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Distribution and seasonal evolution of supraglacial lakes on Shackleton Ice Shelf, East Antarctica

Jennifer Arthur[1], Chris Stokes[1], Stewart Jamieson[1], Rachel Carr[2], Amber Leeson[3]

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jennifer.arthur@durham.ac.uk
@AntarcticJenny

European Geosciences Union

1 Durham University 2 Newcastle University 3 Lancaster University NERC Science of the Environment IAPETUS Doctoral Training Partnership

Motivation

SGLs can cause ice shelves to flex when they pond and drain on their surfaces, which can weaken them and make them more prone to break-up[1]. However, lake observations in East Antarctica are lacking[2, 3] and so our understanding of seasonal lake behaviour and distribution remains limited.

Our aim is to investigate the long-term distribution and evolution of SGLs on Shackleton Ice Shelf.

Objectives

1. To analyse the intra-seasonal and inter-seasonal evolution in the spatial distribution, extent and volume of SGLs over multiple melt seasons from 2000 to 2020 using remote sensing.

2. To explore potential glaciological and climatic controls on SGL formation and distribution on this ice shelf to improve our understanding of its potential vulnerability.

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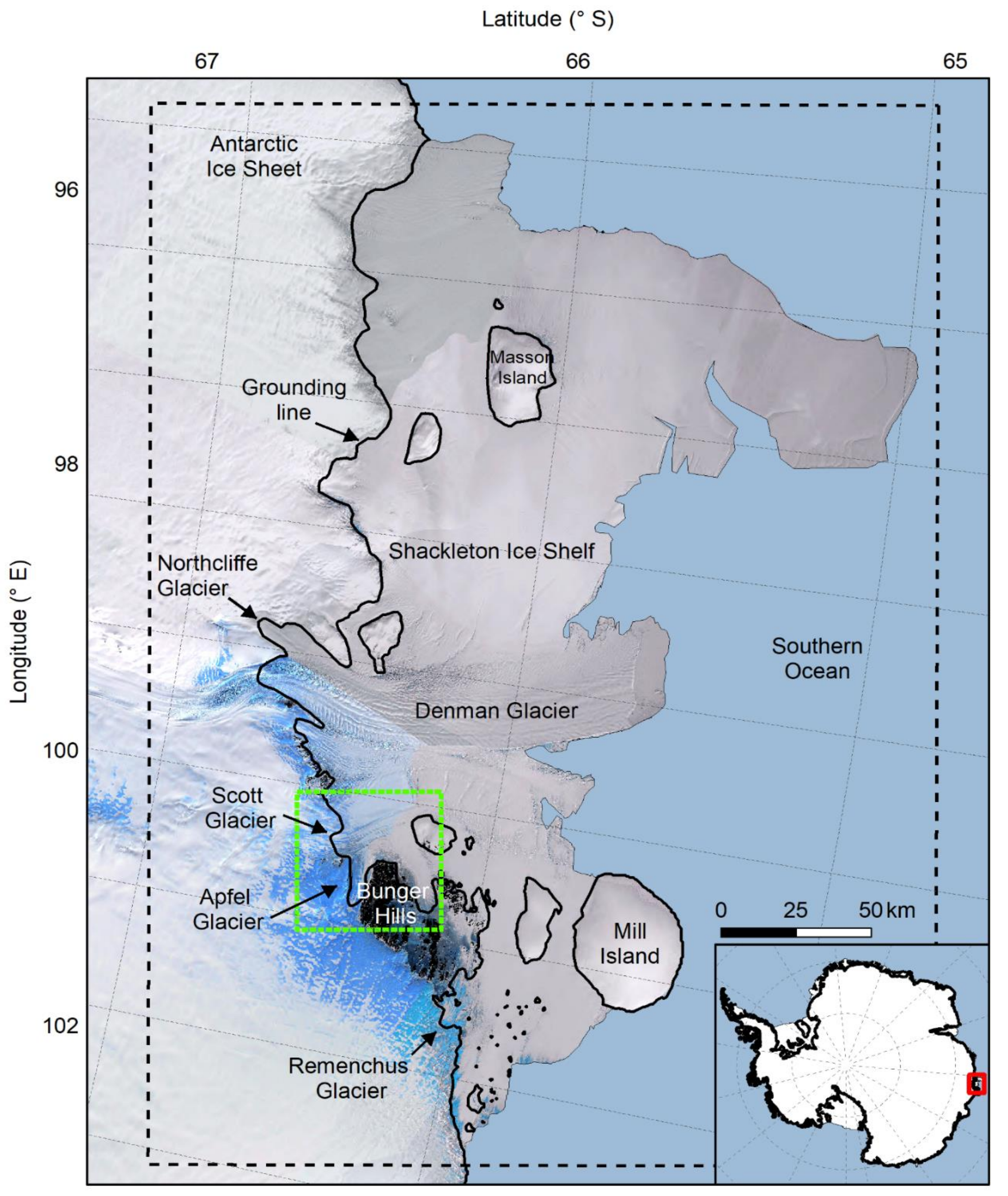
[1]Banwell et al. (2019), [2]Stokes et al. (2019), [3]Arthur et al. (2020)

