Annual mass budget of Antarctic ice shelves, 1997-2021

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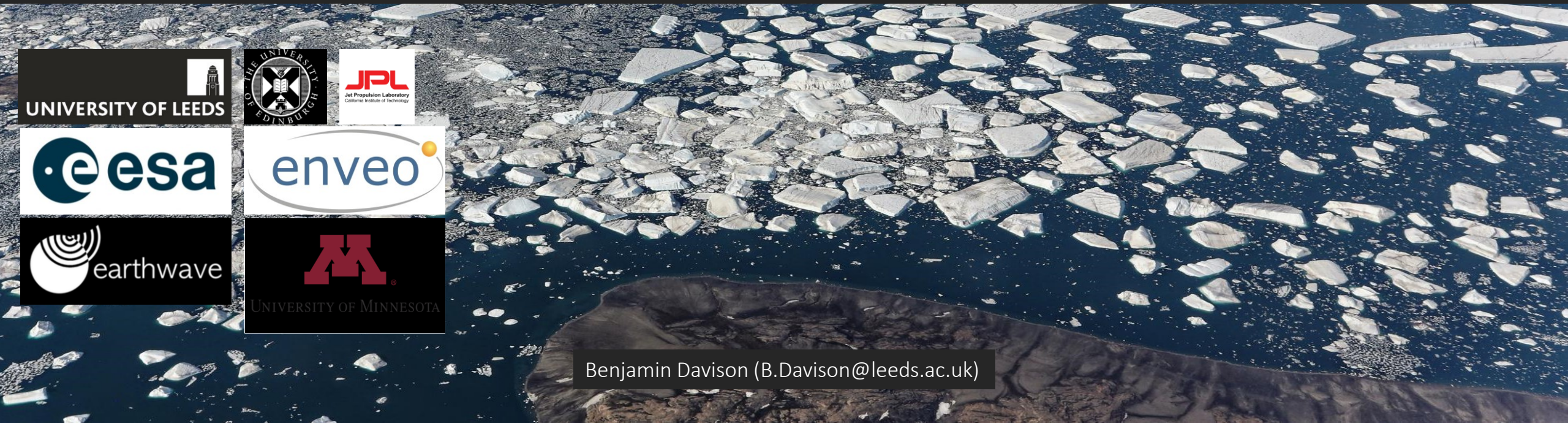
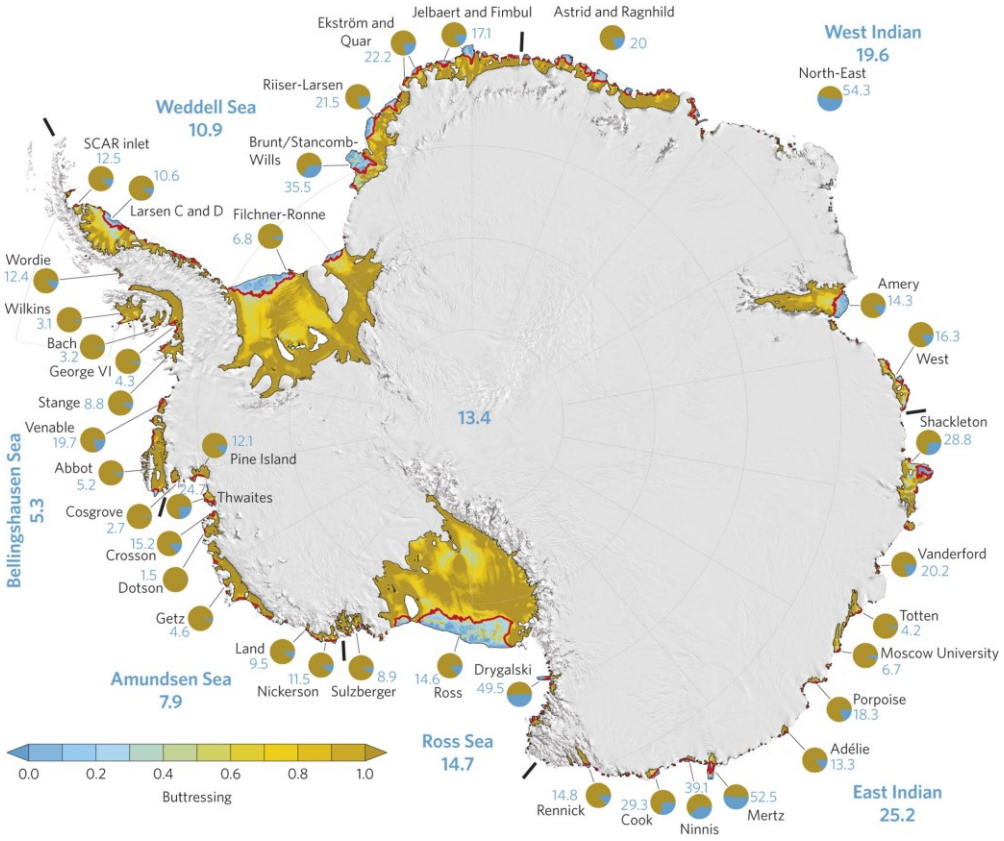
[5]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
[6]University of Minnesota Twin Cities, Minnesota, United States
[7]ESA-ESRIN, Largo Galileo Galilei 1, 00044 Frascati, Italy

