A melt lake model for ice shelves

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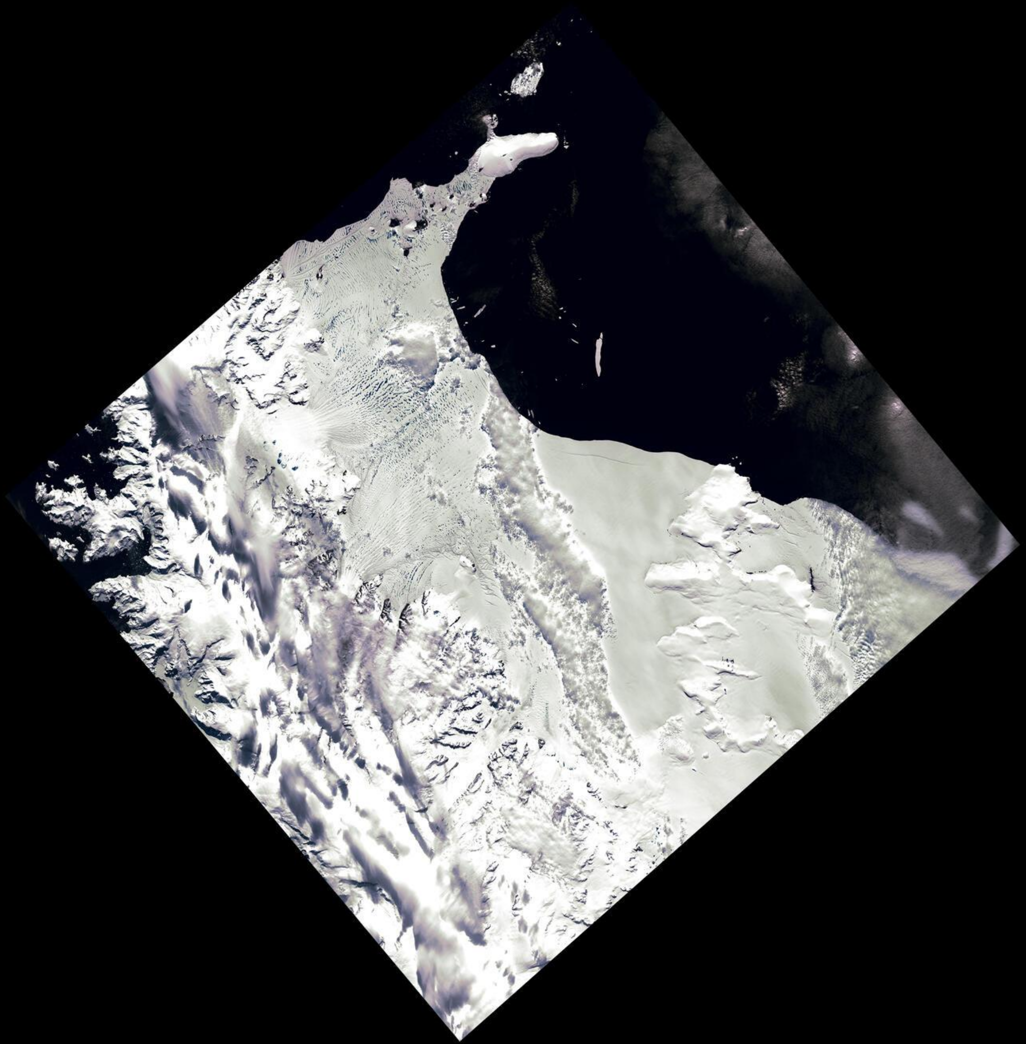
Image: NASA