Shackleton Ice Shelf

- Over 70% of the ice shelf area exerts a buttressing effect on its major outlet glaciers[1].
- Fed by Denman Glacier: catchment holds ice equivalent to ~1.5 m sea-level[2].
- Numerous pinning points.
- High surface melt rates (>200 mm w.e. yr $^{-1}$ in places)[3].
- Low firn air content[4].
- Potentially vulnerable to hydrofracturing.



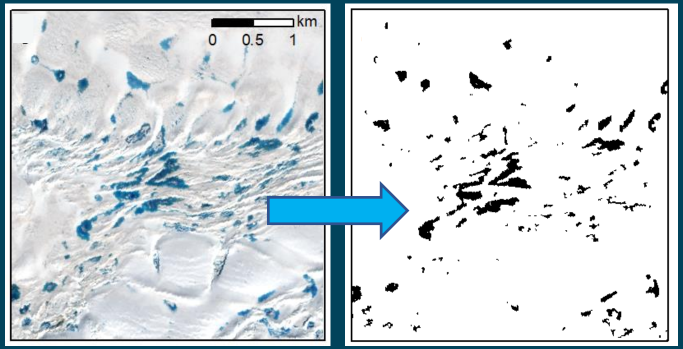
Green box = extent of lake area and volume analysis

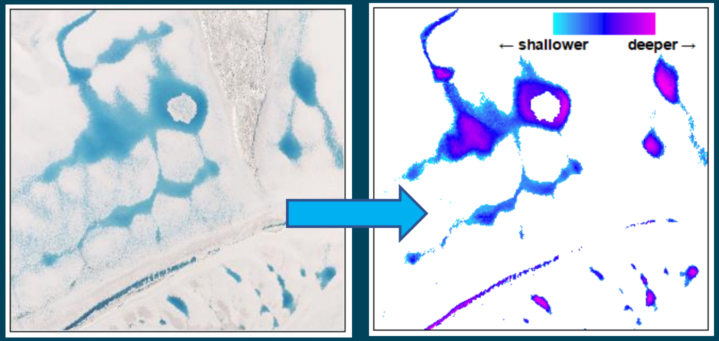
Black box = extent of ERA5 temperature data extraction

[1]Fürst et al. (2016)
[2]Morlighem et al. (2019).
[3]Trusel et al. (2013)
[4]Alley et al. (2018)

Remote sensing approach

Lake extents: NDWI $_{ice}$ (Sentinel 2, Landsat 8 & 7) → **Lake depths**: radiative transfer model[1, 2] → **Lake volumes** (pixel area x water depth within lake boundaries)





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Lake area, depth & volume **time series** from 2000 to 2020

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Near-surface temperature (ERA5) extraction over ice shelf

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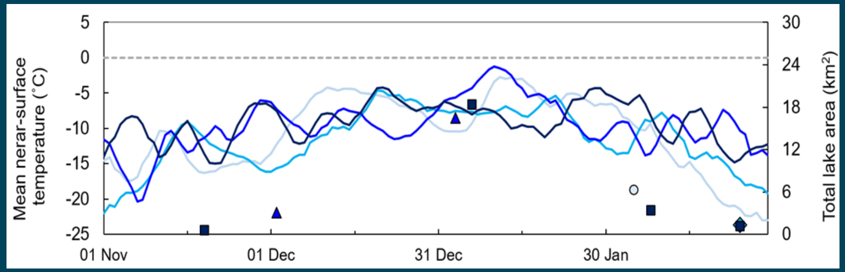

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Mean surface snowmelt and firn air content (RACMO)[3] extraction over ice shelf

