Impacts of Antarctic subglacial freshwater flux from the grounding zone to the open continental shelf

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September 23, 2024

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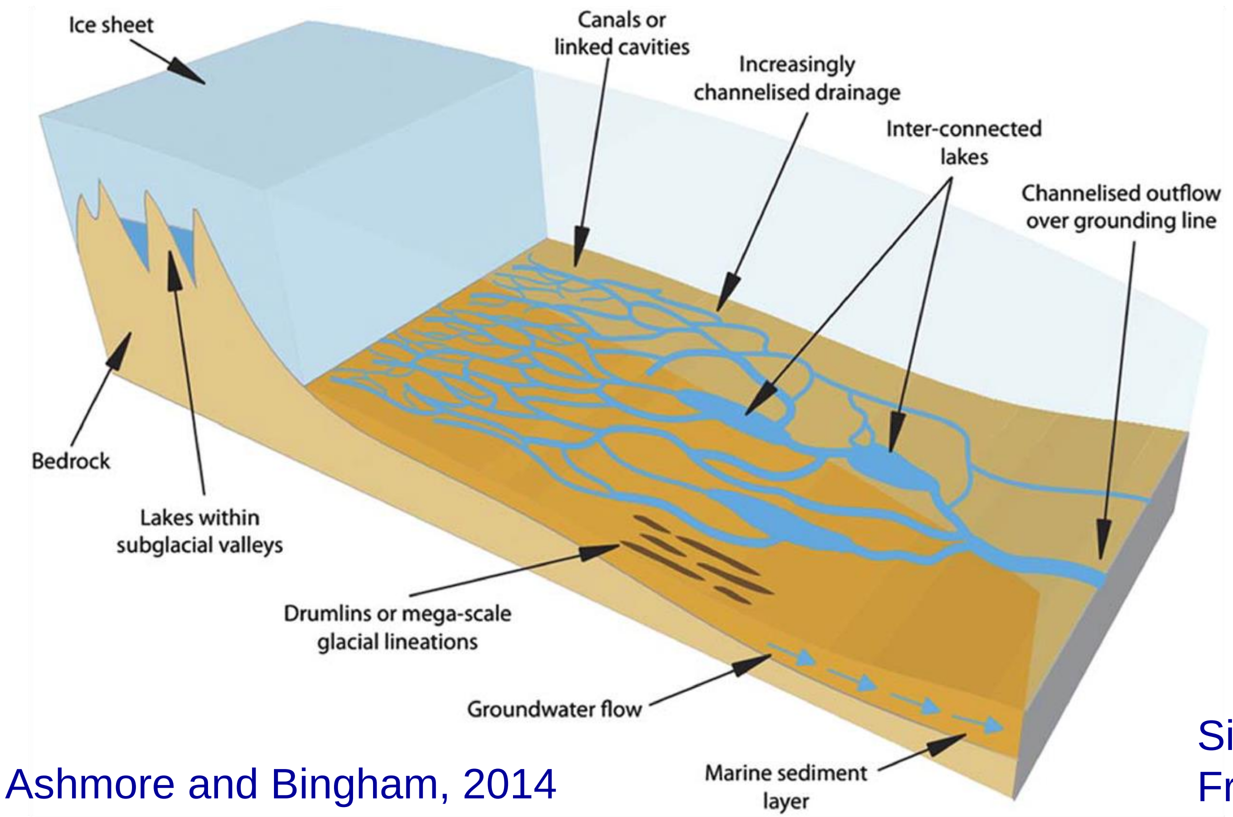
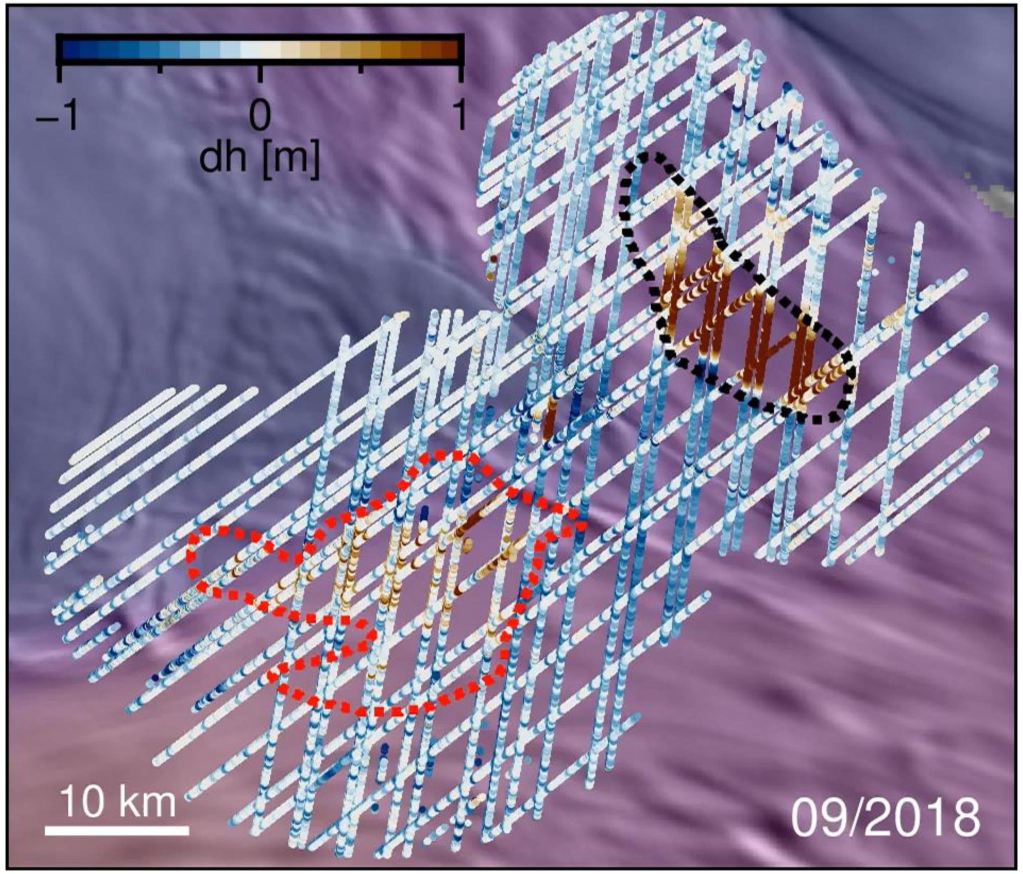