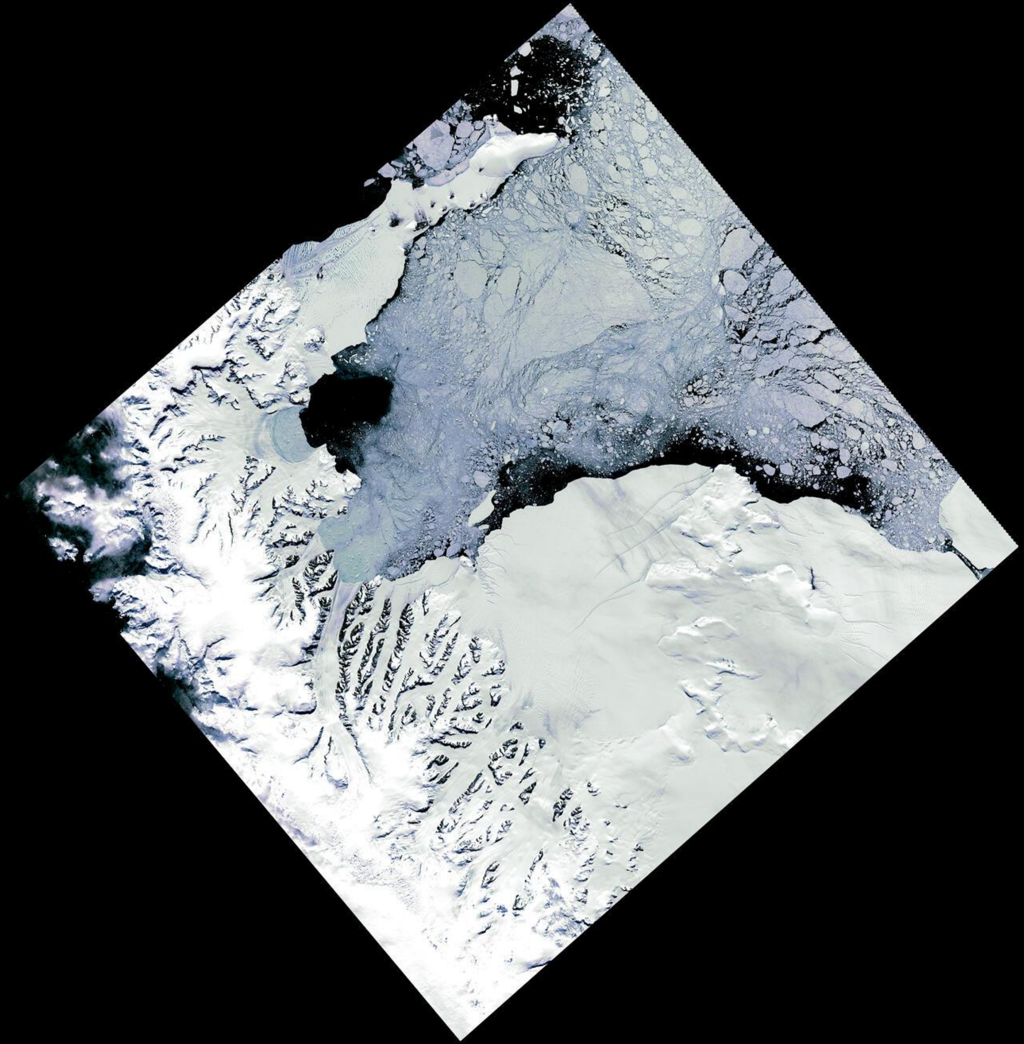
Melt lakes are linked to ice shelf collapse

- Water can propagate into cracks and weaken ice
- Ice shelf collapse leads to loss of buttressing of upstream glaciers
- Lowers albedo, accelerates melting
- Lakes present before Larsen B collapse in 2002