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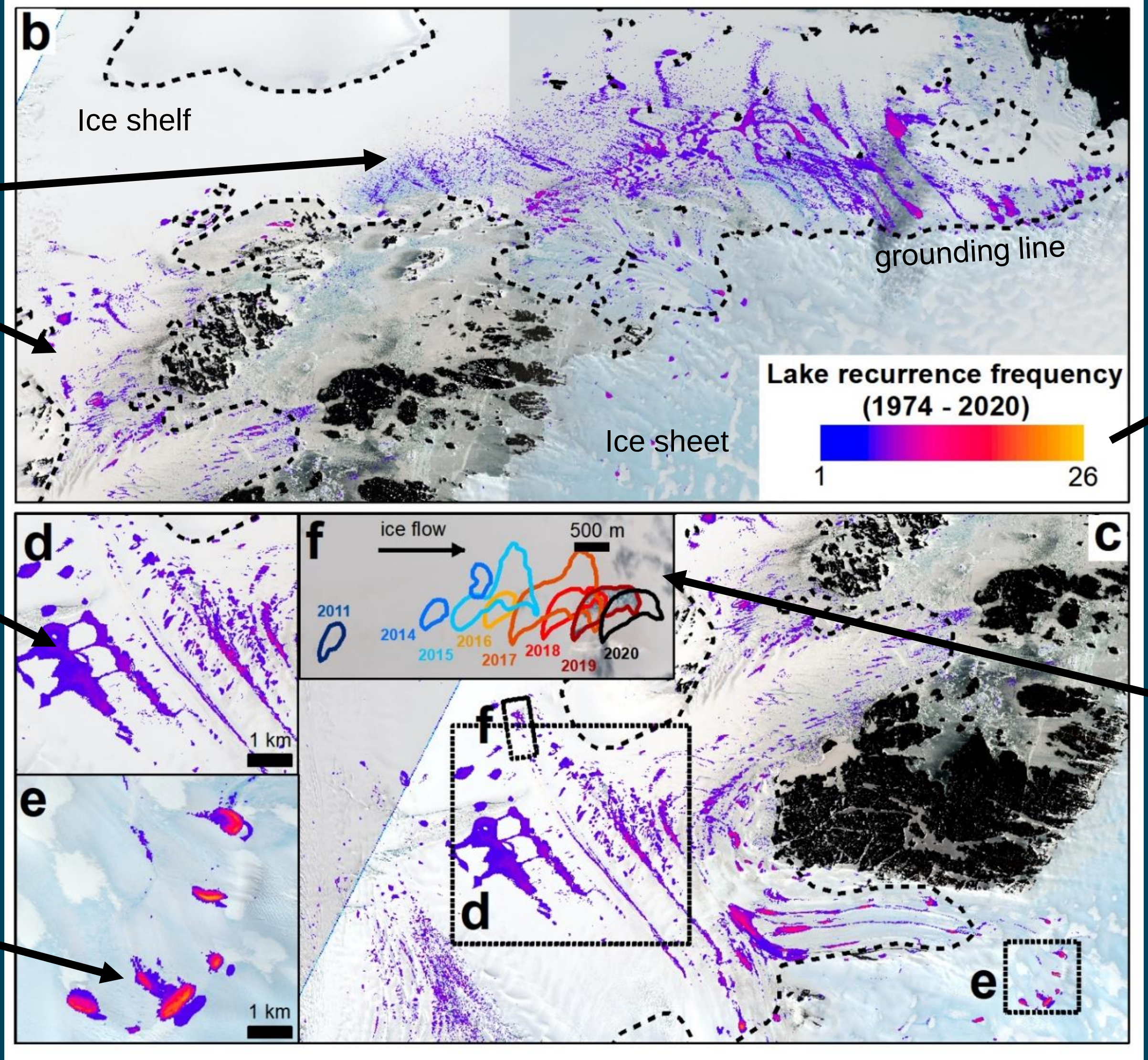
[1]Sneed and Hamilton (2007)
[2]Pope et al. (2016)
[3]van Wessem et al. (2018)

Results: spatial distribution

Lakes are clustered around the ice shelf grounding zone.

Largest recorded lake feature (11.96 km^2) formed January 2020.

Above the grounding line, lakes tend to re-occupy the same surface depressions every year.