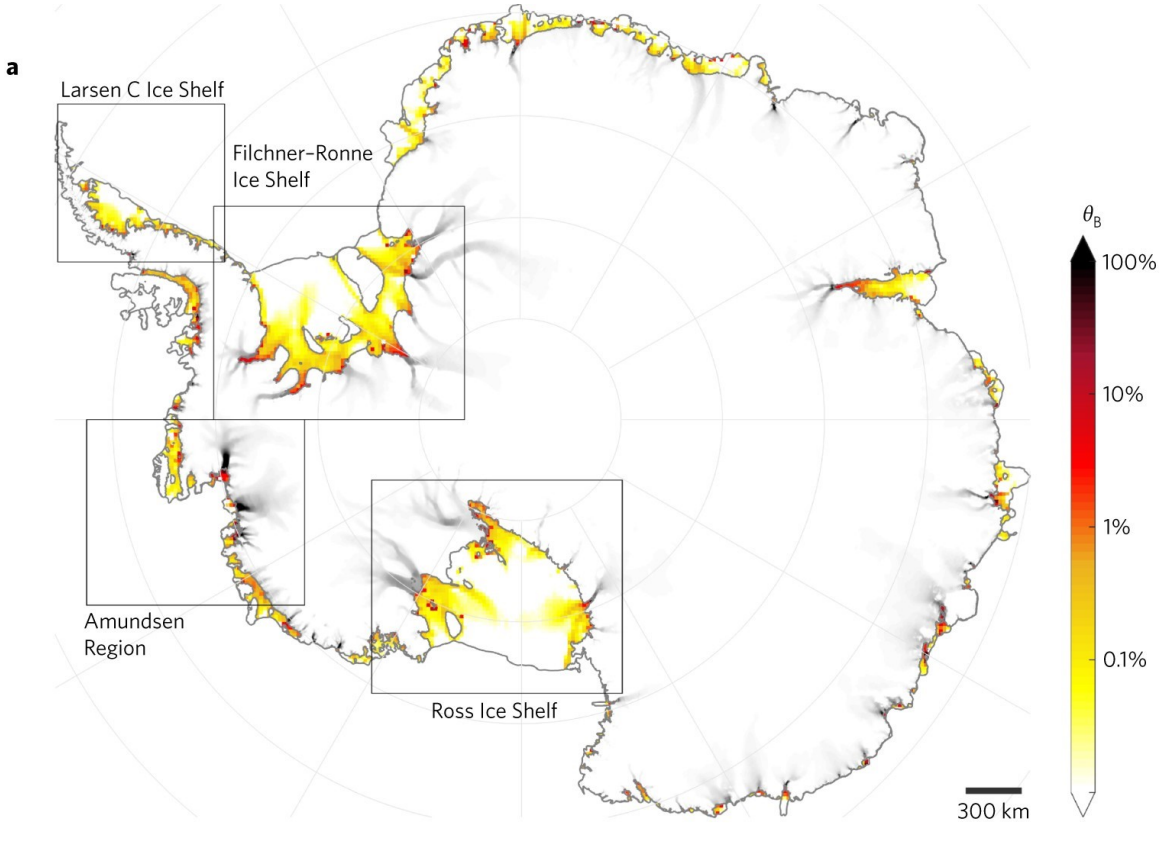


Benjamin Davison (B.Davison@leeds.ac.uk)