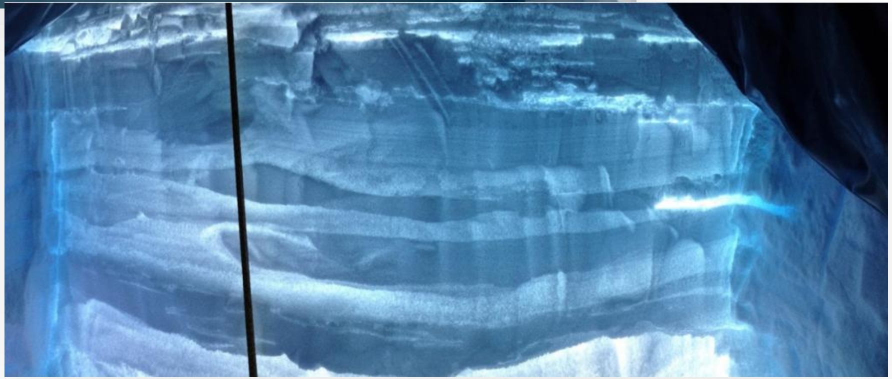
Larsen B ice shelf
31st December 2001

Landsat image from https://www.usgs.gov/



Larsen B ice shelf
18th December 2002

Landsat image from https://www.usgs.gov/



Ice lenses are precursors of melt lakes

- Snow pit on Larsen C Ice Shelf (2014–15) showing ice lenses
- Ice lenses are impermeable barriers needed for melt lake formation
- Formed by refreezing melt water

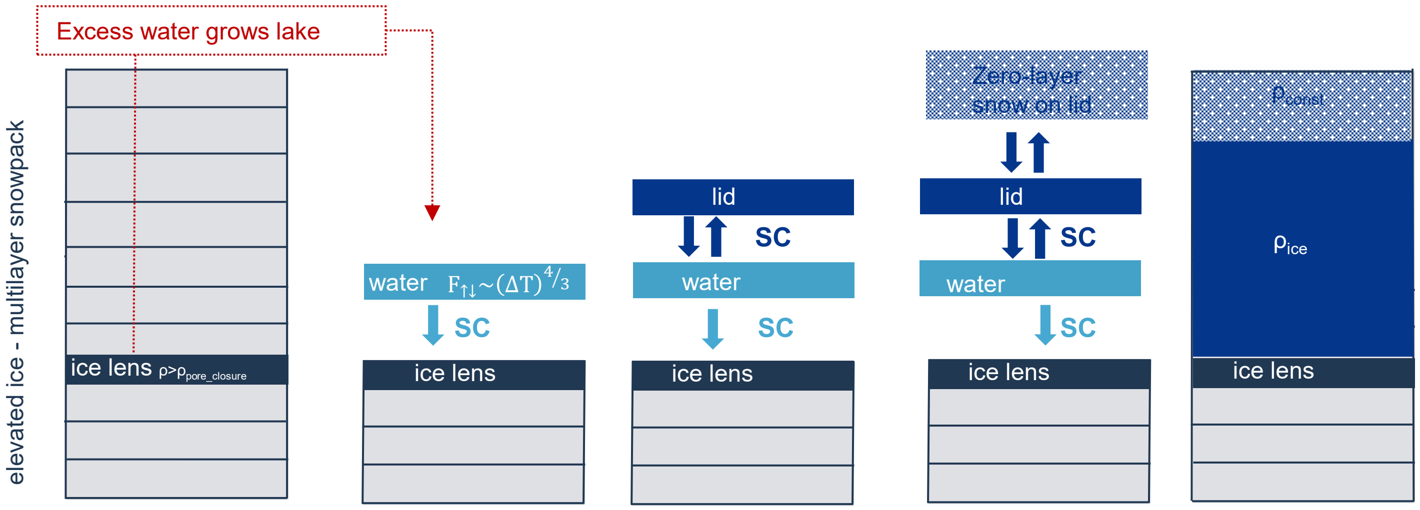
Image: A. Luckmann & B. Hubbard, MIDAS Project, extracted from Buzzard 2017, PhD thesis

MONARCHS melt lake model

- Formation, growth, and refreezing of surface melt lakes on ice shelves
- Surface energy balance, meltwater percolation, ice lenses formation
- Formation of frozen lid, which is injected back into the snowpack when lake fully freezes over

Buzzard et al. (2018) A Mathematical Model of Melt Lake Development on an Ice Shelf