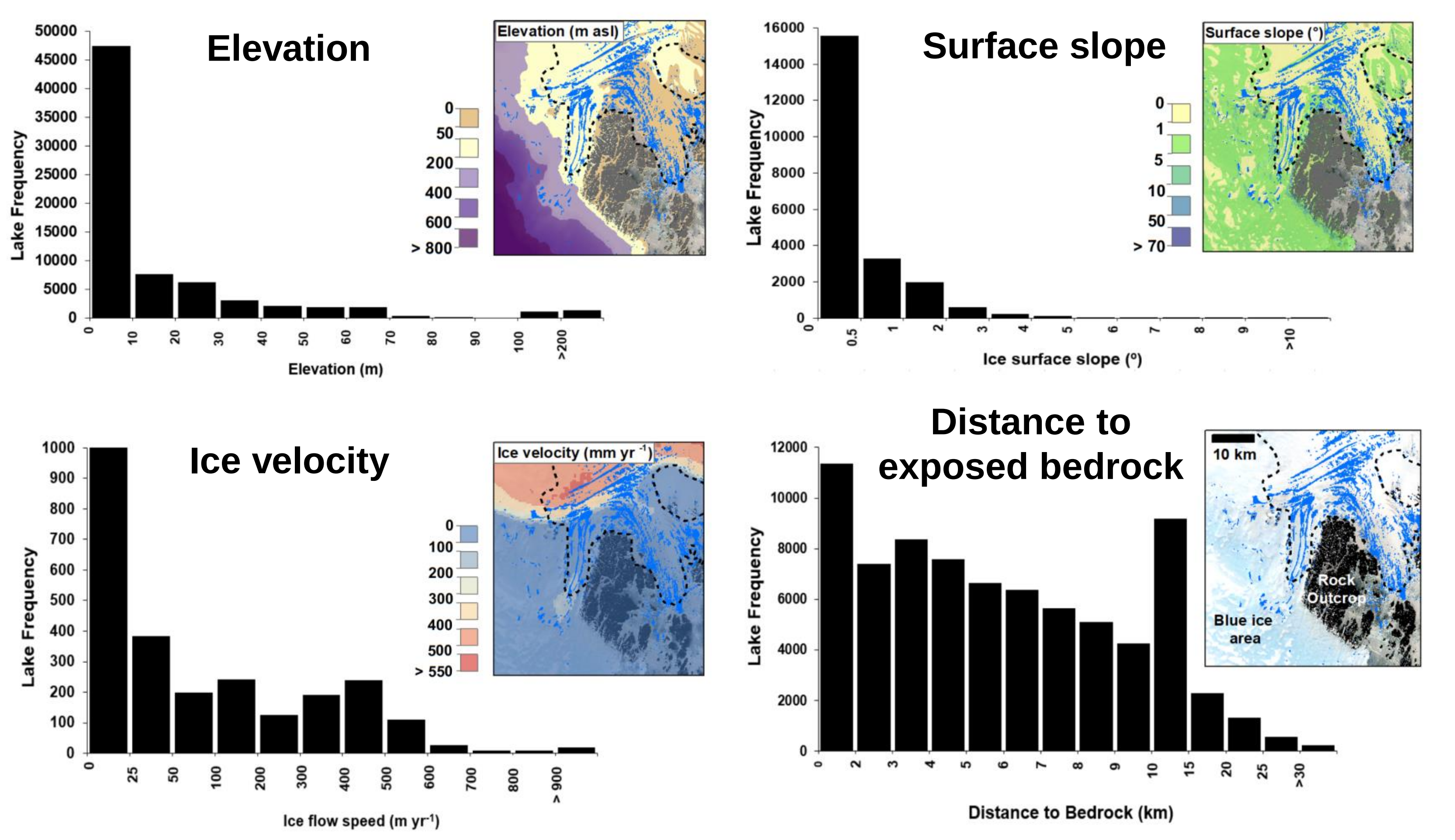


Number of times a lake was recorded in available cloud-free satellite scenes.

Lakes on the ice shelf are advected annually down-stream with ice flow.

Results: spatial distribution

Lakes preferentially form at low (≤10 m) elevations, on low (<1°) ice surface slopes, on slower-moving ice (<50 m yr $^{-1}$), and are found close to exposed bedrock and blue ice areas.

