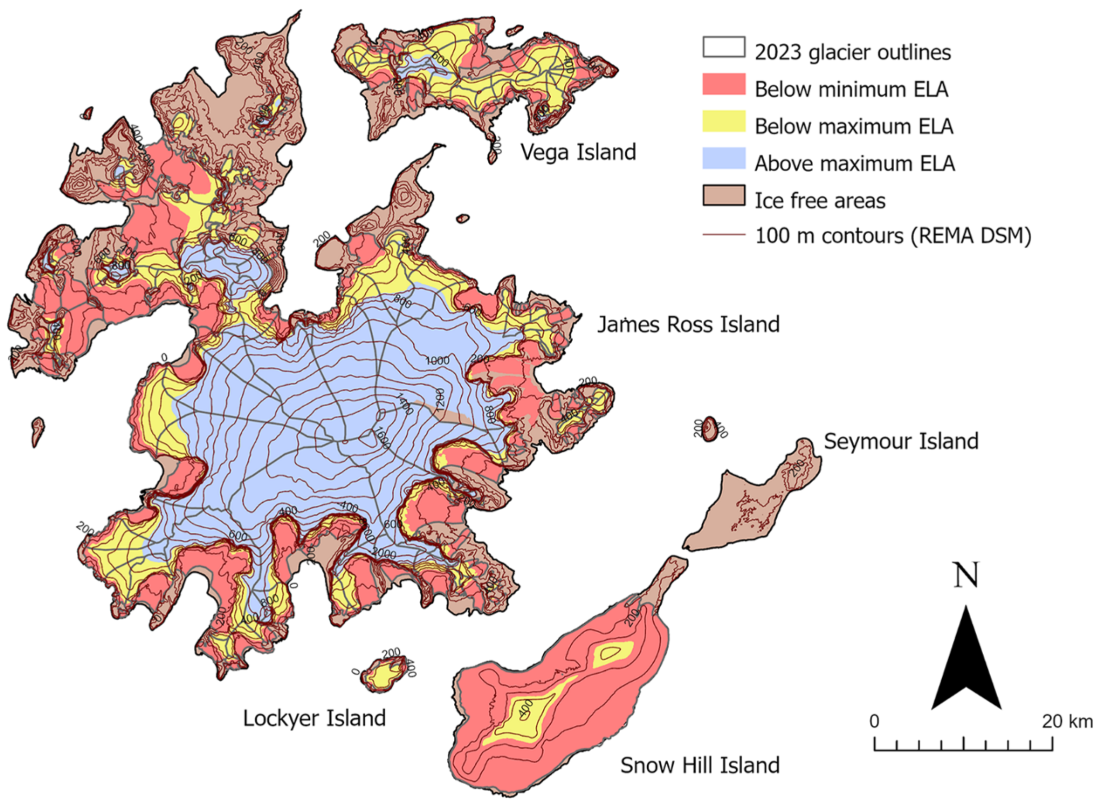

Figure 8. Map of regions with elevation below the minimum and maximum ELAs (equilibrium line altitude, see Figure 5) according to REMA (Howat and others, 2019). The minimum of these values was 238 m, and the maximum was 550 m.

exposed, these glaciers risk becoming dynamically, and subsequently physically, disconnected from their accumulation zone and will become dead-ice without any further mass input from either snowfall or avalanche from the plateaux. Additionally, the surface lowering of ice to the north-west of James Ross Island and on Vega Island also appears to reveal steep topography at the glacier bed that would make several additional glaciers in the archipelago vulnerable to disconnections in the more distant future. This would imply that many glaciers on the James Ross Archipelago are likely to substantially reduce in size in the coming decades, in addition to those already identified as vulnerable (Engel and others, 2019).