The safety band of Antarctic ice shelves

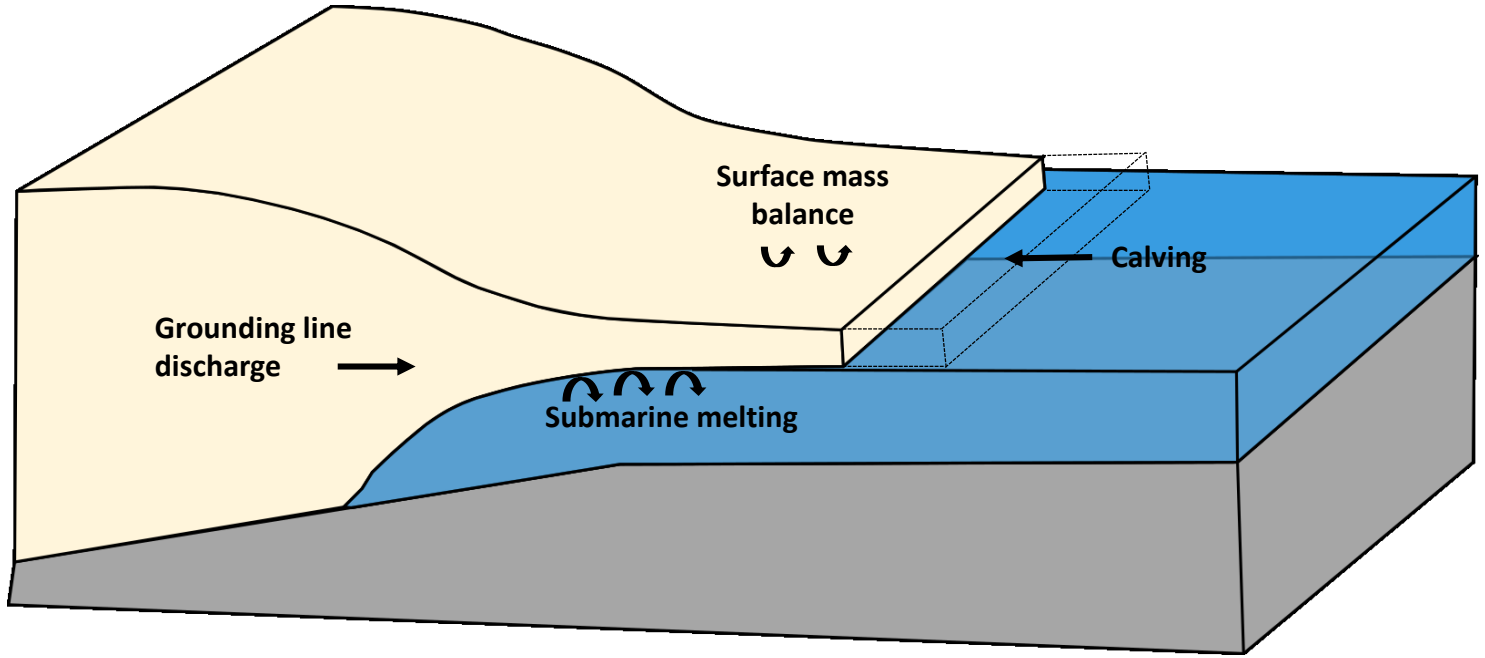


Furst et al. (2016), *Nat Clim Change*



Reese et al. (2018), *Nat Clim Change*

Ice shelf mass balance



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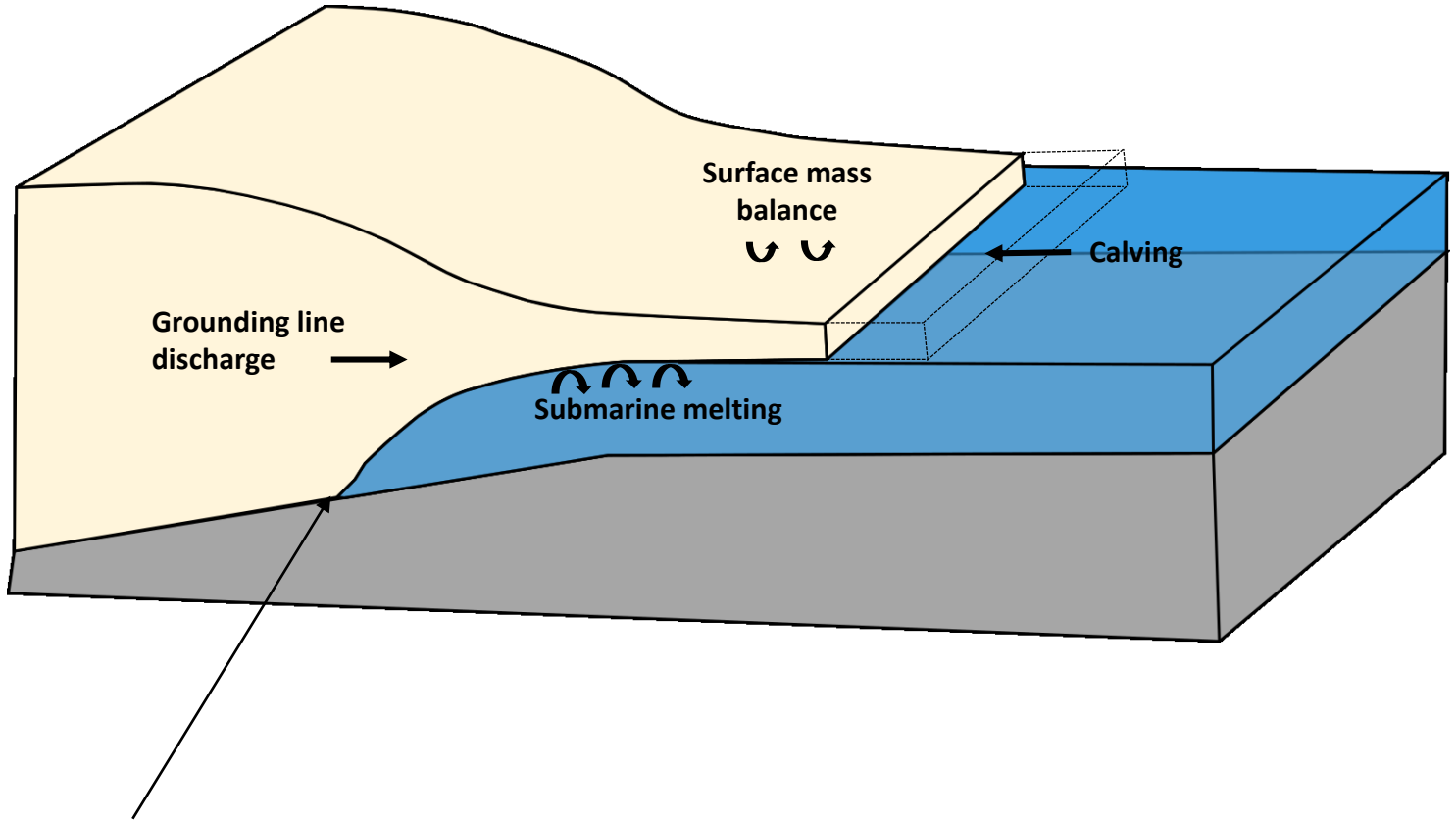
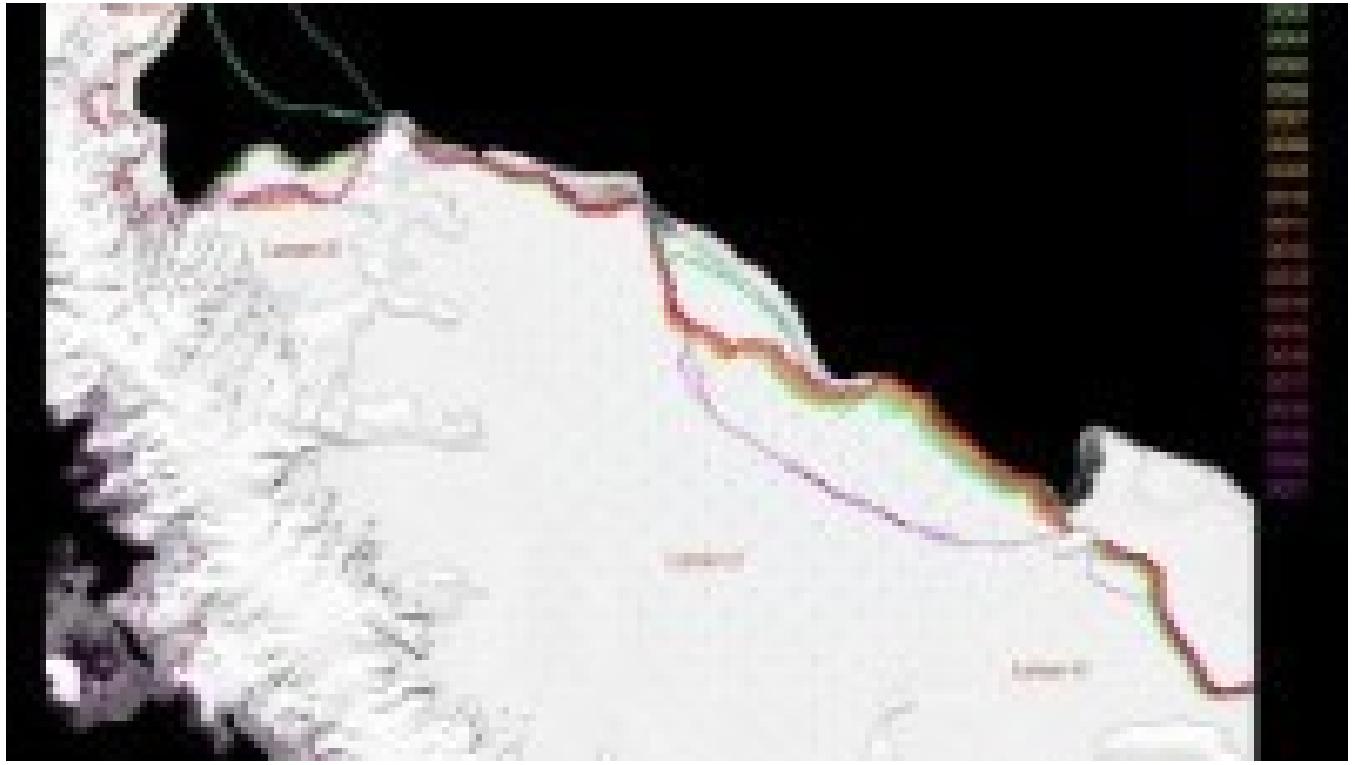


Nb: I assume a static grounding line

Calving

Quasi-annual calving fronts 1997-2021

- Derived from manual coastline delineations constrained by ice flow observations
- 118 ice shelves have retreated
- Net reduction in ice shelf area of 36,701 ± 1,465 km^2
- Area losses dominated by major calving events, but gradual wasting is widespread