1D melt lake model in JULES



SC = Stefan condition

If heat conducted away > heat supplied → freezing; reverse → melting

Lake water melts snowpack, decreasing sice, sliq, ds

4 states
1. multilayer snowpack
2. Exposed water
3. Frozen bare lid
4. Snow on lid

Adapted from MONARCHS model (Buzzard et al. 2018)

New snowpack percolation forms ice lens

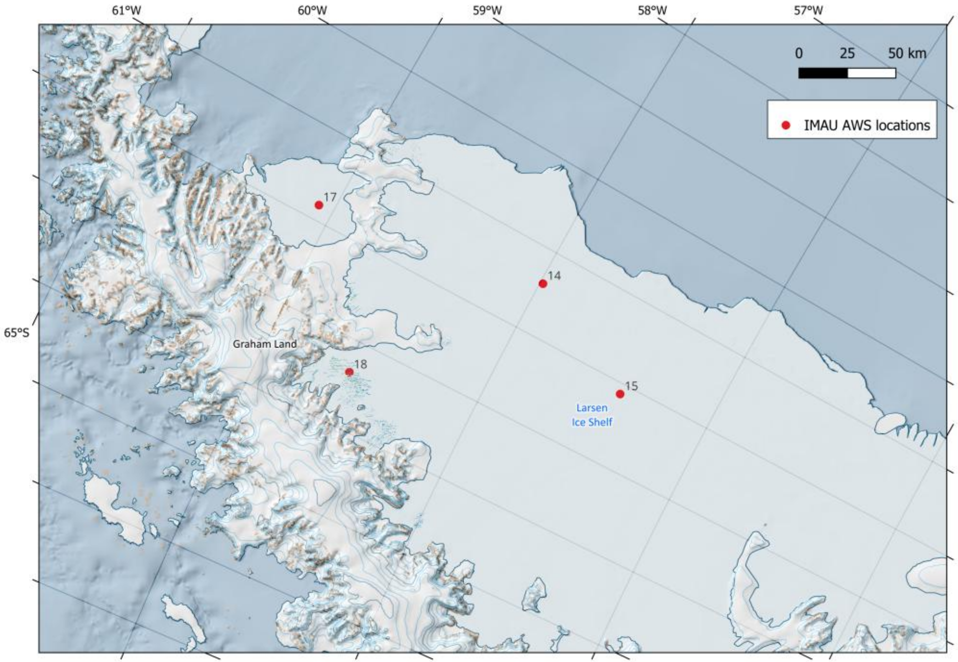
Default (open drain):

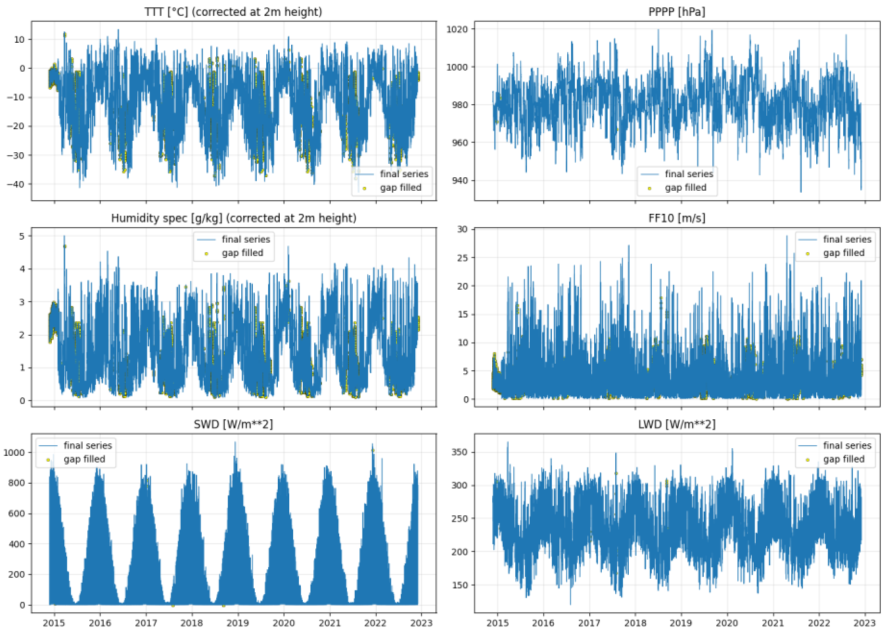
- Snow layers can hold fraction of liquid water (W_{cap})
- Excess liquid passed to layer below or out of snowpack as runoff