Sites below the maximum recorded equilibrium line altitude are comparable to those most likely to face substantial melt, with some parts of this region expected to be glacier-free by 2100 under medium- and high-emission scenarios, according to modelling (using a temperature-index approach) conducted by Lee and others (2017). Our data suggest that significant melting will occur on many glaciers across the archipelago, perhaps indicating the projection of future proglacial area by Lee and others (2017) may be an underestimation if glacier disconnections occur and glaciers recede at a non-linear rate. In addition to disconnections, several other non-linear feedbacks should also be considered in the context of rising equilibrium line altitude. Firstly, a rise in equilibrium line altitude will, due to the low slope of the accumulation area of these ice caps, significantly reduce the size of the accumulation zone and lead to enhanced melt (Åkesson and others, 2017). As equilibrium line altitude rises, so does the area of bare ice, which has a lower albedo than snow and exacerbates melt further (Johnson and Rupper, 2020; Davies and others, 2024). Indeed, the initial melt of the glacier may itself be enhanced by dust deposits that reduce albedo, as may be the case for the glacier thinning observed at Davies Dome and Lookalike Glacier (Fig. 4). Given the low albedo (Fig. 2c) measured across the James Ross Archipelago, in combination with recent increases in equilibrium line altitude, these non-linear feedbacks are likely to affect many glaciers across the region and will lead to substantial melt, particularly if equilibrium line altitude rises above the maximum elevation of some glaciers (McGrath and others, 2017). The majority of the Mount Haddington Ice Cap is currently above the maximum equilibrium line altitude and so at low risk of ablation. However, its relatively low relief means that it is sensitive to rising air temperatures and rising equilibrium line altitudes, and if equilibrium line altitudes continue to rise, it could experience widespread melt (Boston and Lukas, 2019), similar to that occurring on Snow Hill Island (Fig. 5). Furthermore, melt of the ice cap would mean the exposed ice would be at a lower altitude in warmer air temperatures, further decreasing the surface mass balance and creating a surface mass balance-elevation positive feedback; this could exacerbate the impact of rising equilibrium line altitudes, the implication of which is irreversible and accelerating glacier recession, as observed in other parts of the world (Davies and others, 2024). However, it should be noted that the recession of glaciers onto land is likely to somewhat stabilise the surface mass balance of the glacier by reducing sub-glacial melt, perhaps mitigating some of this recession rate (Carrivick and others, 2023).

As with Swift Glacier, many more marine-terminating glaciers are likely to recede onto land as temperatures increase, as has been the case on Svalbard (Kavan and Strzelecki, 2023). Consequently, the proglacial area of the archipelago is likely to increase in size over the coming years. This will impact marine ecosystems

(Szeligowska, 2021) and increase the availability of dust, likely accelerating future glacier melt (Oerlemans and others, 2009). Additionally, glacier recession will change the available habitats in the region; in the Arctic, the loss of tidewater glaciers has been detrimental to the populations of many mammals and seabirds (Lydersen, 2014). While the exposure of new bedrock is likely to be positive for lichens and plants (depending on the availability of liquid water), some of these species may be invasive (Heller and Zavaleta, 2009; Golledge and others, 2010; Olech and Chwedorzewska, 2011).

5. Summary and conclusions

Recent rapid warming across the James Ross Archipelago has been manifested in increased mean annual air temperature of 0.24 ± 0.08°C yr^{-1} between 2010 and 2023. That rate is exceptional compared to the long-term average (1953–2023) of 0.03 ± 0.01°C yr^{-1} and has increased the number of days where melt occurs (sum of positive degree days of 15.0 ± 3.8 K d yr^{-1}), which may explain the rate of glacier area reduction. The median loss of glacier area between 2011 and 2017 was 0.06% yr^{-1}, but then increased to 0.38% yr^{-1} between 2017 and 2023, with small glaciers shown to be particularly vulnerable. These very high air temperatures, combined with decreasing albedo on glacier surfaces (average rate SE sector = −0.07 ± 0.02 decade $^{-1}$; NW sector = −0.07 ± 0.03 decade $^{-1}$), have caused enhanced melt rates since 2020; the most negative point surface mass balance change was −1.39 ± 0.12 m w.e. at 200–300 m a.s.l. on Lookalike Glacier and Davies Dome in 2023. Data from the World Glacier Monitoring Service (WGMS, 2023) and Engel and others (2024) highlight that equilibrium line altitude has also been gradually increasing and reached 550 m a.s.l. ($n = 1$) in 2023, up from a minimum of 238 ± 115 m a.s.l. ($n = 3$) in 2012. The low albedo values recorded in 2023 are likely to be the consequence of low rates of snowfall and the occurrence of localised dust storms in the archipelago's extensive proglacial regions, which will likely exacerbate future melt rates, especially if albedo continues to decline.

Some remarkable changes to glaciers have occurred recently on the James Ross Archipelago. Swift Glacier has receded by 4.2 km since 2011, 3.3 km of which occurred in 2018/19. This is among the fastest glacier recession rates observed anywhere globally. We interpret this recession to be the result of rising air and ocean temperatures, as well as a disconnection from the Mount Haddington Ice Cap. This dramatic loss of ice highlights the non-linearity of glacier recession that can be experienced by ice cap outlet glaciers draining from plateaux edges. It illustrates the vulnerability of other glaciers on the southern and eastern coasts of James Ross Island to becoming disconnected from the Mount Haddington Ice Cap, which will fundamentally change outlet glacier dynamics and in combination reduce glacier longevity from that previously supposed.

Kotick Glacier increased in velocity in the terminus region from 41 ± 29 m yr^{-1} to 130 ± 29 m yr^{-1} between 2014 and 2015 (Gardner, 2018). This tripling of frontal velocity, combined with the rapid terminus position advance and formation of a bulge (increase) in ice surface elevation near the terminus, leads us to conclude that this is, to the best of our knowledge, the first surge-type glacier to have been identified in Antarctica from velocity and surface elevation change data. The cause of an advance of the terminus position of Whisky Glacier is less clear, and further research should be conducted to monitor future changes in its frontal position and velocity.