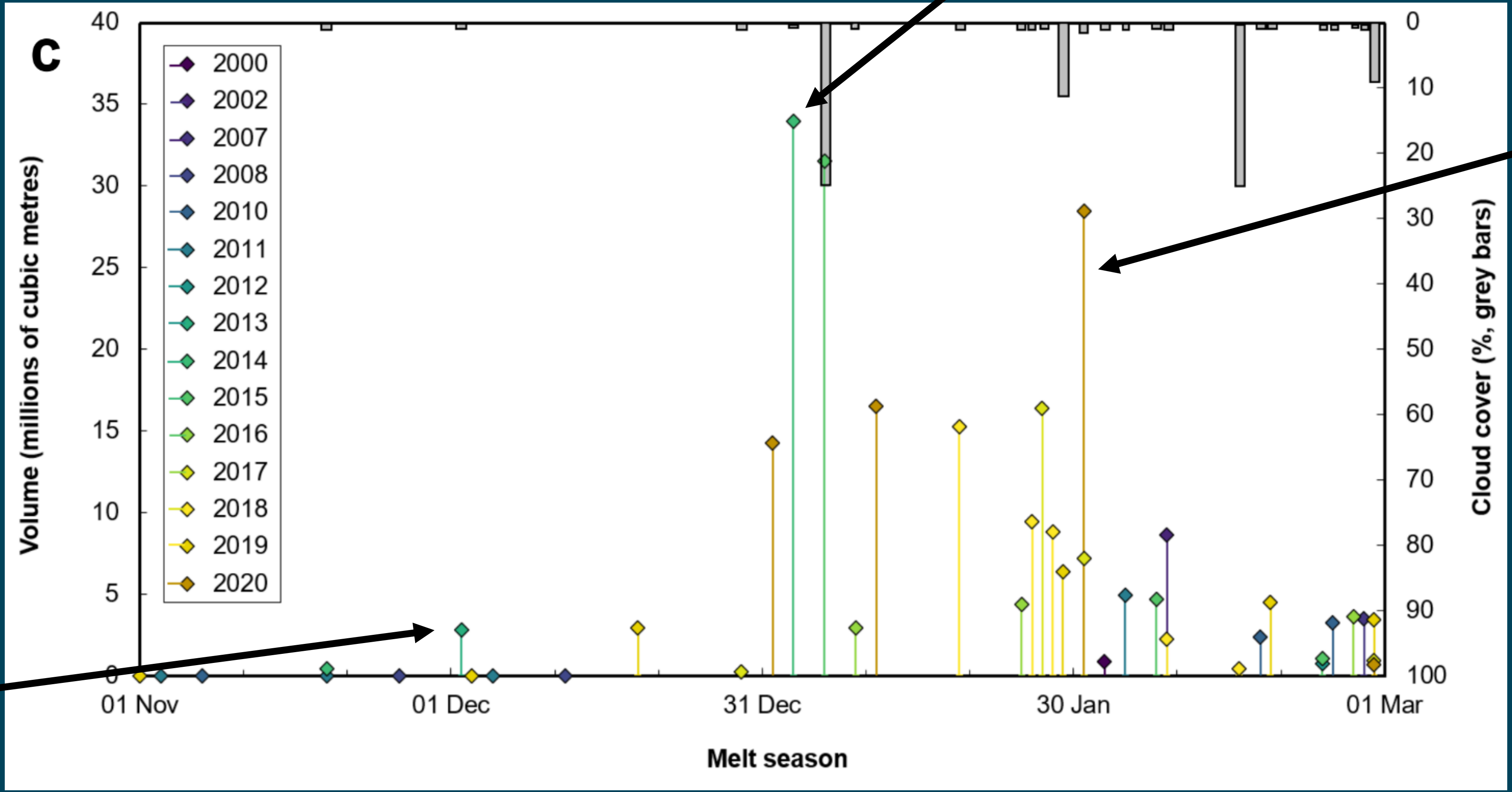


Results: seasonal evolution

Total lake volume reached a maximum of 28.4 x10^6 m^3 on 31st January 2020.

Peak melt-water storage is reached in early- to late-January.

Lakes start forming in late November.



In an average melt season, SGLs held a total meltwater volume of 7.45 x10^6 m^3.