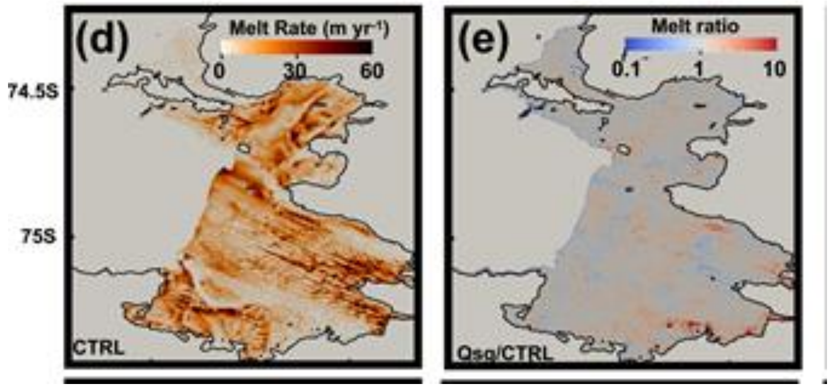
Ashmore and Bingham, 2014

Siegfried and Fricker, 2021

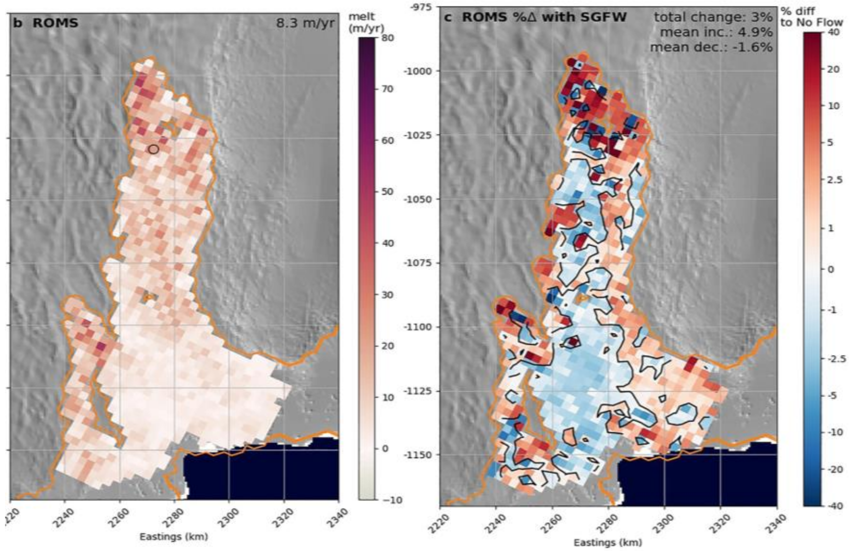


What is the impact of temporal and spatial varying freshwater from the continent?

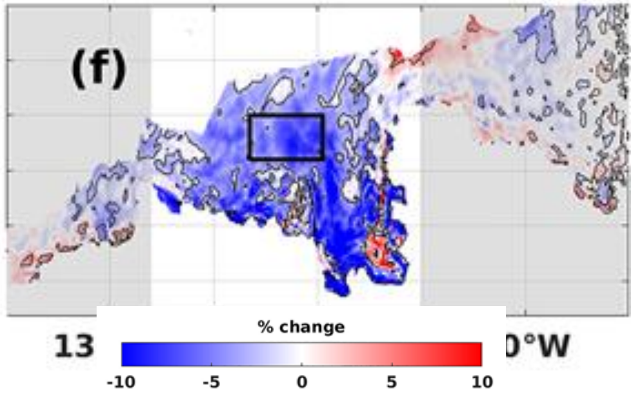
Step 1: Estimate time-varying input (satellite altimetry of active subglacial lakes)
Step 2: Use input to drive coupled ice-ocean-sea ice models



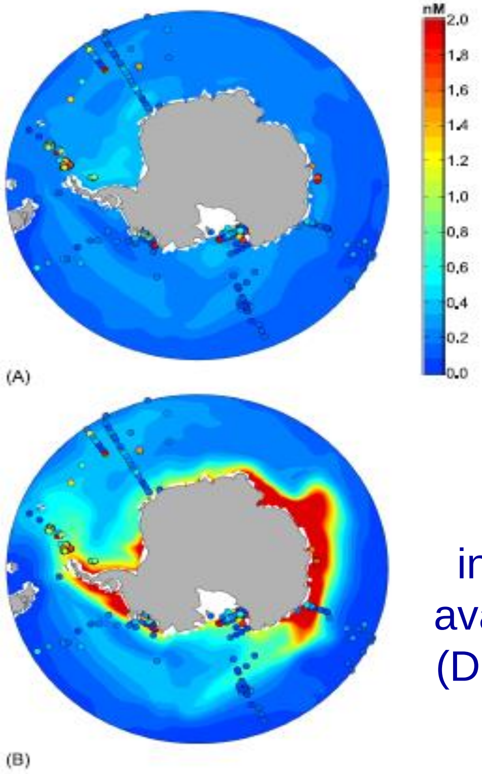
6% increase in total melt under Pine Island (Nakayama et al., 2021)



3% increase in total melt under Totten (Gwyther et al., 2023)



~10% decrease in summer sea ice thickness near Amundsen shelves (Goldberg et al., 2023)



massive increase in available dFe (DeAth et al., 2014)

Previous modeling studies of impact of subglacial meltwater

- Small increases in overall basal melt, but large increases in important locations
- Changes to sea ice conditions just outside the ice shelves
- Possible important source of limiting micronutrient dFe

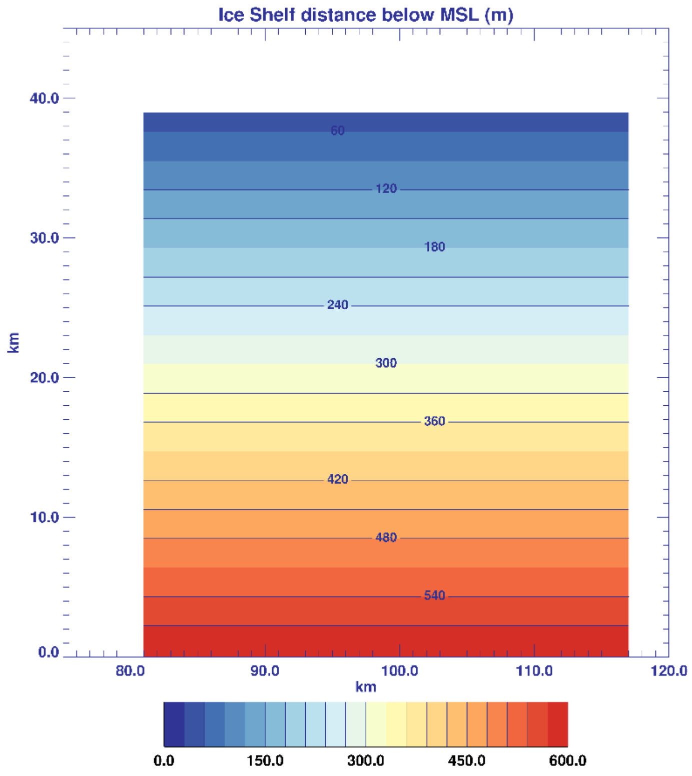
Details of the flux (amount, temporal variability, location) matter