Overall, future research should seek to monitor albedo and equilibrium line altitude in situ. More attention should be given to the glaciers on the south of James Ross Island that are at risk of glacier disconnections. Future numerical modelling efforts should include the possibility of (more) extreme air temperatures in the future and of non-linear threshold processes and feedbacks associated with glacier recession (e.g. through the use of ice-dynamical models instead of surface mass balance models based on a fixed geometry).

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/jog.2025.10075.

Data availability statement. The code to calculate albedo is available here: https://code.earthengine.google.com/80a2062a5a05c33c31406027e01e2e04. Other data from this study are available in the supplementary material, including the glacier outlines produced.

Acknowledgements. This work was supported by the Leeds-York-Hull NERC Doctoral Training Partnership (DTP) Panorama under grant number NE/S007458/1. The Czech Science Foundation (project number GC20-20240S) funded the glaciological and meteorological monitoring. The Czech Antarctic Research Programme provided logistics and accommodation to support C.D.S., Z.E., M.M. and K.L. at JGM in 2022 and M.M. in 2023. We also thank the reviewers for their constructive and insightful comments.

Author contributions. C.D.S. designed and led the study, produced the albedo results and prepared the manuscript. M.W.M. produced results. J.L.C. produced area results, provided ongoing advice to C.D.S. and, with D.N., edited the first full draft of the manuscript. Z.E. produced the ablation results. K.L. and M.M. produced the meteorological results. C.H. provided velocity data. D.N., D.J.Q. and B.J.D. provided text edits of the manuscript before submission. C.D.S. completed this work as part of a PhD, supervised by J.L.C., D.J.Q. and D.N. All authors contributed to writing the final version of the manuscript.

References

Adakudlu M and 41 others (2019) *Climate in Svalbard 2100*. The Norwegian Centre for Climate Services (NCCS). https://www.miljodirektoratet.no/globalassets/publikasjoner/m1242/m1242.pdf.

Åkesson H, Nisancioglu KH, Giesen RH and Morlighem M (2017) Simulating the evolution of Hardangerjøkulen ice cap in southern Norway since the mid-Holocene and its sensitivity to climate change. *Cryosphere* **11**(1), 281–302. doi:10.5194/tc-11-281-2017

Ambrozova K, Laska K, Hrbacek F, Kavan J and Ondruch J (2019) Air temperature and lapse rate variation in the ice-free and glaciated areas of Northern James Ross Island, Antarctic Peninsula, during 2013–2016. *International Journal of Climatology* **39**(2), 643–657. doi:10.1002/joc.5832

Arndt KA and 8 others (2019) Arctic greening associated with lengthening growing seasons in Northern Alaska. *Environmental Research Letters* **14**(12), 125018. doi:10.1088/1748-9326/ab5e26

Banwell AF and 7 others (2021) The 32-year record-high surface melt in 2019/2020 on the northern George VI Ice Shelf, Antarctic Peninsula. *Cryosphere* **15**(2), 909–925. doi:10.5194/tc-15-909-2021

Batchelor CL and 7 others (2023) Rapid, buoyancy-driven ice-sheet retreat of hundreds of metres per day. *Nature* **617**(7959), 105–110. doi:10.1038/s41586-023-05876-1

Bell RE, Banwell AF, Trusel LD and Kingslake J (2018) Antarctic surface hydrology and impacts on ice-sheet mass balance. *Nature Climate Change* **8**(12), 1044–1052. doi:10.1038/s41558-018-0326-3

Benn DI (2021) Surging glaciers in Scotland. *Scottish Geographical Journal* **137**(1–4), 1–40. doi:10.1080/14702541.2021.1922738

Benn DI, Fowler AC, Hewitt I and Sevestre H (2019) A general theory of glacier surges. *Journal of Glaciology* **65**(253), 701–716. doi:10.1017/jog.2019.62

Bevan S, Luckman A, Hendon H and Wang G (2020) The 2020 Larsen C Ice Shelf surface melt is a 40-year record high. *The Cryosphere* **14**(10), 3551–3564. doi:10.5194/tc-14-3551-2020

Błaszczyk M and 12 others (2021) Factors controlling terminus position of Hansbreen, a Tidewater Glacier in Svalbard. *Journal of Geophysical Research: Earth Surface* **126**(2), e2020JF005763. doi:10.1029/2020JF005763

Błaszkiewicz M, Andrzejewski L, Dudek J, Sobota I and Czarnecki K (2023) The role of dead ice in transforming glacier forelands under the rapid climate warming of recent decades, Oscar II Land, Svalbard. *Land Degradation & Development* **34**(14), 4328–4345. doi:10.1002/ldr.4780