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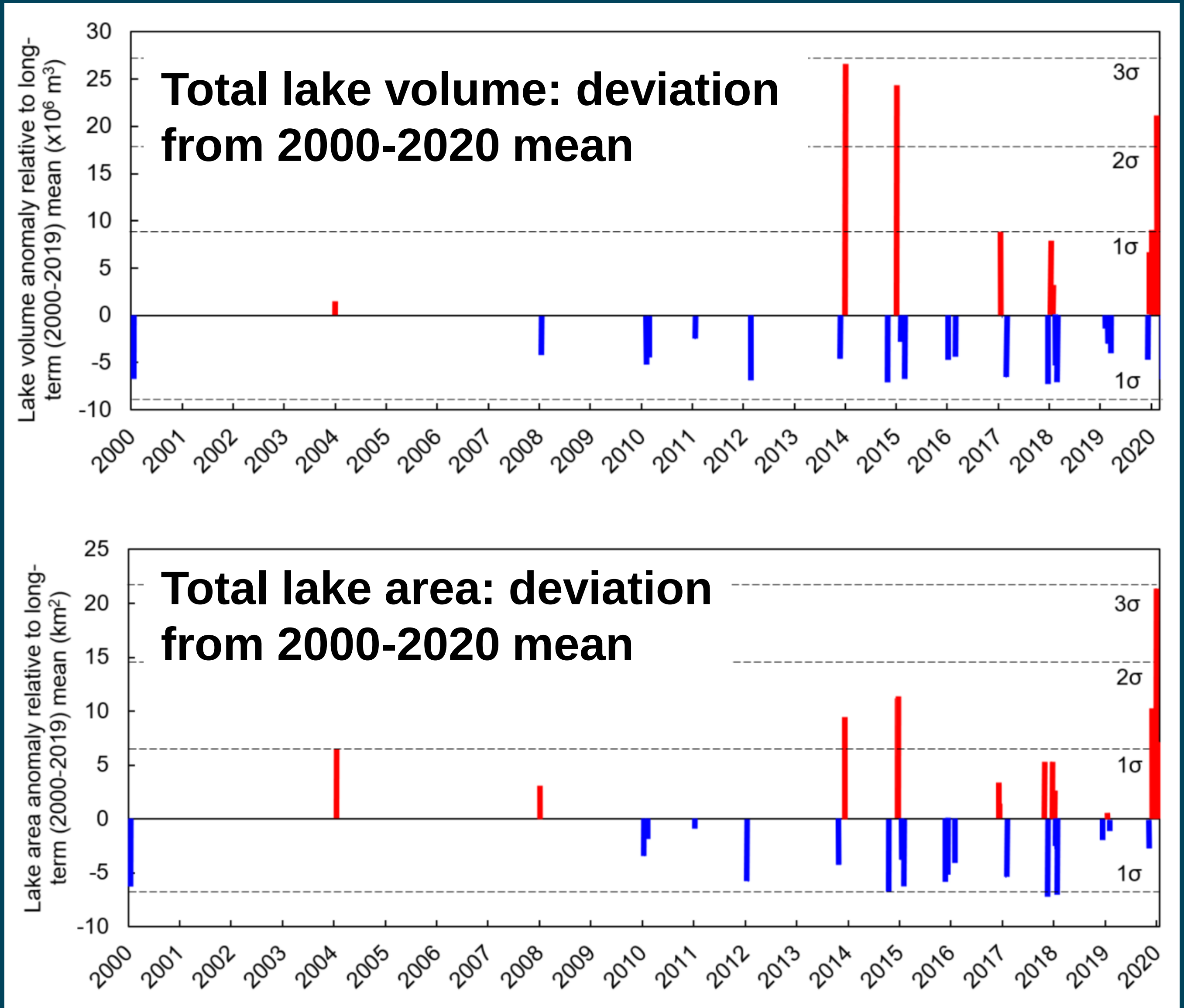
Results: longer-term lake evolution

2014, 2015, 2017, 2018 and 2020 = peak years of surface meltwater storage.