ROMS modeling with idealized domain and realistic Ross Sea and Amundsen Sea (all with dynamic sea ice and thermodynamically active ice shelves)

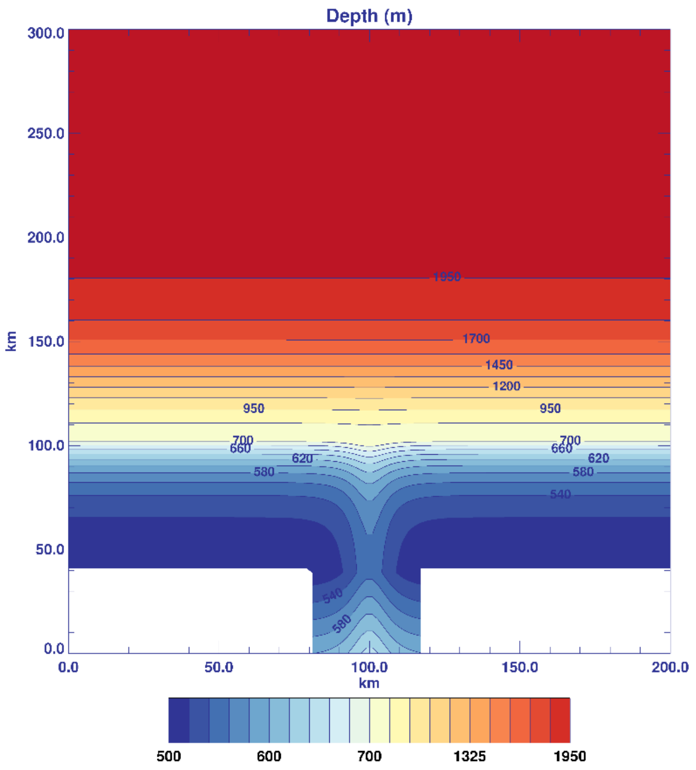
Subglacial flux added as freshwater momentum sources at grounding zone at appropriate pressure dependent freezing point

Idealized Domain:

Small-ish (1600 km^2) ice shelf, open continental shelf (with a trough), abyssal ocean



Base case ice shelf

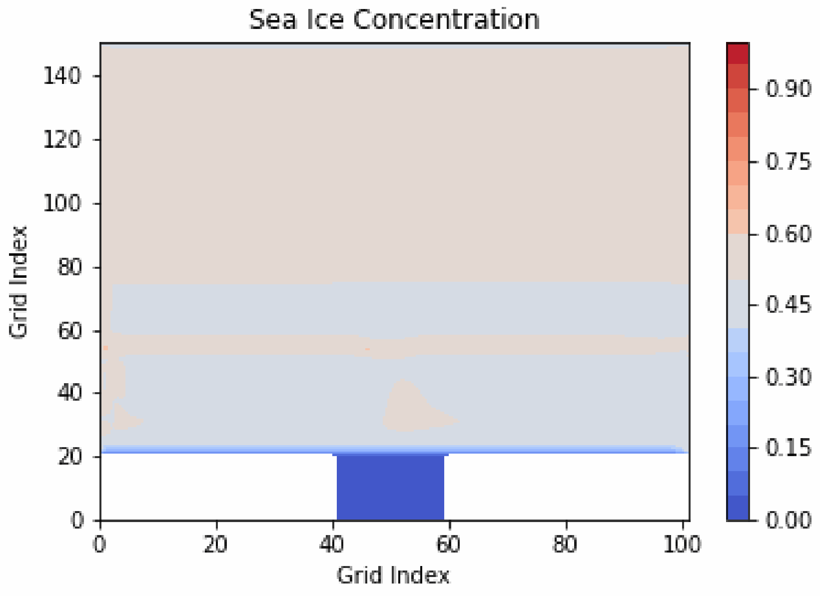


Bathymetry

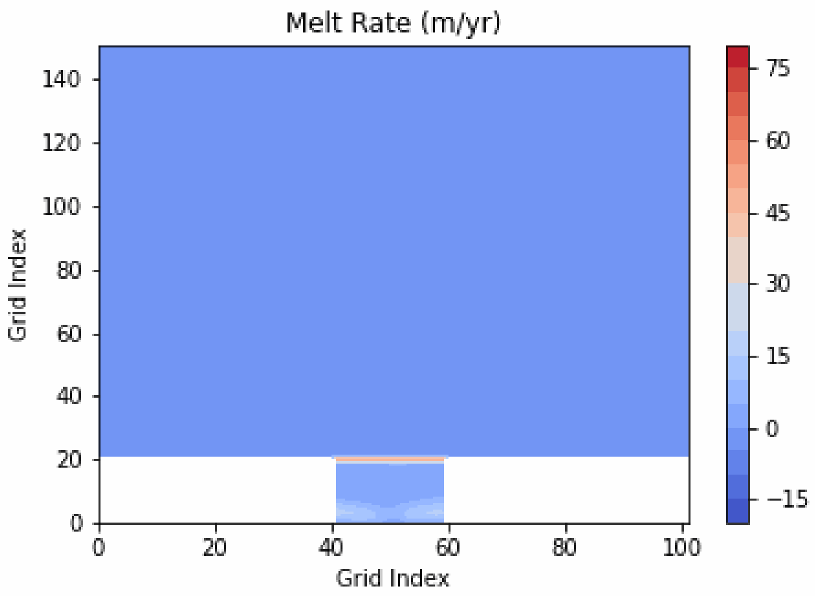
2-km horizontal resolution, 25 vertical levels, warm continental shelf initial conditions for T and S