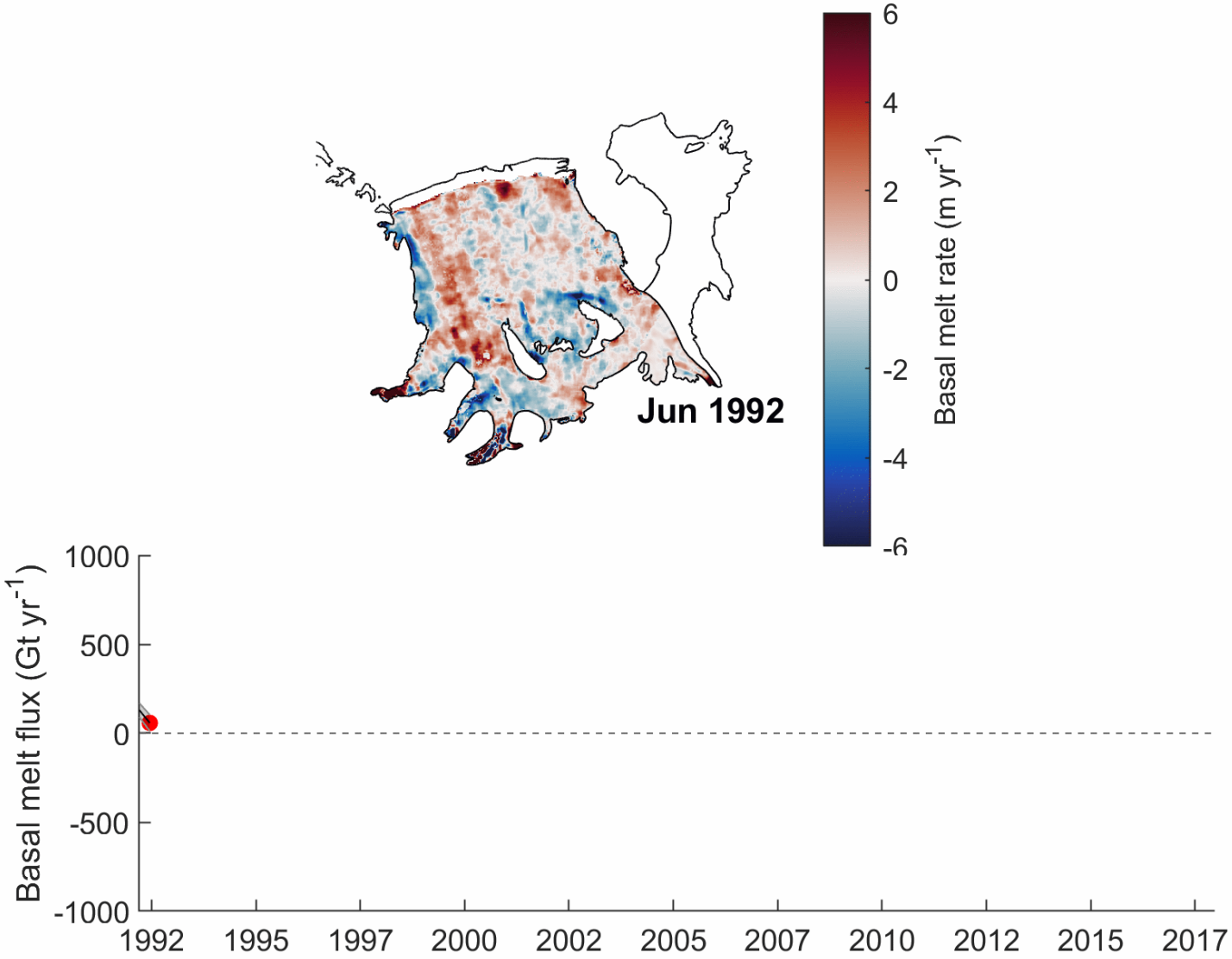


Submarine melting

Combine two basal melt rate estimates

1. 1997-2017: quarterly, ~2x2 km (Paolo et al., 2022)
2. 2010-2020: monthly, 500x500 m (Noel Gourmelen & Livia Jakob)

Integrated over time-varying ice shelf masks



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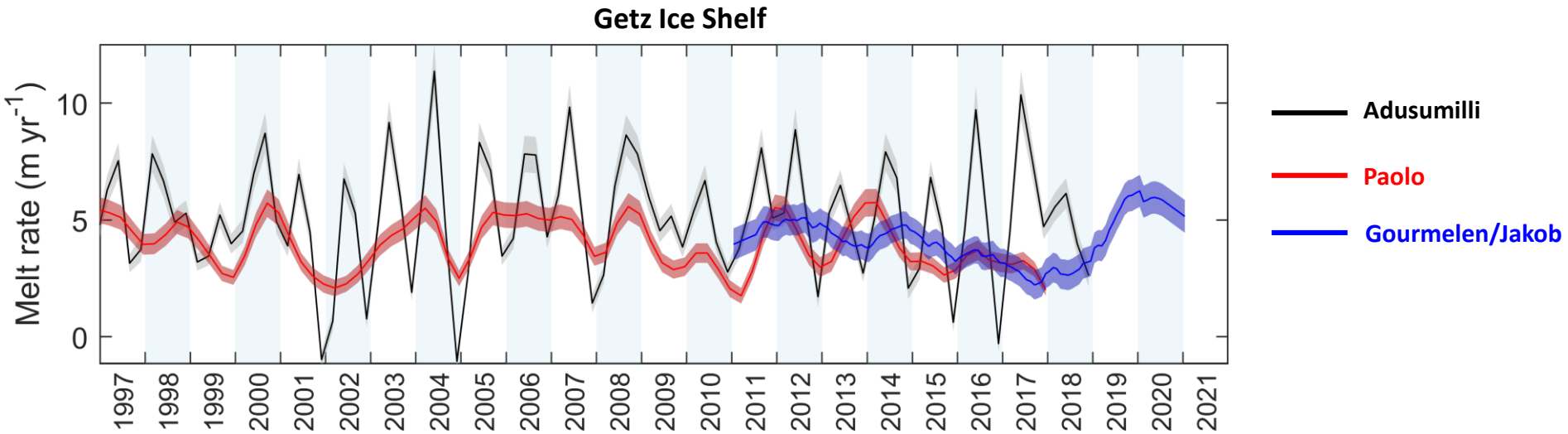
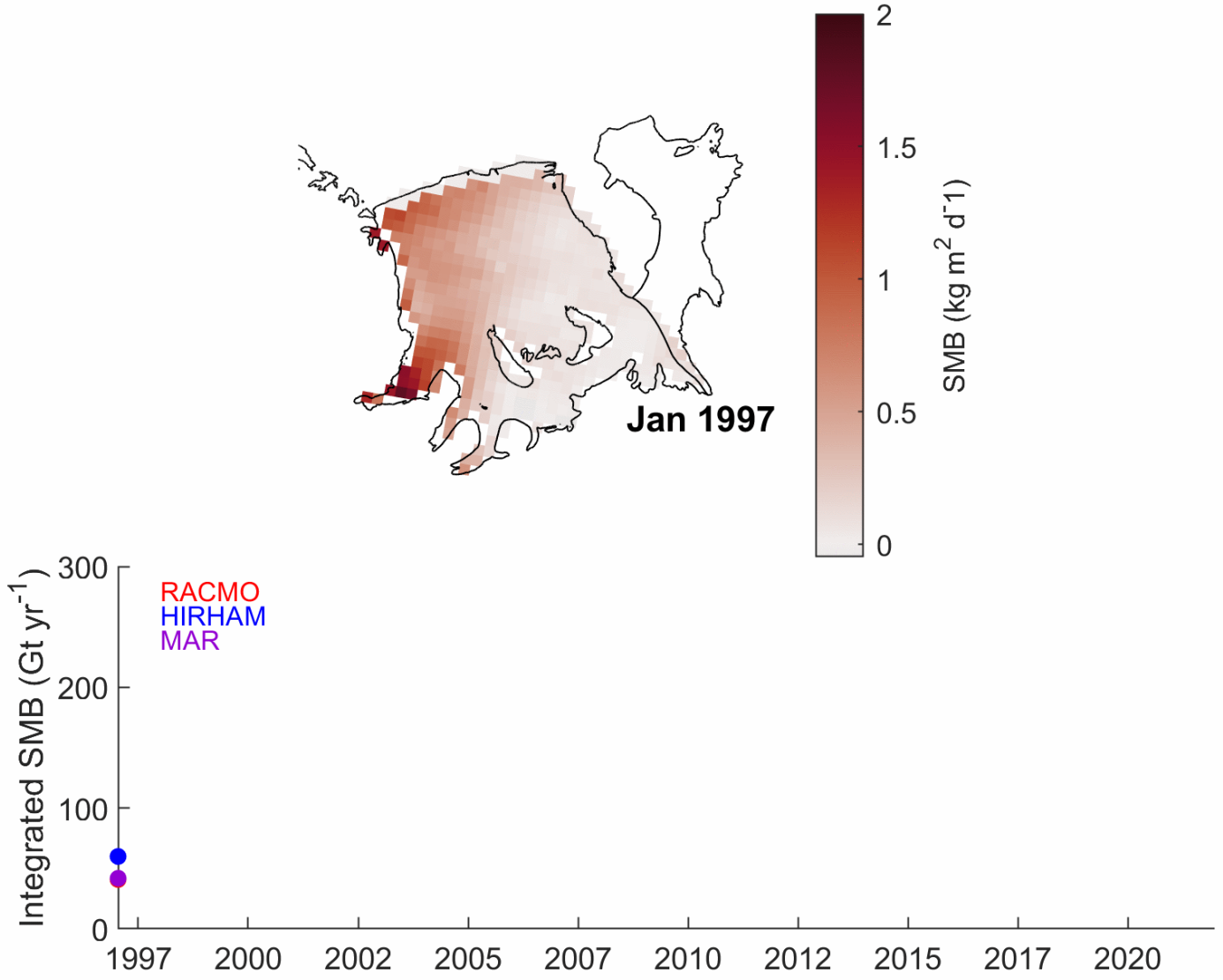