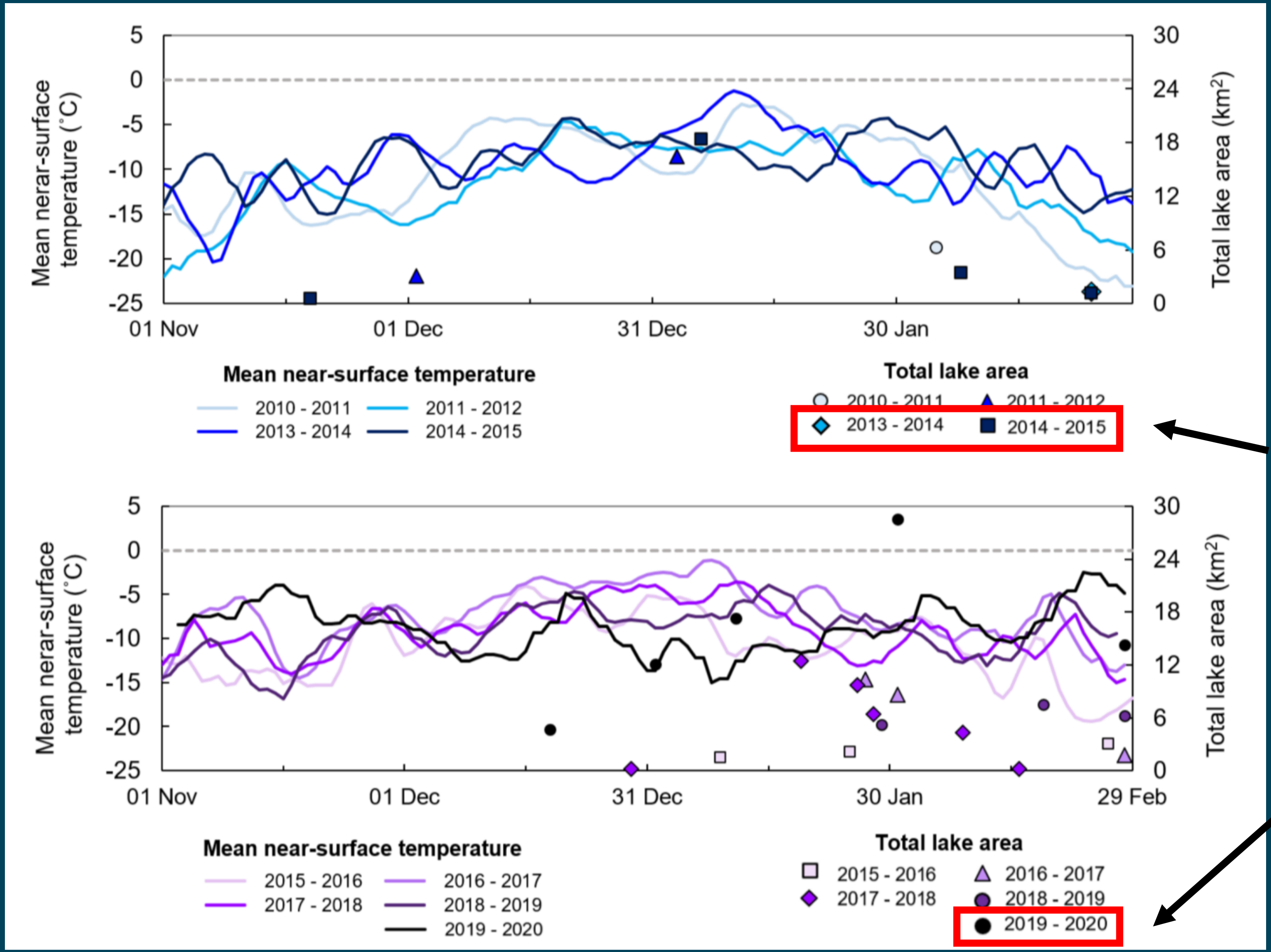
In these years:

- Total lake volume was up to 4.5 times higher than the long-term mean.
- Total lake area was up to 3.9 times higher than the long-term mean.



Results: lake evolution with climate

- Peaks in lake coverage only exhibit a weak relationship with near-surface temperature.
- Suggests other important controls on lake evolution.