240d simulations with most atmospheric forcing constant (winter conditions) except winds:

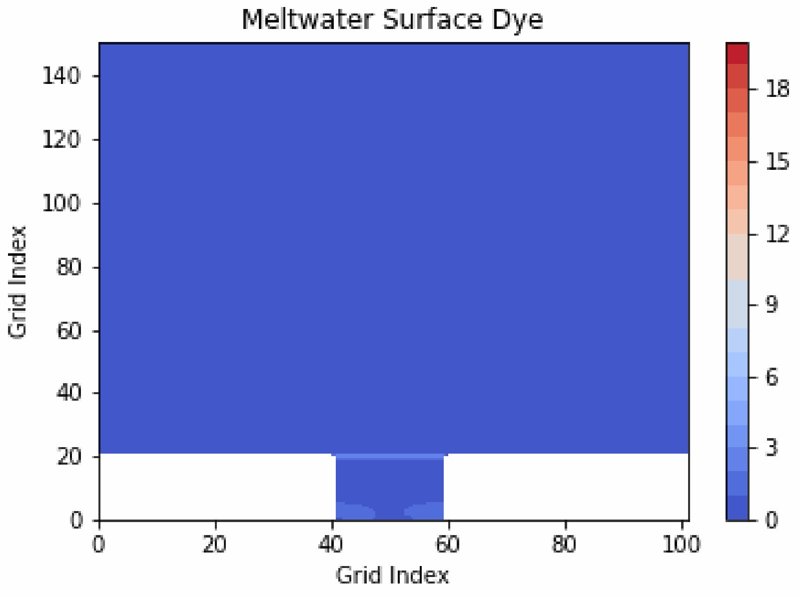
5 m/s easterlies and time varying N/S component from +20 to -10 m/s over shelf (weaker over open ocean)