Boston CM and Lukas S (2019) Topographic controls on plateau icefield recession: Insights from the Younger Dryas Monadhliath Icefield, Scotland. *Journal of Quaternary Science* **34**(6), 433–451. doi:10.1002/jqs.3111

Carr JR, Stokes ChrisR and Vieli A (2017) Threefold increase in marine-terminating outlet glacier retreat rates across the Atlantic Arctic: 1992–2010. *Annals of Glaciology* **58**(74), 72–91. doi:10.1017/aog.2017.3

Carr R, Murphy Z, Nienow P, Jakob L and Gourmelen N (2023) Rapid and synchronous response of outlet glaciers to ocean warming on the Barents Sea coast, Novaya Zemlya. *Journal of Glaciology*, 1–35. doi:10.1017/jog.2023.104

Carrasco JF, Bozkurt D and Cordero RR (2021) A review of the observed air temperature in the Antarctic Peninsula. Did the warming trend come back after the early 21st hiatus? *Polar Science* **28**, 100653. doi:10.1016/j.polar.2021.100653

Carrasco JF and Cordero RR (2020) Analyzing precipitation changes in the northern tip of the antarctic peninsula during the 1970–2019 period. *Atmosphere* **11**(12), 1–19. doi:10.3390/atmos11121270

Carrivick JL, Brown LE, Hannah DM and Turner AGD (2012a) Numerical modelling of spatio-temporal thermal heterogeneity in a complex river system. *Journal of Hydrology* **414–415**, 491–502. doi:10.1016/j.jhydrol.2011.11.026

Carrivick JL, Davies BJ, Glasser NF, Nývlt D and Hambrey MJ (2012b) Late-Holocene changes in character and behaviour of land-terminating glaciers on James Ross Island, Antarctica. *Journal of Glaciology* **58**(212), 1176–1190. doi:10.3189/2012JoG11J148

Carrivick JL and Rushmer EL (2009) Inter- And intra-catchment variations in proglacial Geomorphology: An example from Franz Josef glacier and fox glacier, New Zealand. *Arctic, Antarctic, and Alpine Research* **41**(1), 18–36. doi:10.1657/1523-0430-41.1.18

Carrivick JL, Smith MW, Sutherland JL and Grimes M (2023) Cooling glaciers in a warming climate since the Little Ice Age at Qaanaaq, northwest Kalaallit Nunaat (Greenland). *Earth Surface Processes and Landforms* **48**(13), 2446–2462. doi:10.1002/esp.5638

Carrivick JL and Tweed FS (2021) Deglaciation controls on sediment yield: Towards capturing spatio-temporal variability. *Earth-Science Reviews* **221**, 103809. doi:10.1016/j.earscirev.2021.103809

Chu VW, Smith LC, Rennermalm AK, Forster RR, Box JE and Reeh N (2009) Sediment plume response to surface melting and supraglacial lake drainages on the Greenland ice sheet. *Journal of Glaciology* **55**(194), 1072–1082. doi:10.3189/002214309790794904

Clarke GKC and Blake EW (1991) Geometric and thermal evolution of a surge-type glacier in its quiescent state: Trapridge Glacier, Yukon Territory, Canada, 1969–89. *Journal of Glaciology* **37**(125), 158–169. doi:10.3189/s002214300004291x

Colwell S (2013) Surface meteorology at British Antarctic Survey Stations, 1947-2013 [Data set]. *Polar Data Centre; British Antarctic Survey, Natural Environment Research Council*. doi:10.5285/569d53fb-9b90-47a6-b3ca-26306e696706

Cook AJ, Holland PR, Meredith MP, Murray T, Luckman A and Vaughan DG (2016) Ocean forcing of glacier retreat in the western Antarctic Peninsula. *Science* **353**(6296), 283–286. doi:10.1126/science.aae0017

Cook AJ and Vaughan DG (2010) Overview of areal changes of the ice shelves on the Antarctic Peninsula over the past 50 years. *Cryosphere* **4**(1), 77–98. doi:10.5194/tc-4-77-2010

Costi J and 7 others (2018) Estimating surface melt and runoff on the Antarctic Peninsula using ERA-Interim reanalysis data. *Antarctic Science* **30**(6), 379–393. doi:10.1017/S0954102018000391

Davies B and 9 others (2022) Topographic controls on ice flow and recession for Juneau Icefield (Alaska/British Columbia). *Earth Surface Processes and Landforms* **47**(9), 2357–2390. doi:10.1002/esp.5383

Davies B and 9 others (2024) Accelerating glacier volume loss on Juneau Icefield driven by hypsometry and melt-accelerating feedbacks. *Nature Communications* **15**(1), 5099. doi:10.1038/s41467-024-49269-y