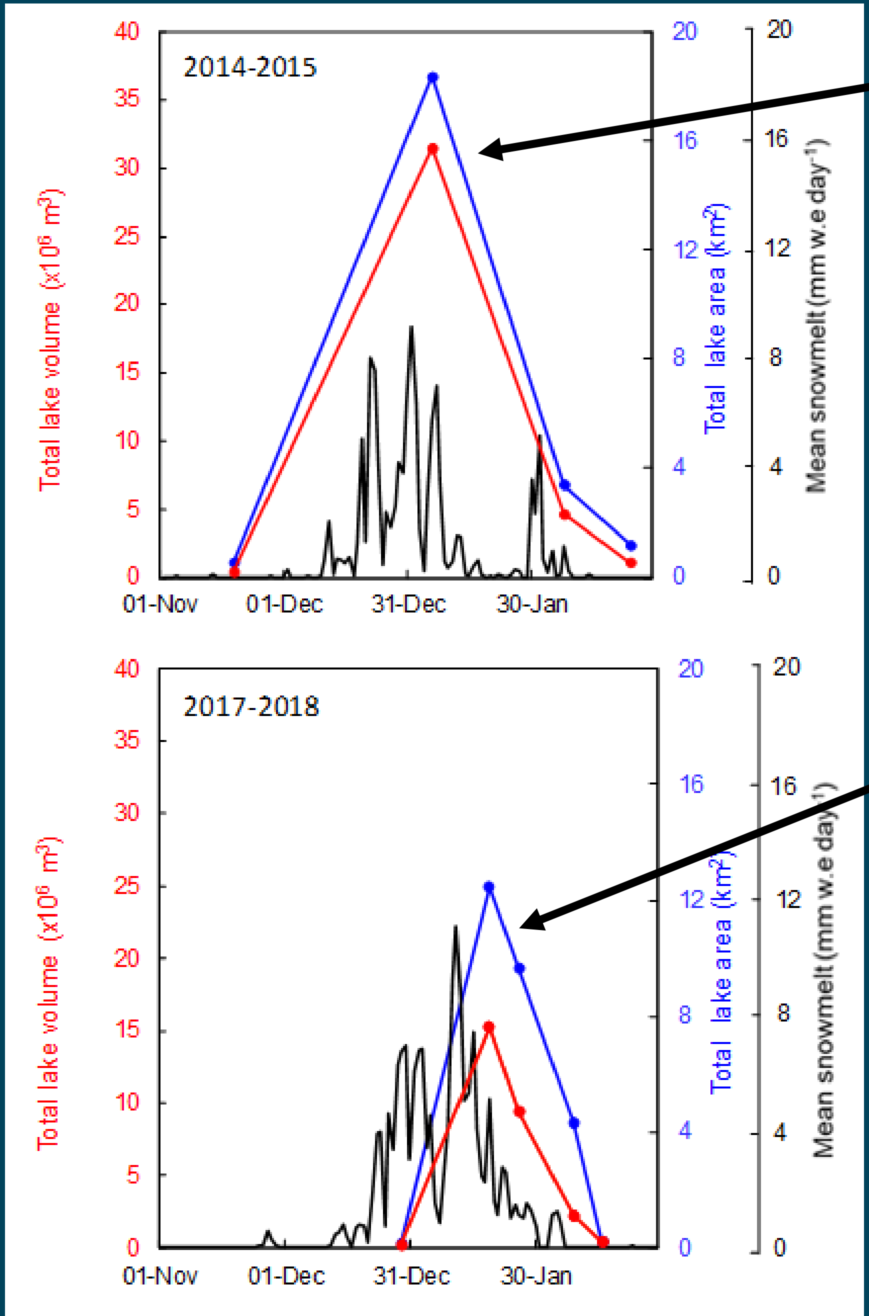
Warmer melt seasons ≠ more extensive lakes (e.g. 2014, 2015, 2020)

Results: relationship with surface melt

A correspondence between peak lake area, volume and surface melt is particularly apparent in 2014, 2015, 2017 and 2018.

Short-lived (≤1 week) intense (>4 mm w.e. day $^{-1}$) melt events appear to determine seasonal variability in lake extent and volume.

We suggest this is associated with katabatic wind-driven melting.



Total lake area and volume peak 5 days after a large surface melt event (9 mm w.e day $^{-1}$.

Total lake area and volume peak 8 days after a large surface melt event (11 mm w.e day $^{-1}$.

Conclusions

1. Lakes on Shackleton Ice Shelf cluster around the grounding line, controlled by localised albedo-lowering feedbacks (katabatic-driven melting, blue ice and exposed bedrock).

2. Lakes begin to form from mid-November and their total volume peaks in early-late January each year, which reached a maximum of 28.4 $x10^6$ m^3 on 31st January 2020.

3. Lakes were most extensive, deepest, and formed at the highest recorded elevation (527 m) in 2014, 2015, 2017, 2018 and 2020.

4. Short-lived high magnitude snowmelt events correspond with peak total lake area and volume during these years of high surface meltwater storage.

5. Seasonal variability in lake extents is more sensitive to the intensity of individual melt events rather than mean near-surface summer temperatures, which we suggest is driven by localised katabatic wind-induced melting.

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