Sea ice



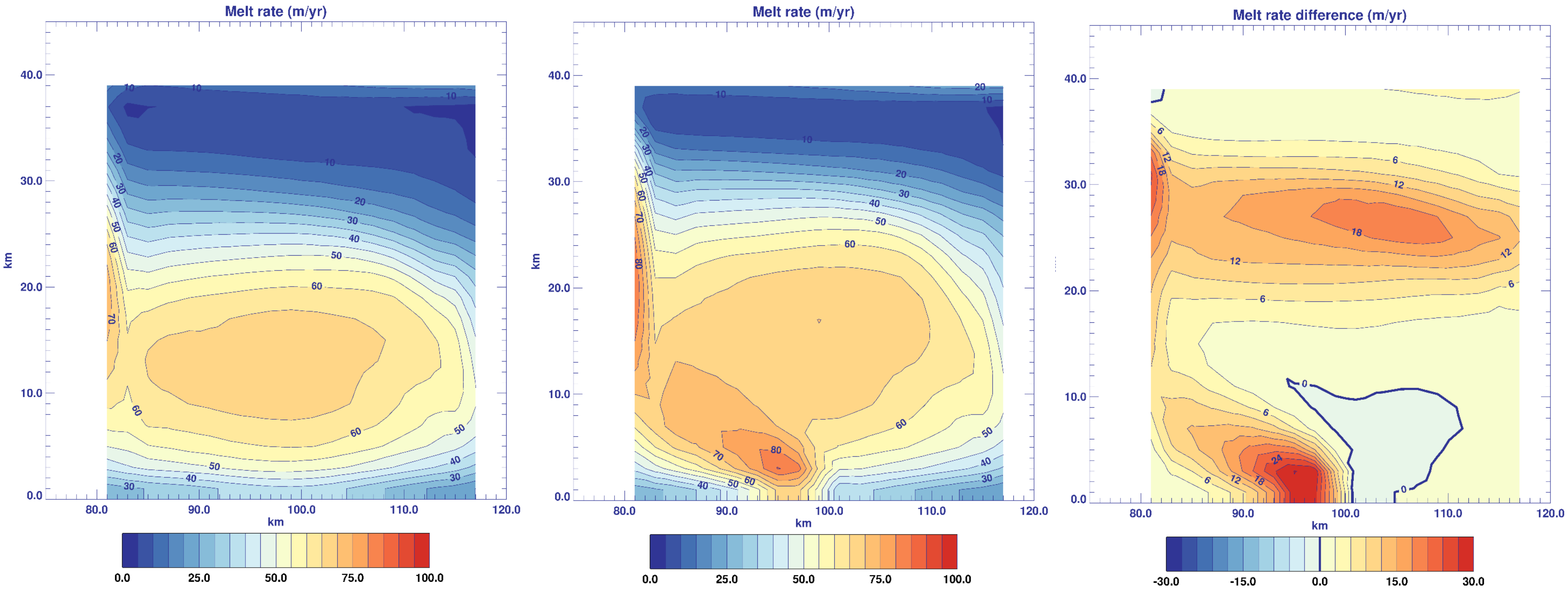
Ice shelf basal melt



Ice shelf meltwater at surface

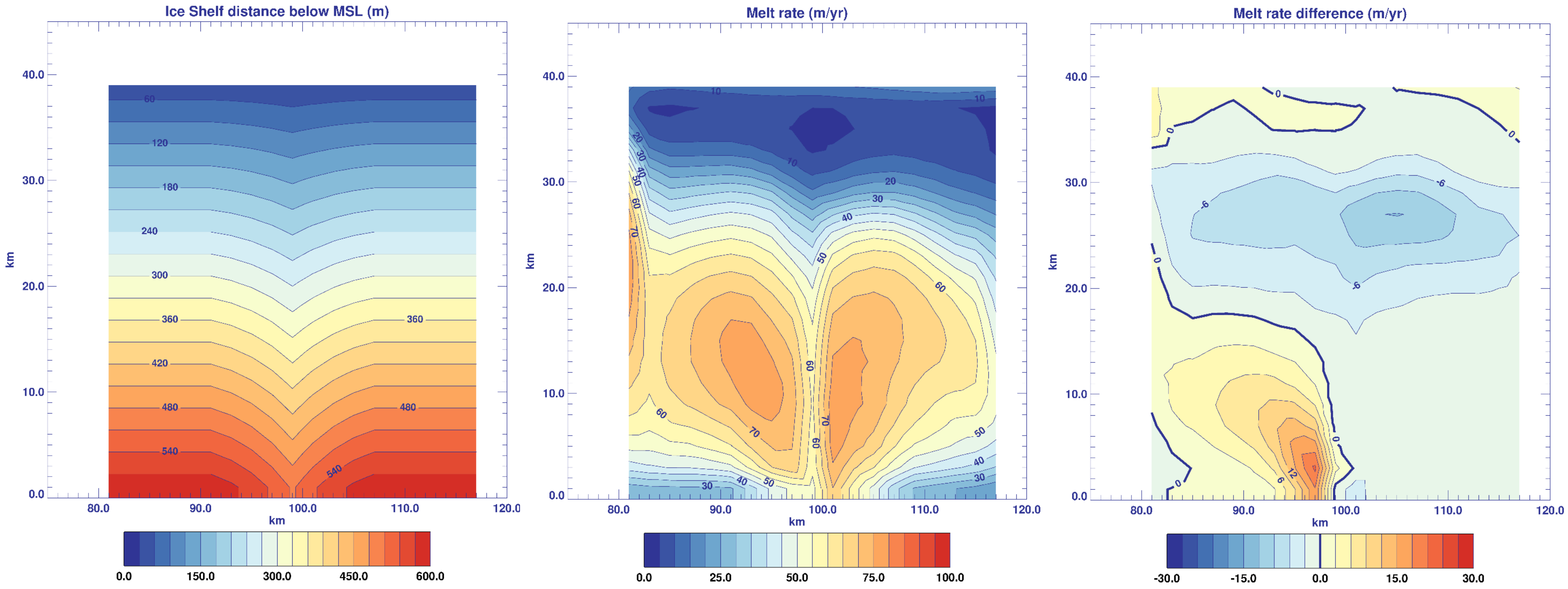
Opening and closing of the coastal polynya due to changing winds leads to variability in

- Sea ice formation and vertical mixing of heat on the continental shelf
- Variability in heat transport into the ice shelf cavity
- Ice shelf basal melt
- Transport of melt water out into the open ocean



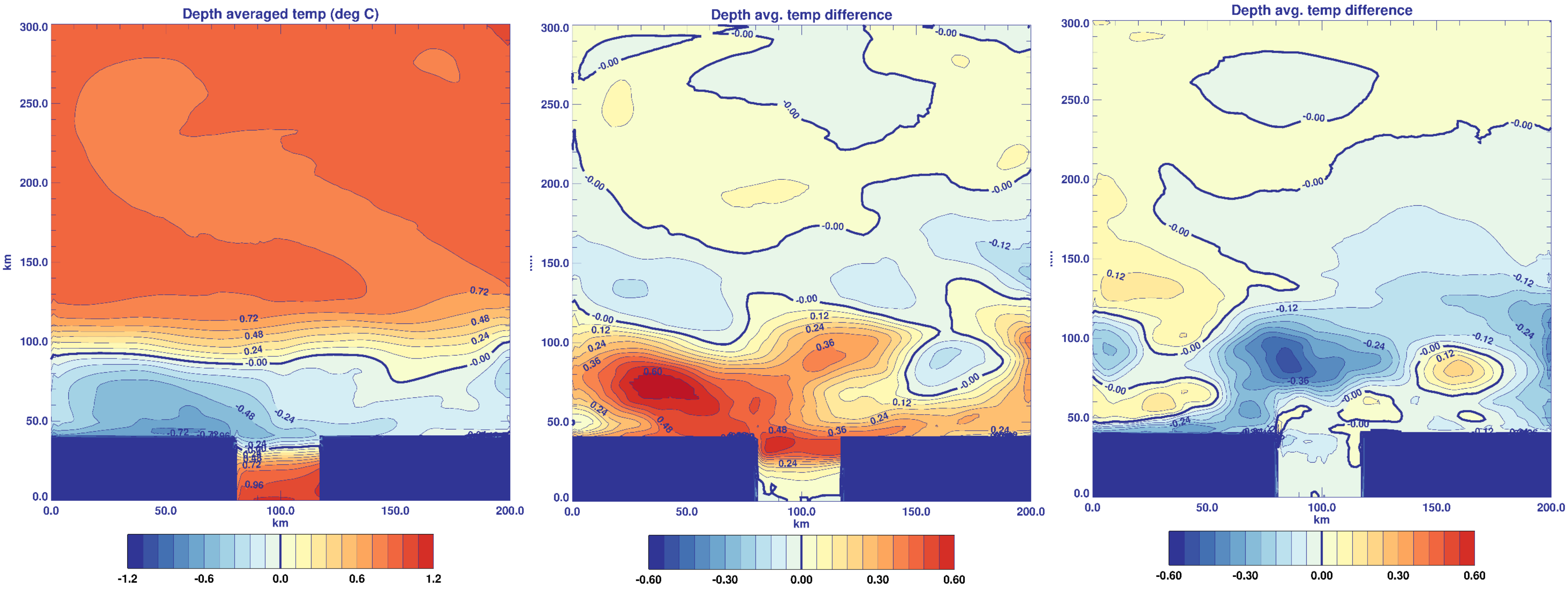
Added SGD (constant 80 m^3/s total flux…similar to Hager et al. (2022) mean estimate for Thwaites) over 3 horizontal grid cells in center of southern boundary

Melt increases as expected: Area and time averaged melt increases by 16% (39.5 (left) to 46.0 (center) m/yr), increased melting along expected path of plume (along the pressure/shelf base depth gradient and pushed to the left by Coriolis) as well as an expanded area of high melt