New scheme (blocked drain):

- Lens IF $\rho_{snow} > \rho_{pore\_closure}$
- Water accumulates above lens, filling up available pore space
- If layers above the lens are saturated, then excess water passed to the lake
- No lens, 5% liquid retained in the capillaries

1D test : West Larsen C

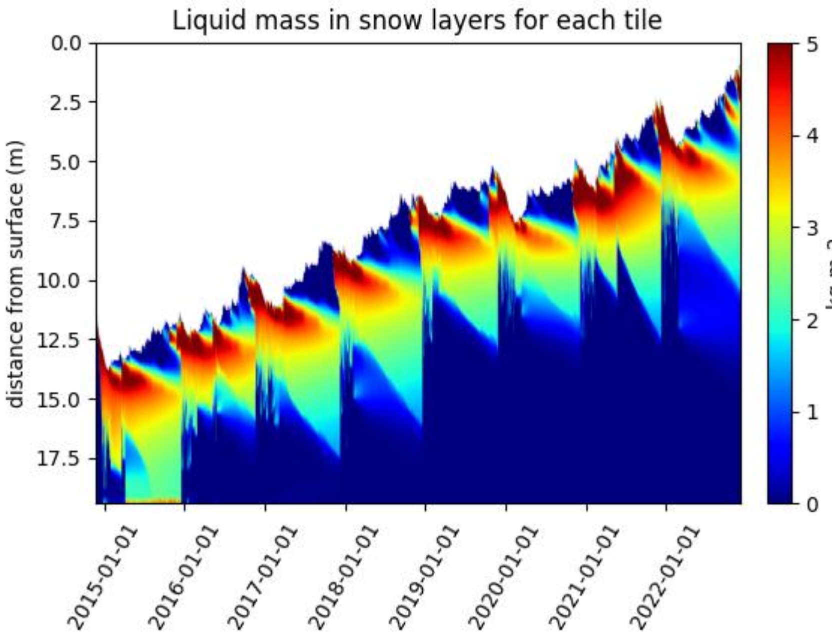




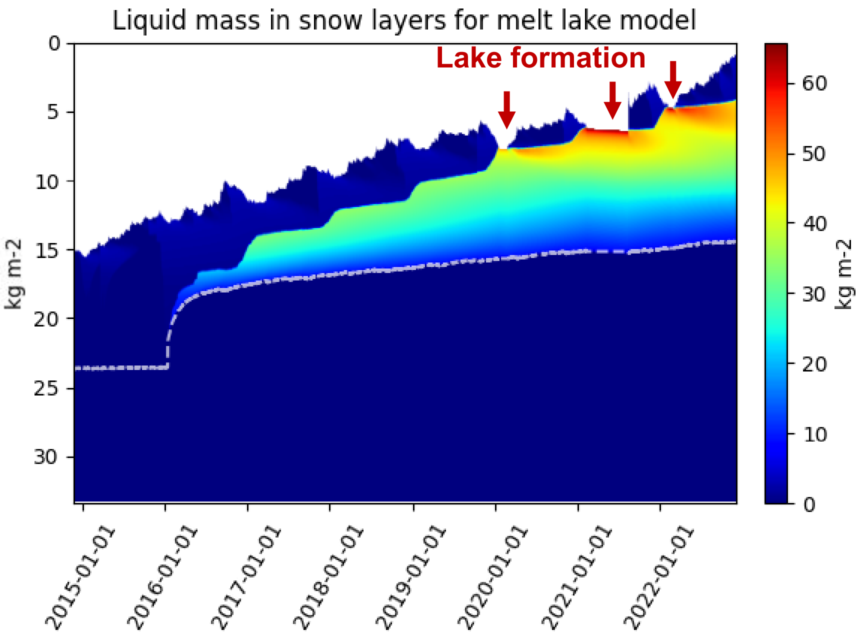
IMAU Antarctic automatic weather station data, Van Tiggelen et al., 2025
Precipitation not measured: use ERA5 rain + snowfall, LandSat8 + Sentinel 1 show lakes at site 18