Davies BJ, Carrivick JL, Glasser NF, Hambrey MJ and Smellie JL (2012) Variable glacier response to atmospheric warming, northern Antarctic Peninsula, 1988-2009. *Cryosphere* **6**(5), 1031–1048. doi:10.5194/tc-6-1031-2012

De Angelis H and Skvarca P (2003) Glacier surge after ice shelf collapse. *Science* **299**(5612), 1560–1562. doi:10.1126/science.1077987

DeConto RM and Pollard D (2016) Contribution of Antarctica to past and future sea-level rise. *Nature* **531**(7596), 591–597. doi:10.1038/nature17145

Dumont M and 6 others (2012) Linking glacier annual mass balance and glacier albedo retrieved from MODIS data. *The Cryosphere* **6**(6), 1527–1539. doi:10.5194/tc-6-1527-2012

Edwards TL and 83 others (2021) Projected land ice contributions to twenty-first-century sea level rise. *Nature* **593**(7857), 74–82. doi:10.1038/s41586-021-03302-y

Engel Z, Kropáček JAN and Smolíková J (2019) Surface elevation changes on Lachman Crags ice caps (north-eastern Antarctic Peninsula) since 1979 indicated by DEMs and ICESat data. *Journal of Glaciology* **65**(251), 410–421. doi:10.1017/jog.2019.19

Engel Z, Láska K, Kavan J and Smolíková J (2023) Persistent mass loss of Triangular Glacier, James Ross Island, north-eastern Antarctic Peninsula. *Journal of Glaciology* **69**(273), 27–39. doi:10.1017/jog.2022.42

Engel Z, Láska K, Nývlt D and Stachoň Z (2018) Surface mass balance of small glaciers on James Ross Island, north-eastern Antarctic Peninsula, during 2009-2015. *Journal of Glaciology* **64**(245), 349–361. doi:10.1017/jog.2018.17

Engel Z, Láska K, Smolíková J and Kavan J (2024) Recent change in surface mass-balance trends of glaciers on james ross Island, North-Eastern Antarctic Peninsula. *Journal of Glaciology*, 1–15. doi:10.1017/jog.2024.16

England MR, Eisenman I, Lutsko NJ and Wagner TJW (2021) The Recent Emergence of Arctic Amplification. *Geophysical Research Letters* **48**(15), e2021GL094086. doi:10.1029/2021GL094086

Fan X, Duan Q, Shen C, Wu Y and Xing C (2020) Global surface air temperatures in CMIP6: Historical performance and future changes. *Environmental Research Letters* **15**(10), 104056. doi:10.1088/1748-9326/abb051

Fassnacht SR, Cherry ML and Venable NBH (2015) Snow and albedo climate change impacts across the United States Northern Great Plains. *Cryosphere Discussions* **9**(3), 3331–3349. doi:10.5194/tcd-9-3331-2015

Garbe J, Zeitz M, Krebs-Kanzow U and Winkelmann R (2023) The evolution of future Antarctic surface melt using PISM-dEBM-simple. *The Cryosphere* **17**(11), 4571–4599. doi:10.5194/tc-17-4571-2023

Gardner AS and 6 others (2018) Increased West Antarctic and unchanged East Antarctic ice discharge over the last 7 years. *The Cryosphere* **12**(2), 521–547.

Glasser NF and 6 others (2014) Ice-stream initiation, duration and thinning on James Ross Island, northern Antarctic Peninsula. *Quaternary Science Reviews* **86**, 78–88. doi:10.1016/j.quascirev.2013.11.012

Glasser NF, Scambos TA, Bohlander J, Truffer M, Pettit E and Davies BJ (2011) From ice-shelf tributary to tidewater glacier: Continued rapid recession, acceleration and thinning of Röhss Glacier following the 1995 collapse of the Prince Gustav Ice Shelf, Antarctic Peninsula. *Journal of Glaciology* **57**(203), 397–406. doi:10.3189/002214311796905578

Golledge NR, Everest JD, Bradwell T and Johnson JS (2010) Lichenometry on adelaide island, antarctic peninsula: Size-frequency studies, growth rates and snowpatches. *Geografiska Annaler: Series A, Physical Geography* **92**(1), 111–124. doi:10.1111/j.1468-0459.2010.00381.x

Gonçalves VN and 9 others (2022) Diversity and ecology of fungal assemblages present in lake sediments at Clearwater Mesa, James Ross Island, Antarctica, assessed using metabarcoding of environmental DNA. *Fungal Biology* **126**(10), 640–647. doi:10.1016/j.funbio.2022.08.002

Heller NE and Zavaleta ES (2009) Biodiversity management in the face of climate change: A review of 22 years of recommendations. *Biological Conservation* **142**(1), 14–32. doi:10.1016/j.biocon.2008.10.006

Hock R (2003) Temperature index melt modelling in mountain areas. *Journal of Hydrology* **282**(1–4), 104–115. doi:10.1016/S0022-1694(03)00257-9

Howat IM, Porter C, Smith BE, Noh M-J and Morin P (2019) The Reference Elevation Model of Antarctica. *The Cryosphere* **13**(2), 665–674. doi:10.5194/tc-13-665-2019.