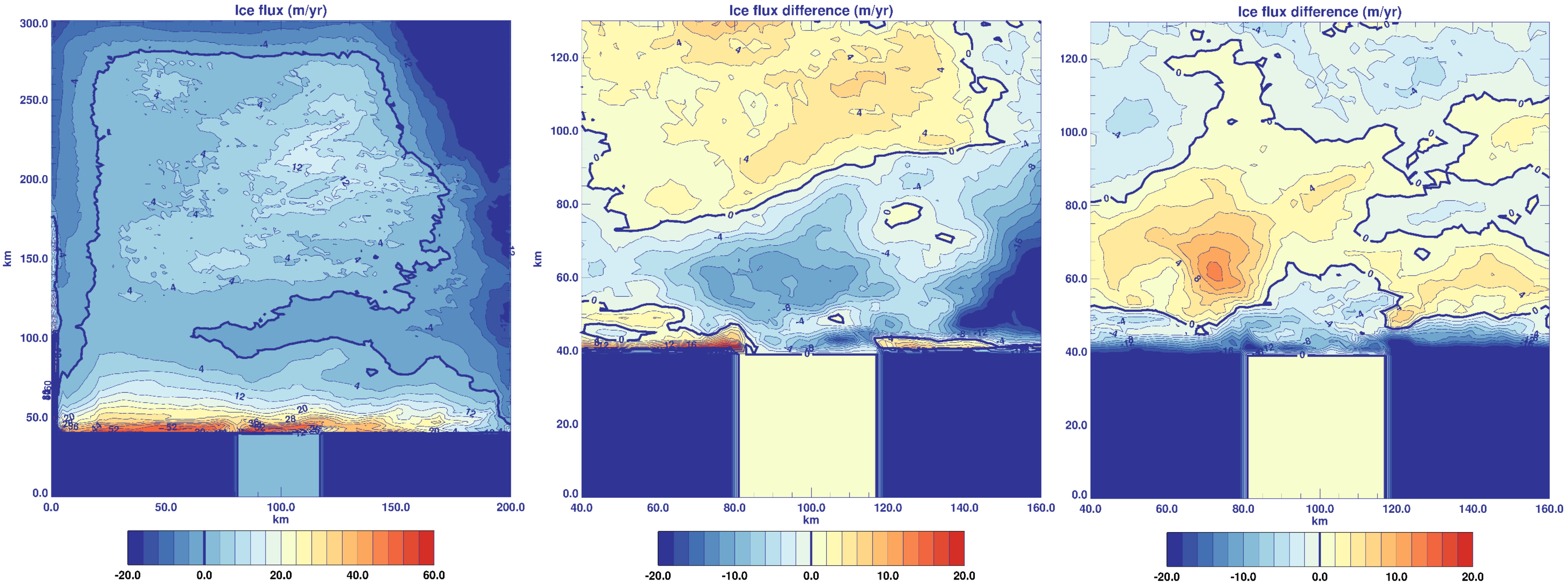
Adding a channel in the ice shelf (left) changes the basal melt pattern (center)

However, adding SGD (same 80 m^3/s as before) now leads to a slight decrease (3%) in the total averaged basal melt (44.5 to 43.3 m/yr: right)



Depth averaged temperature (or heat content) for base simulation (left) shows at the end of the simulation there is still a good bit of heat left over the open continental shelf

Adding SGD leads to a warmer continental shelf (center) with a simple ice shelf, but a colder continental shelf when there is a trough in the ice shelf



Net vertical mass flux between sea ice and ocean for base simulation (left: positive means net ice creation/salt flux) and differences over nearby continental shelf when adding SGD for simple (center) and more complex (right) ice shelves

Differences in how meltwater gets out onto the open continental shelf feed back into polynya processes in front of the ice shelf (tidal forcing, not shown, impacts this feedback)

Ross Sea simulation

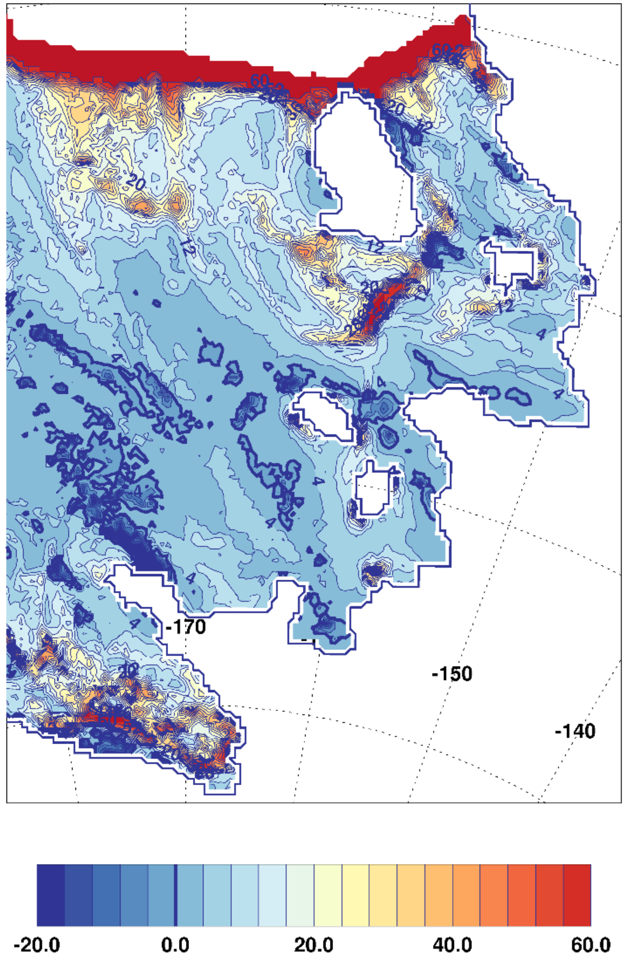
Base case is 15 year simulation at 5 km resolution (Dinniman et al., 2018)

Subglacial flux added at 6 sites along Siple Coast based on Carter and Fricker (2012)

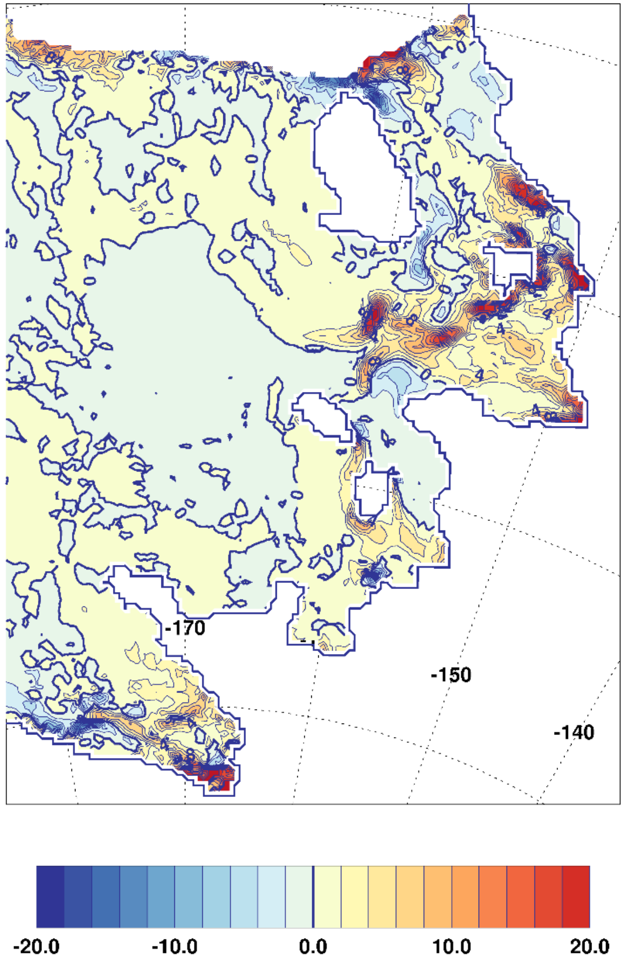
Added a tracer based on observed subglacial dFe at Mercer Subglacial Lake (Hawkings et al., 2020)