Preliminary results : West Larsen C

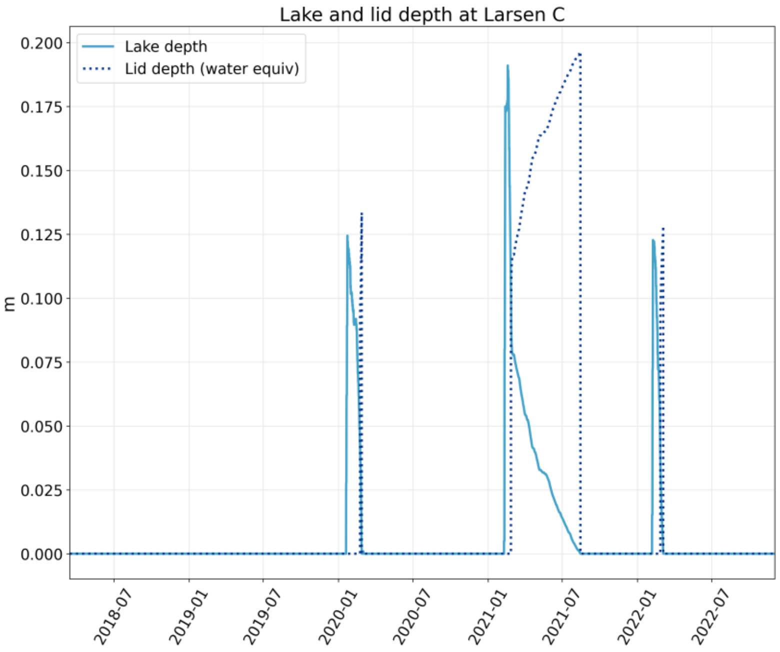
Old percolation



New percolation

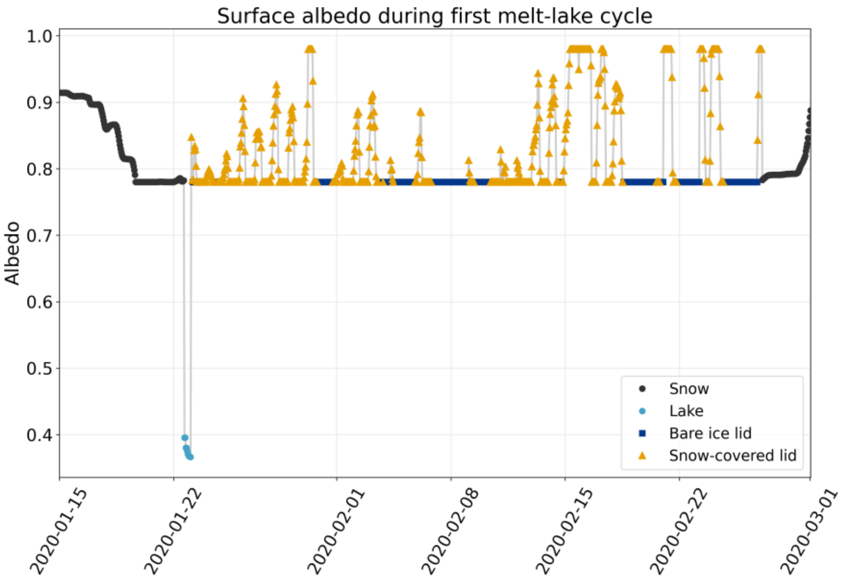


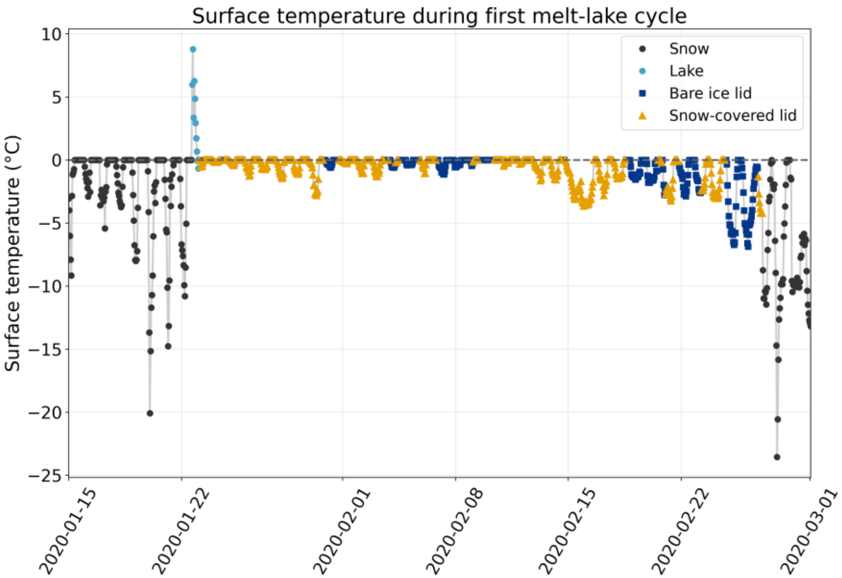
Preliminary results : West Larsen C



- 3 full lake cycles 2020 – 2022
- growth → refreezing → injection of ice & snow back into snowpack
- Lakes are unrealistically shallow ~ 20cm. Typical depths are 0.5-1 m (no water routing)

Preliminary results : West Larsen C



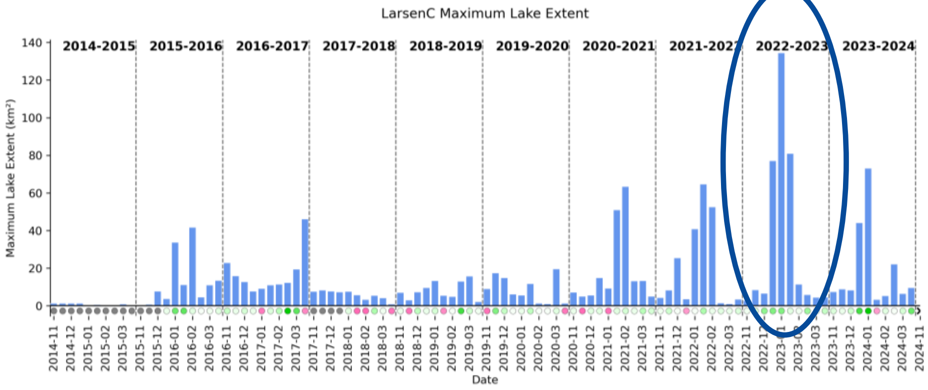


Albedo range 0.36 (exposed water) to 0.98 (fresh snow on lid)

Lake warms the surface ~ 9^{o}C, lake depth ~ 12cm

Next steps: move from 1D testing to Antarctic wide simulations

- Adjust lake area fraction
- Melt water routing (possibly)
- Optimisation (nsmax~200)
- Site evaluation
- Run PolarRes simulations (11 km) to look at future lake distribution across Antarctica



Lake area extent was very high in 2022 (satellite Sentinel 1 + 2) extant@bas.ac.uk | LinkedIn

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ExtAnt will provide the first comprehensive assessment of present day and future high impact extreme weather events in Antarctica, and associated risks. Key risks include impacts of extreme weather on vulnerable ice shelves, the breakup of which can speed up flow of grounded ice and affect global sea level, and on the highly specialised Antarctic biodiversity. This ambitious programme brings together leading UK and international scientists to use new modelling resources and methods to elucidate drivers of extreme events. New modelling capability will be developed to quantify impacts of extreme events on surface melt of ice shelves. These advances will bring a step change over current knowledge of extremes. ExtAnt's legacy will include a dataset for advancing research into broader impacts, for example on ecosystems.