Surface mass balance

Combine three regional climate models

1. RACMO (van Wessem et al. 2018)
2. HIRHAM (Hansen et al. 2021)
3. MAR (Agosta et al. 2019; Kittel et al. 2018)

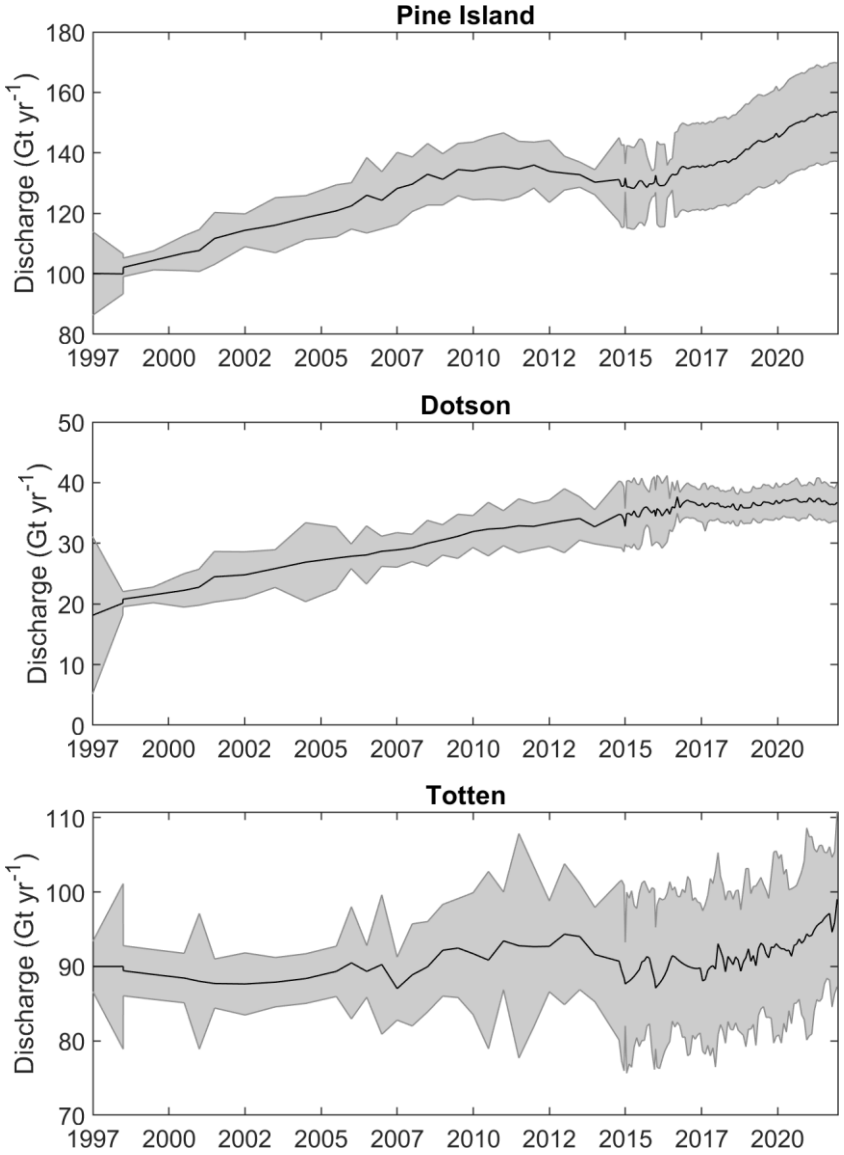
Integrated over time-varying ice shelf masks



Grounding line discharge

Combine a range of datasets:

- Ice velocity: MEaSUREs annual, ITS-LIVE annual, ENVEO monthly
- Bed topography: BedMachine v2, H&F Peninsula, Cui Princess Elizabeth Land
- Ice surface: REMA 200 m DEM, time-varying
- Firn models: IMAU FDM (RACMO), GSFC-MERRA2
- Utilise multiple flux gates, corrected for gate-to-grounding line surface mass changes