Hrbáček F, Engel Z, Kňažková M and Smolíková J (2021) Effect of summer snow cover on the active layer thermal regime and thickness on CALM-S JGM site, James Ross Island, eastern Antarctic Peninsula. *Catena* **207**, 105608. doi:10.1016/j.catena.2021.105608

Hugonnet R and 10 others (2021) Accelerated global glacier mass loss in the early twenty-first century. *Nature* **592**(7856), 726–731. doi:10.1038/s41586-021-03436-z

Huss M, Bauder A and Funk M (2009) Homogenization of long-term mass-balance time series. *Annals of Glaciology* **50**(50), 198–206.

Jena B, Bajish CC, Turner J, Ravichandran M, Anilkumar N and Kshitija S (2022) Record low sea ice extent in the Weddell Sea, Antarctica in April/May 2019 driven by intense and explosive polar cyclones. *Npj Climate and Atmospheric Science* **5**(1), 19. doi:10.1038/s41612-022-00243-9

Johnson E and Rupper S (2020) An Examination of Physical Processes That Trigger the Albedo-Feedback on Glacier Surfaces and Implications for Regional Glacier Mass Balance Across High Mountain Asia. *Frontiers in Earth Science*, 8. doi:10.3389/feart.2020.00129

Jonsell UY, Navarro FJ, Bañón M, Lapazaran JJ and Otero J (2012) Sensitivity of a distributed temperature-radiation index melt model based on AWS observations and surface energy balance fluxes, Hurd Peninsula glaciers, Livingston Island, Antarctica. *Cryosphere* **6**(3), 539–552. doi:10.5194/tc-6-539-2012

Joughin I, Shapero D, Smith B, Dutrieux P and Barham M (2021) Ice-shelf retreat drives recent Pine Island Glacier speedup. *Science Advances* **7**(24), eabg3080. doi:10.1126/sciadv.abg3080.

Kaplan Pastíriková L, Hrbáček F, Uxa T and Láska K (2023) Permafrost table temperature and active layer thickness variability on James Ross Island, Antarctic Peninsula, in 2004–2021. *Science of the Total Environment* **869**, 161690. doi:10.1016/j.scitotenv.2023.161690

Kavan J, Hrbáček F and Stringer CD (2023) Proglacial streams runoff dynamics in Devil´s Bay, Vega Island, Antarctica. *Hydrological Sciences Journal* **68**(7), 967–981. doi:10.1080/02626667.2023.2195559

Kavan J and Nývlt D (2018) Where does the Antarctic fluvial suspended sediment come from? [Poster].

Kavan J, Nývlt D, Láska K, Engel Z and Kňažková M (2020) High-latitude dust deposition in snow on the glaciers of James Ross Island, Antarctica. *Earth Surface Processes and Landforms* **45**(7), 1569–1578. doi:10.1002/esp.4831

Kavan J and Strzelecki MC (2023) Glacier decay boosts the formation of new Arctic coastal environments—Perspectives from Svalbard. *Land Degradation & Development* **34**(12), 3467–3474. doi:10.1002/ldr.4695

Lee JR and 6 others (2017) Climate change drives expansion of Antarctic ice-free habitat. *Nature* **547**(7661), 49–54. doi:10.1038/nature22996

Lydersen C and 12 others (2014) The importance of tidewater glaciers for marine mammals and seabirds in Svalbard, Norway. *Journal of Marine Systems* **129**, 452–471. doi:10.1016/j.jmarsys.2013.09.006

Malmros JK, Mernild SH, Wilson R, Yde JC and Fensholt R (2016) Glacier area changes in the central Chilean and Argentinean Andes 1955-2013/14. *Journal of Glaciology* **62**(232), 391–401. doi:10.1017/jog.2016.43

Marinsek S and Ermolin E (2015) 10 year mass balance by glaciological and geodetic methods of Glaciar Bahía del Diablo, Vega Island, Antarctic Peninsula. *Annals of Glaciology* **56**(70), 141–146. doi:10.3189/2015AoG70A958

McGrath D, Sass L, O'Neel S, Arendt A and Kienholz C (2017) Hypsometric control on glacier mass balance sensitivity in Alaska and northwest Canada. *Earth's Future* **5**(3), 324–336. doi:10.1002/2016EF000479.