Definition of extreme weather events

We consider directly impactful extreme weather events ('extreme events'). An important impact is the creation of surface melt. Specific thresholds on variables such as surface air temperature, precipitation, wind speed and surface energy balance will depend on the objectives and will in some cases be clarified through sensitivity studies. We consider spatial scales from the local (~10 km), e.g. over a specific ice shelf, to synoptic (up to ~2,000 km), e.g. related to larger-scale weather systems. We consider timescales from days, to capture specific weather events, to seasonal, to capture potential cumulative impacts of multiple extreme weather events or sustained anomalies.

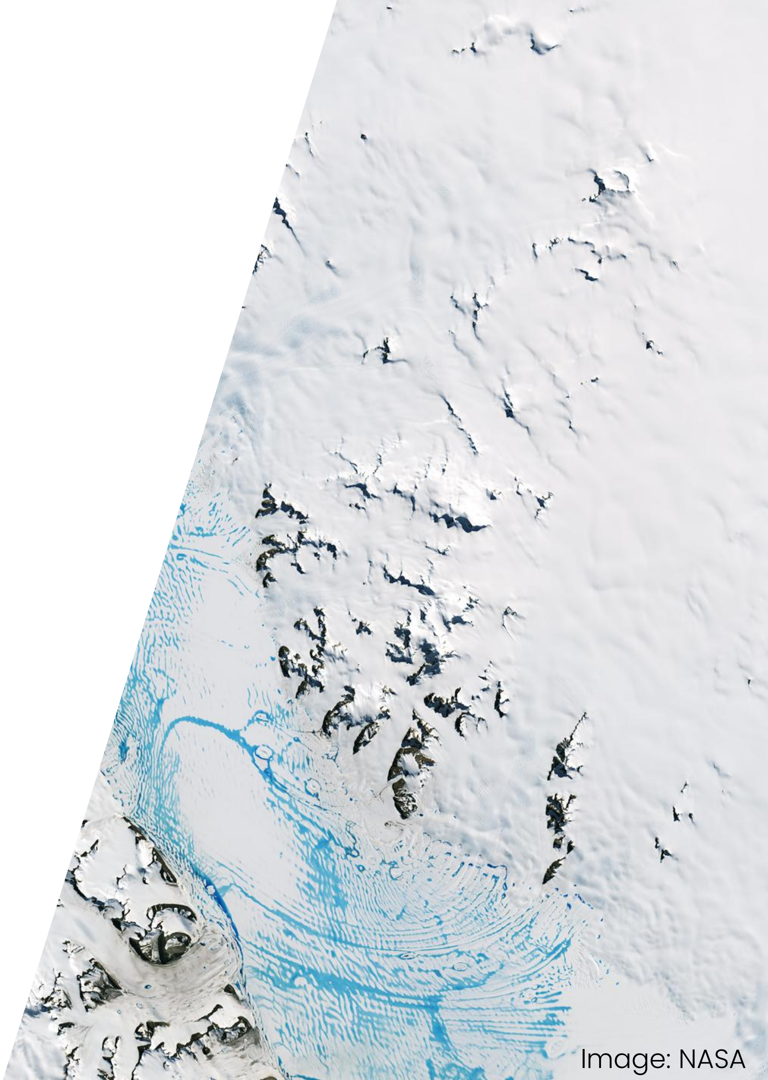

Image: NASA