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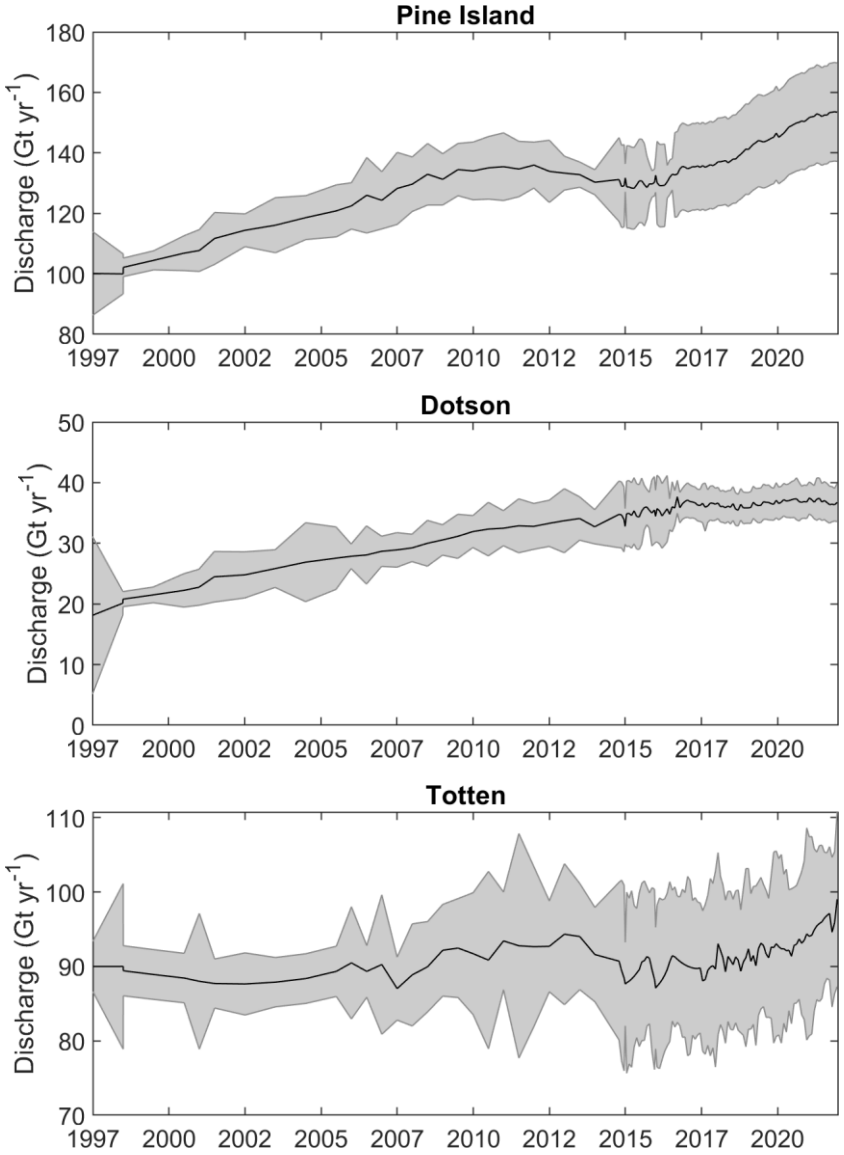

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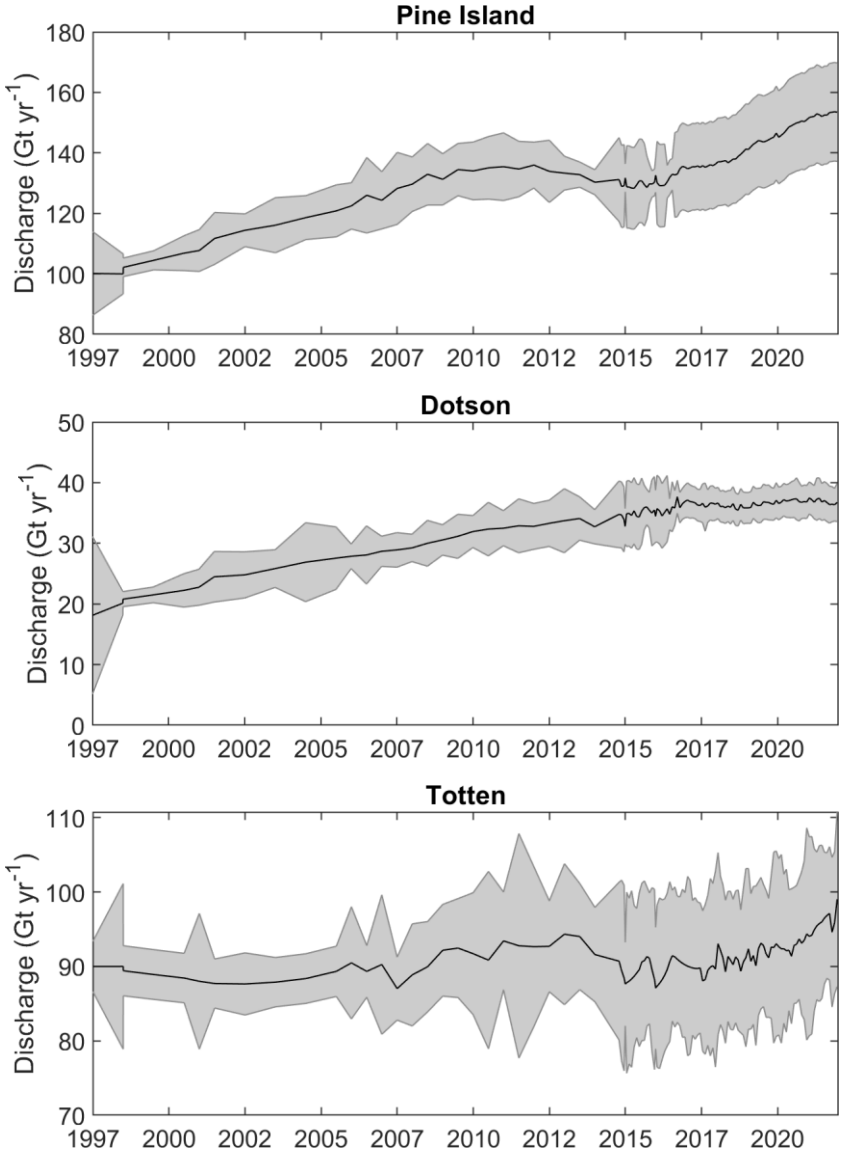
Which shows up in these