Meire L and 9 others (2023) Glacier retreat alters downstream fjord ecosystem structure and function in Greenland. *Nature Geoscience* **16**(8), 671–674. doi:10.1038/s41561-023-01218-y

Mlčoch B, Nývlt D and Mixa P (2019) Geological map of James Ross Island–Northern part 1: 25,000. Praha: Czech Geological Survey.

Morris EM and Vaughan DG (2003) Spatial and temporal variation of surface temperature on the Antarctic peninsula And the limit of viability of ice shelves. *Antarctic Research Series* **79**(10.1029), 61–68. doi:10.1029/ar079p0061

Naegeli K and Huss M (2017) Sensitivity of mountain glacier mass balance to changes in bare-ice albedo. *Annals of Glaciology* **58**(75), 119–129. doi:10.1017/aog.2017.25

Naegeli K, Huss M and Hoelzle M (2019) Change detection of bare-ice albedo in the Swiss Alps. *The Cryosphere* **13**(1), 397–412. doi:10.5194/tc-13-397-2019.

Nedbalová L, Nývlt D, Kopáček J, Šobr M and Elster J (2013) Freshwater lakes of Ulu Peninsula, James Ross Island, north-east Antarctic Peninsula: Origin, geomorphology and physical and chemical limnology. *Antarctic Science* **25**(3), 358–372. doi:10.1017/S0954102012000934

Nichols RL (1973) Antarctic glacial surges? *Journal of Glaciology* **12**(66), 524–525. doi:10.3189/s0022143000031981

Nývlt D and 6 others (2016) Death age, seasonality, taphonomy and colonization of seal carcasses from Ulu Peninsula, James Ross Island, Antarctic Peninsula. *Antarctic Science* **28**(1), 3–16. doi:10.1017/S095410201500036X

Oerlemans J, Giesen RH and Van Den Broeke MR (2009) Retreating alpine glaciers: Increased melt rates due to accumulation of dust (Vadret da Morteratsch, Switzerland. *Journal of Glaciology* **55**(192), 729–736. doi:10.3189/002214309789470969

Olech M and Chwedorzewska KJ (2011) Short note: The first appearance and establishment of an alien vascular plant in natural habitats on the forefield of a retreating glacier in Antarctica. *Antarctic Science* **23**(2), 153–154. doi:10.1017/S0954102010000982

Oliva M and 7 others (2017) Recent regional climate cooling on the Antarctic Peninsula and associated impacts on the cryosphere. *Science of the Total Environment* **580**, 210–223. doi:10.1016/j.scitotenv.2016.12.030

Osborn TJ and 7 others (2021) Land Surface Air Temperature Variations Across the Globe Updated to 2019: The CRUTEM5 Data Set. *Journal of Geophysical Research: Atmospheres* **126**(2), e2019JD032352. doi:10.1029/2019JD032352

Palerme C, Genthon C, Claud C, Kay JE, Wood NB and L'Ecuyer T (2017) Evaluation of current and projected Antarctic precipitation in CMIP5 models. *Climate Dynamics* **48**(1), 225–239. doi:10.1007/s00382-016-3071-1

Paul F and 10 others (2017) Error sources and guidelines for quality assessment of glacier area, elevation change, and velocity products derived from satellite data in the Glaciers_cci project. *Remote Sensing of Environment* **203**, 256–275. doi:10.1016/j.rse.2017.08.038

Pfeffer WT and 19 others (2014) The randolph glacier inventory: A globally complete inventory of glaciers. *Journal of Glaciology* **60**(221), 537–552. doi:10.3189/2014JoG13J176

Rachlewicz G, Szczuciński W and Ewertowski M (2007) Post-"Little Ice Age" retreat rates of glaciers around Billefjorden in central Spitsbergen, Svalbard. *Polish Polar Research* **28**(3), 159–186.

Raup B, Racoviteanu A, Khalsa SJS, Helm C, Armstrong R and Arnaud Y (2007) The GLIMS geospatial glacier database: A new tool for studying glacier change. *Global and Planetary Change* **56**(1–2), 101–110. doi:10.1016/j.gloplacha.2006.07.018

RGI 7.0 Consortium (2023) Randolph Glacier Inventory - A Dataset of Global Glacier Outlines, Version 7.0. In *Nsidc*. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center.

Rignot E, Casassa G, Gogineni P, Krabill W, Rivera A and Thomas R (2004) Accelerated ice discharge from the Antarctic Peninsula following the collapse of Larsen B ice shelf. *Geophysical Research Letters* **31**(18), L18401. doi:10.1029/2004GL020697.