Only a 3% increase in the total ice shelf basal melt (20.5 to 21.1 cm/yr)

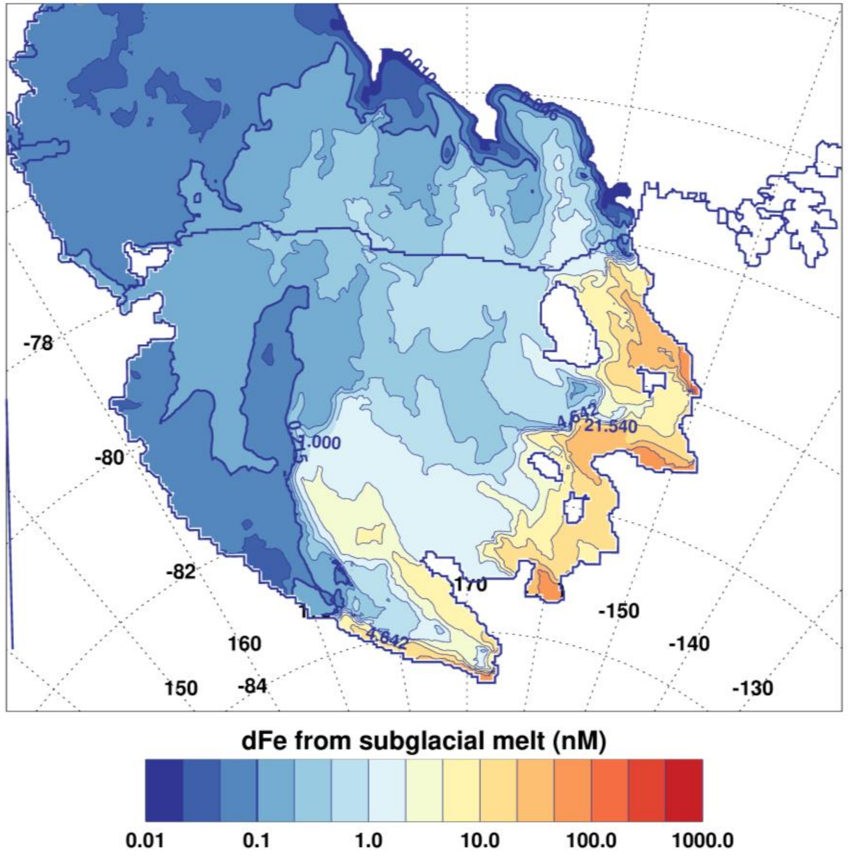
However, large increases in several areas that would be important to ice flow…not just at Siple Coast grounding zone, but also at pinning points away from SGD input



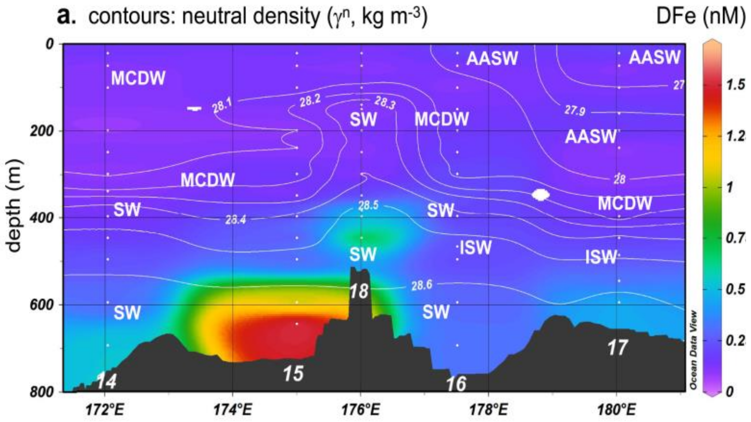
Base case melt (cm/yr) for eastern 2/3 of Ross Ice Shelf



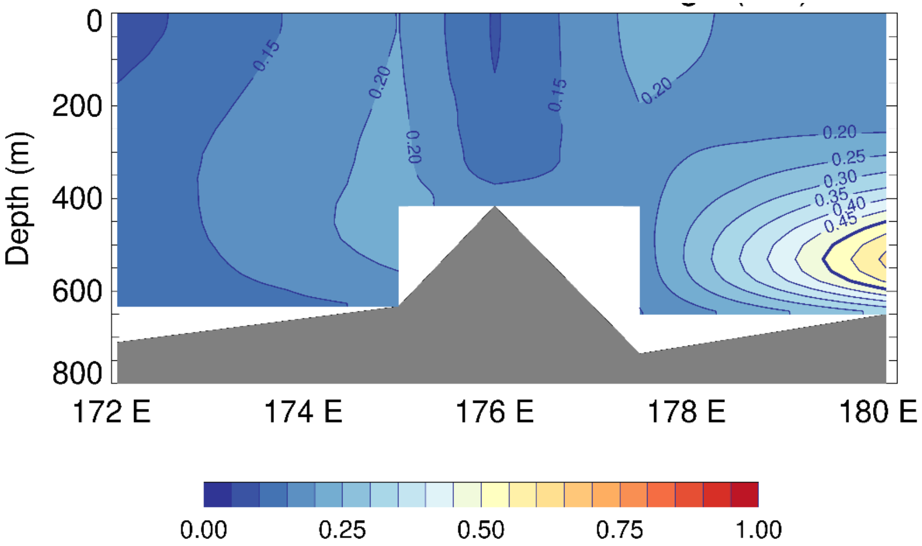
Difference in melt when SGD added



Model top 10m “dFe” from SGD source after five years



Observed dFe section across RIS front
(Sedwick et al., 2022)