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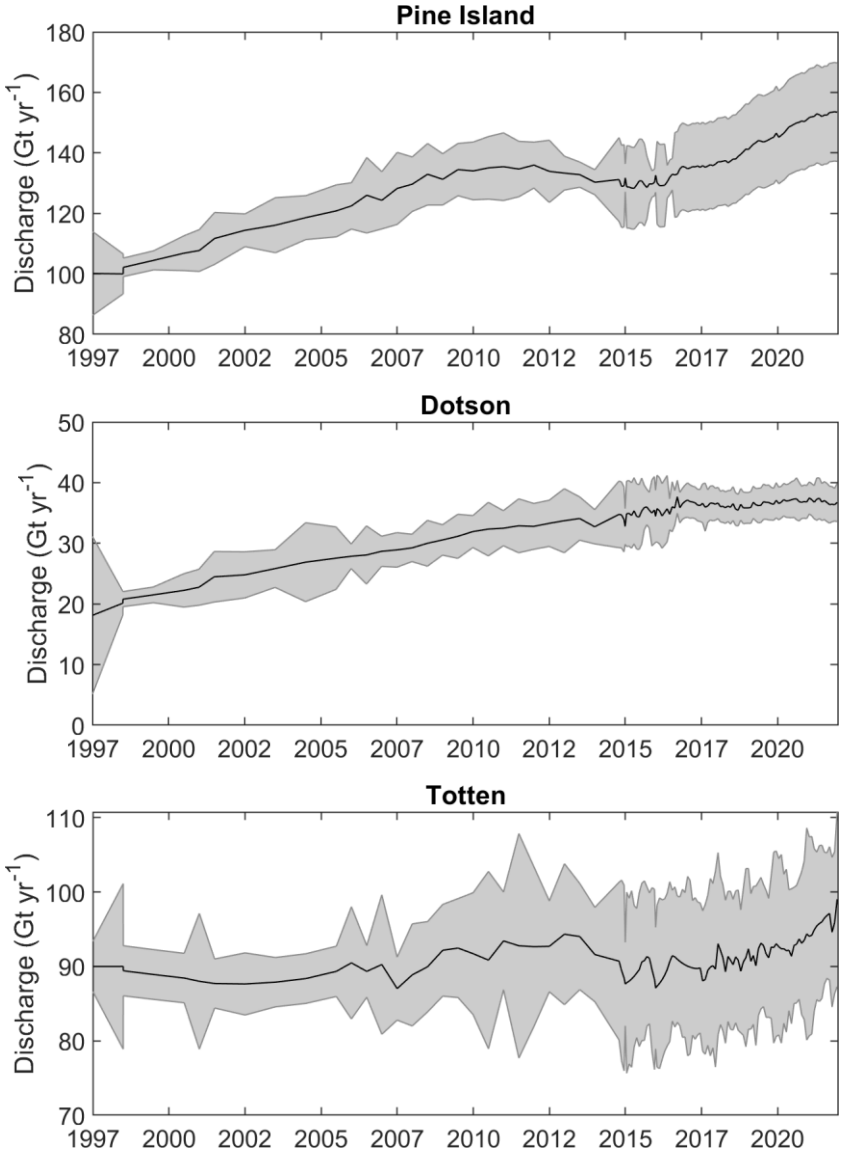
Will be made freely available across all of Antarctica
(not just ice shelves!)



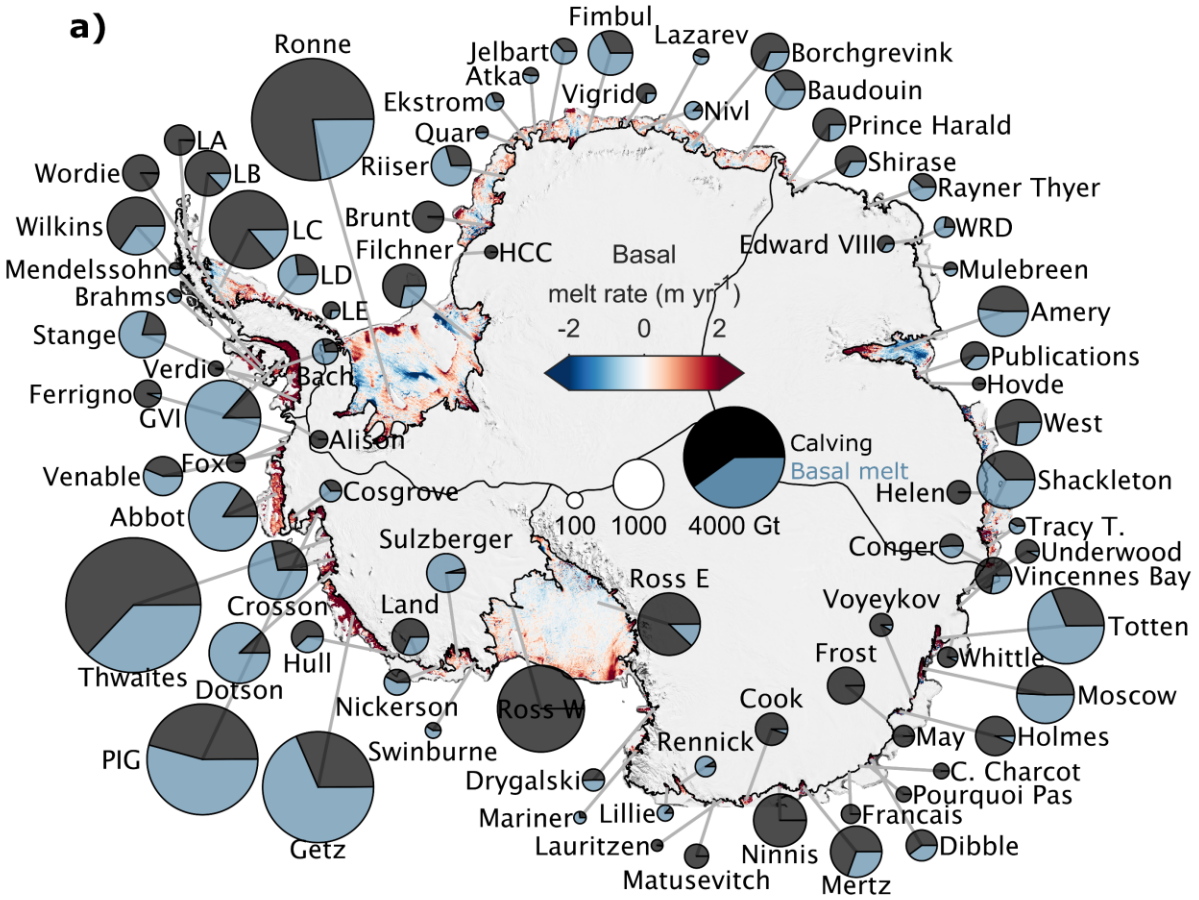
Ice shelf freshwater export

Total freshwater export:
- 66,000 ± 13,500 Gt 1997-2021

Annual freshwater export:
- Total: 2,640 ± 540 Gt/yr
- Solid: 1557 ± 346 Gt/yr
- Liquid: 1083 ± 259 Gt/yr