Riihelä A, Bright RM and Anttila K (2021) Recent strengthening of snow and ice albedo feedback driven by Antarctic sea-ice loss. *Nature Geoscience* **14**(11), 832–836. doi:10.1038/s41561-021-00841-x

Rippin DM, Sharp M, Van Wychen W and Zubot D (2020) 'Detachment' of icefield outlet glaciers: Catastrophic thinning and retreat of the Columbia Glacier (Canada). *Earth Surface Processes and Landforms* **45**(2), 459–472. doi:10.1002/esp.4746

Schomacker A and Kjær KH (2008) Quantification of dead-ice melting in ice-cored moraines at the high-Arctic glacier Holmströmbreen, Svalbard. *Boreas* **37**(2), 211–225. doi:10.1111/j.1502-3885.2007.00014.x

Sevestre H and Benn DI (2015) Climatic and geometric controls on the global distribution of surge-type glaciers: Implications for a unifying model of surging. *Journal of Glaciology* **61**(228), 646–662. doi:10.3189/2015JoG14J136

Siegert MJ and 13 others (2023) Antarctic extreme events. *Frontiers in Environmental Science* **11**. doi:10.3389/fenvs.2023.1229283 https://www.frontiersin.org/articles/10.3389/fenvs.2023.1229283

Skvarca P, Rott H and Nagler T (1995) Satellite imagery, a base line for glacier variation study on James Ross Island, Antarctica. *Annals of Glaciology* **21**, 291–296. doi:10.3189/s0260305500015962

Smellie JL (2013) Geological map of James Ross Island 1. James Ross Island Volcanic Group. *BAS GEOMAP 2 Series, Sheet 5, British Antarctic Survey, Cambridge*. https://www.bas.ac.uk/data/our-data/publication/geological-map-of-james-ross-island-i-james-ross-island/ (accessed 1 October 2023).

Stringer CD and 9 others (2024) Quantifying sediment sources, pathways, and controls on fluvial transport dynamics on James Ross Island, Antarctica. *Journal of Hydrology* **635**, 131157. doi:10.1016/j.jhydrol.2024.131157

Szeligowska M and 7 others (2021) The interplay between plankton and particles in the Isfjorden waters influenced by marine- and land-terminating glaciers. *Science of the Total Environment* **780**, 146491. doi:10.1016/j.scitotenv.2021.146491

Taylor LS, Quincey DJ, Smith MW, Potter ER, Castro J and Fyffe CL (2022) Multi-decadal glacier area and mass balance change in the Southern Peruvian Andes. *Frontiers in Earth Science*, 10. doi:10.3389/feart.2022.863933

Thibert E, Blanc R, Vincent C and Eckert N (2008) Glaciological and volumetric mass-balance measurements: Error analysis over 51 years for Glacier de Sarennes, French Alps. *Journal of Glaciology* **54**(186), 522–532. doi:10.3189/002214308785837093

Traversa G, Fugazza D, Senese A and Frezzotti M (2021) Landsat 8 oli broadband albedo validation in Antarctica and Greenland. *Remote Sensing* **13**(4), 1–19. doi:10.3390/rs13040799

Tuckett PA and 6 others (2019) Rapid accelerations of Antarctic Peninsula outlet glaciers driven by surface melt. *Nature Communications* **10**(1), 4311. doi:10.1038/s41467-019-12039-2

Turner J, Marshall GJ, Clem K, Colwell S, Phillips T and Lu H (2020) Antarctic temperature variability and change from station data. *International Journal of Climatology* **40**(6), 2986–3007. doi:10.1002/joc.6378

Vaughan DG and 8 others (2003) Recent rapid regional climate warming on the Antarctic Peninsula. *Climatic Change* **60**(3), 243–274. doi:10.1023/A:1026021217991

Wallis BJ, Hogg AE, van Wessem JM, Davison BJ and van den Broeke MR (2023) Widespread seasonal speed-up of west Antarctic Peninsula glaciers from 2014 to 2021. *Nature Geoscience* **16**(3), 231–237. doi:10.1038/s41561-023-01131-4

Wellman P (1982) Surging of Fisher Glacier, Eastern Antarctica: Evidence From Geomorphology. *Journal of Glaciology* **28**(98), 23–28. doi:10.3189/s0022143000011758

WGMS (2023) *Global Glacier Change Bulletin No. 5 (2020–2021)* Zemp, M, Gärtner-Roer, I, Nussbaumer, S.U, Welty, E.Z, Dussaillant, I, Bannwart, J. World Glacier Monitoring Service. Zurich, Switzerland.

Xu M and 6 others (2021) Dominant role of vertical air flows in the unprecedented warming on the Antarctic Peninsula in February 2020. *Communications Earth & Environment* **2**(1), 133. doi:10.1038/s43247-021-00203-w

Zekollari H, Huss M and Farinotti D (2020) On the Imbalance and Response Time of Glaciers in the European Alps. *Geophysical Research Letters* **47**(2), e2019GL085578. doi:10.1029/2019GL085578