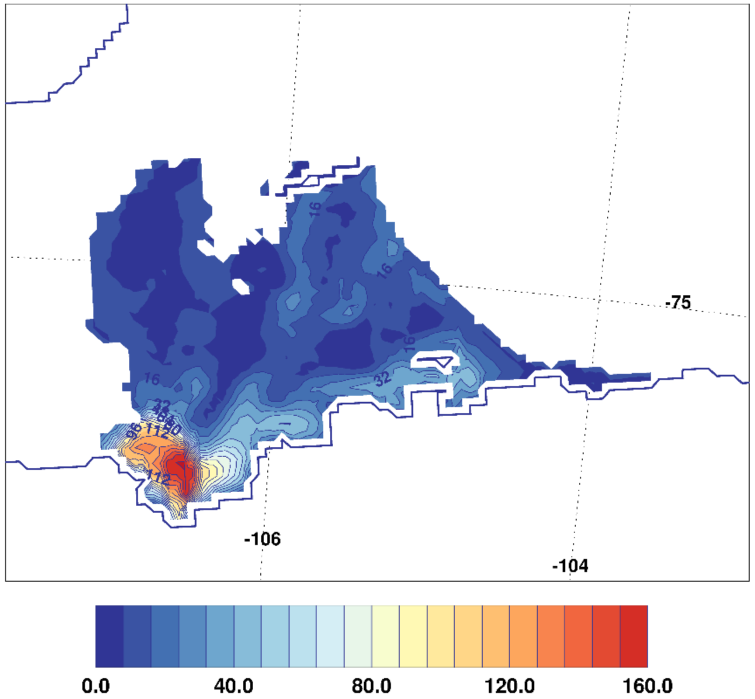


Model section change in “dFe” from SGD source over a year

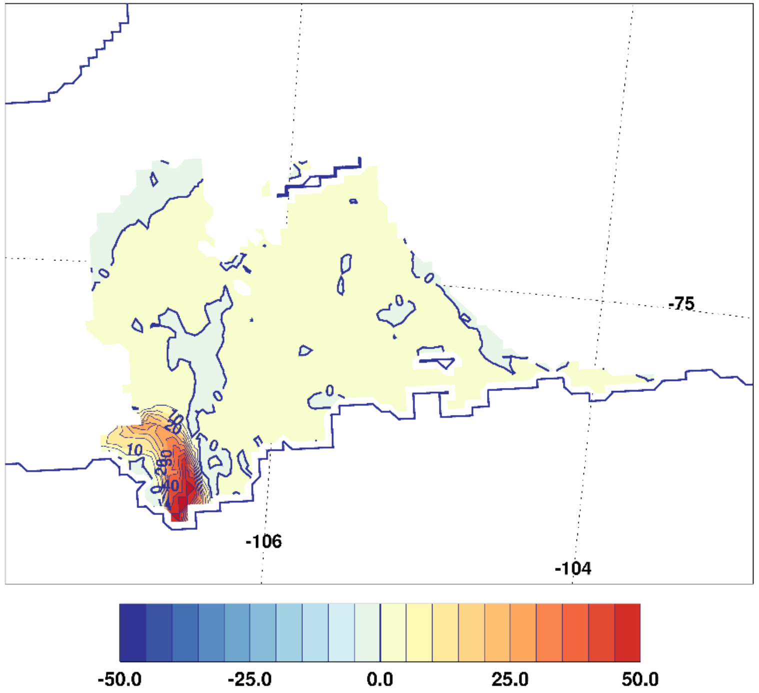
Expected high concentrations at SGD input locations, but biologically relevant (> 0.1 nM) dFe concentrations are maintained seaward of the ice-front

Subglacial dFe end member is very poorly known (only 2 measurements?), this assumes no biological uptake or scavenging, and many other caveats apply

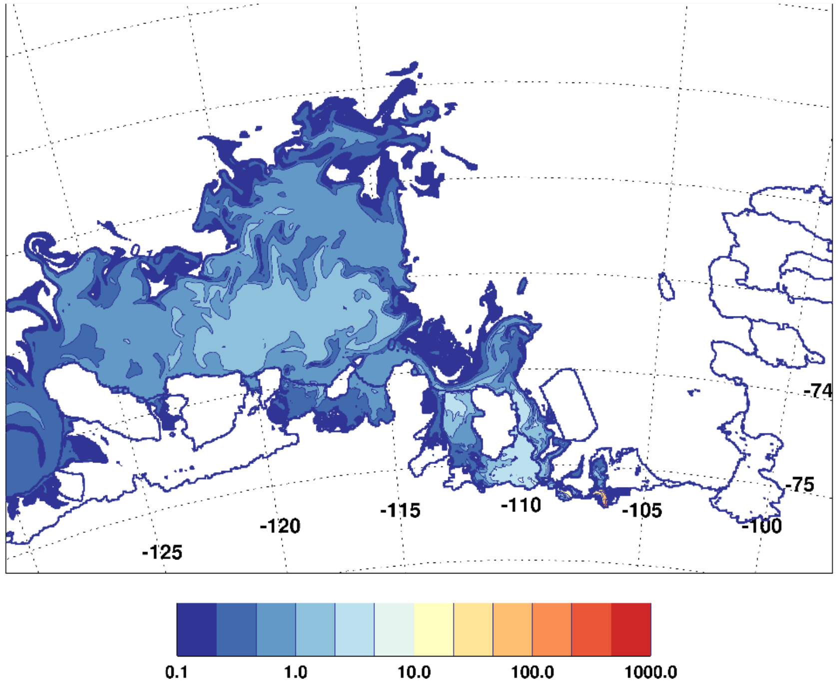
But it could be an important source…



Base case melt (m/yr) for Thwaites Ice Shelt



Difference in melt (m/yr) when SGD added



Model top 10m “dFe” from SGD source after one year

Amundsen Sea (Thwaites) simulation: 8 year simulation at 1.5 km resolution (Millan et al., 2020)

Subglacial flux added at the Thwaites grounding zone based on Hager et al. (2022)

Only a 9% increase in total basal melt (20.1 to 21.9 m/yr), but large increases (> 20 m/yr) in areas that will be important to ice flow and matches Adusumilli et al. (2020) better at grounding zone

“dFe” end member likely too large (besides other issues), but this estimate would eliminate dFe resource limitation for much of the Amundsen shelf

Summary

- Freshwater discharged from beneath the grounded ice sheet may be one of the key missing processes in sub-ice-shelf cavity modeling
- Idealized and realistic domain ROMS models show impacts on both near- and far-field basal melt, sea ice creation, and (?) nutrient availability
- Future plans include running several regional models (Amundsen, Ross, circum-Antarctic, new Weddell) with estimates of time-varying freshwater discharge based on high resolution satellite altimetry and subglacial routing models
- Thanks to NASA (80NSSC24K0169) for support