Nb: excluding subglacial melt and surface runoff

Total freshwater export



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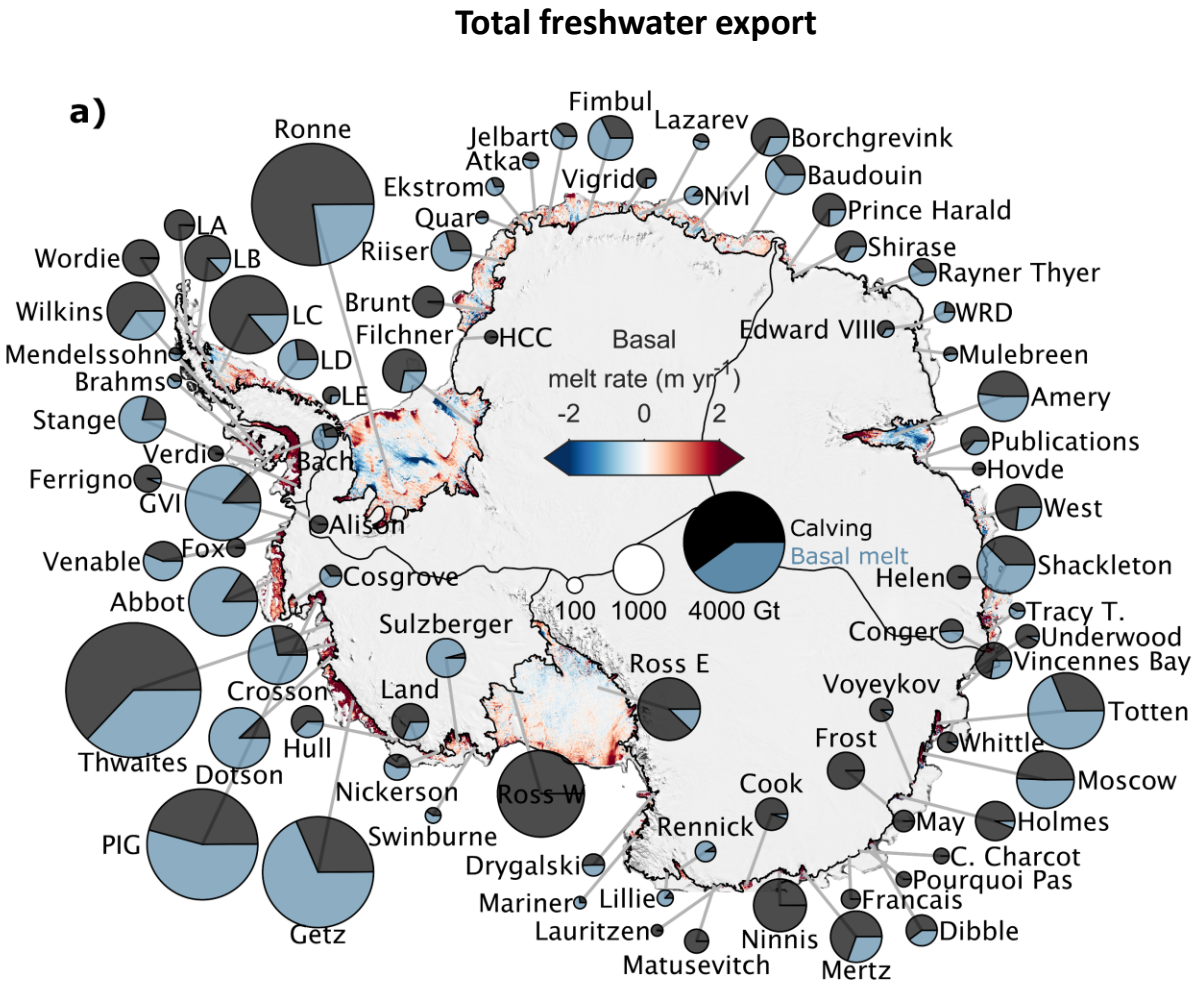
Solid vs liquid freshwater:
- 41% of total freshwater export is liquid
- ~50% if 6 largest calving events are excluded



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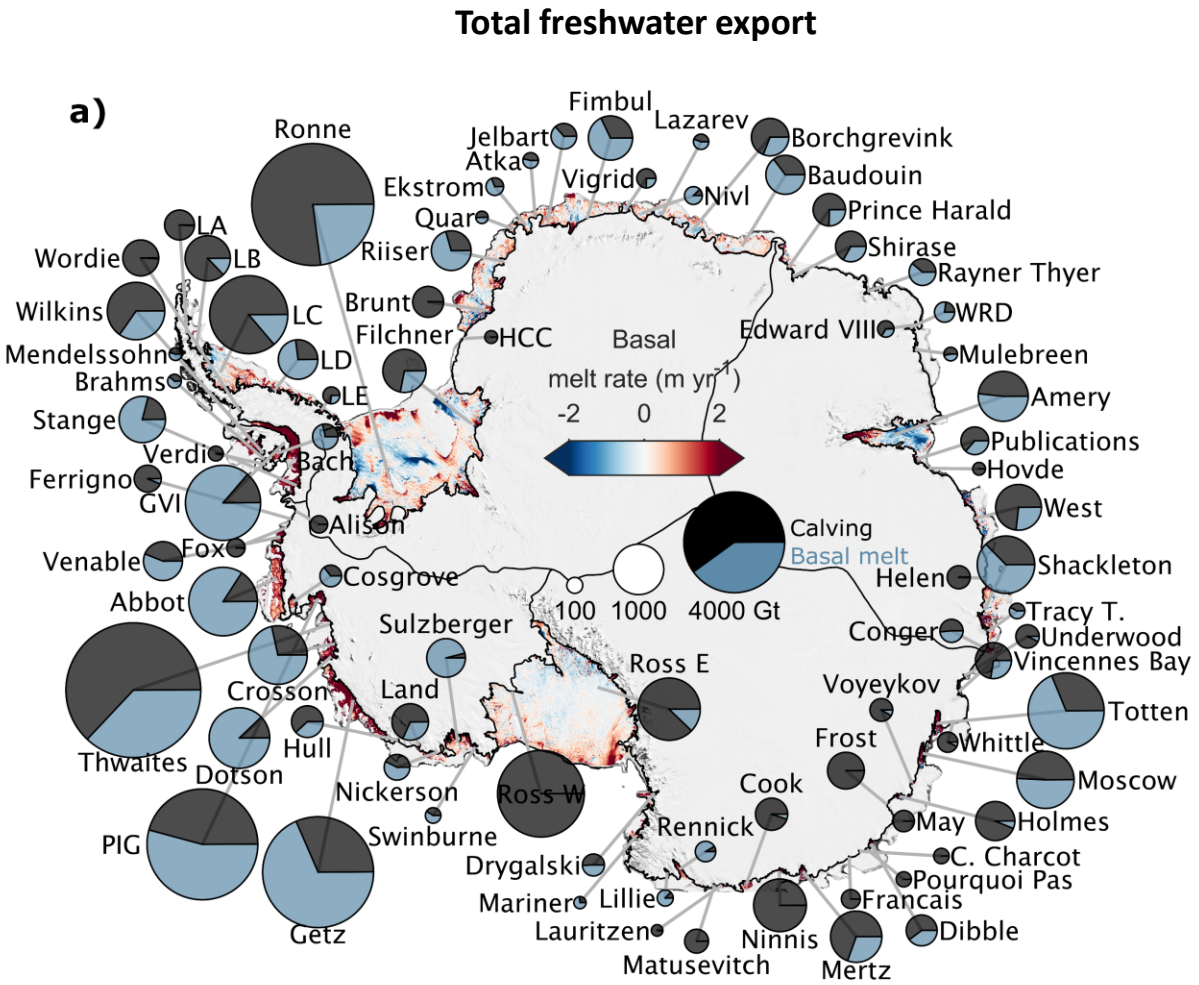

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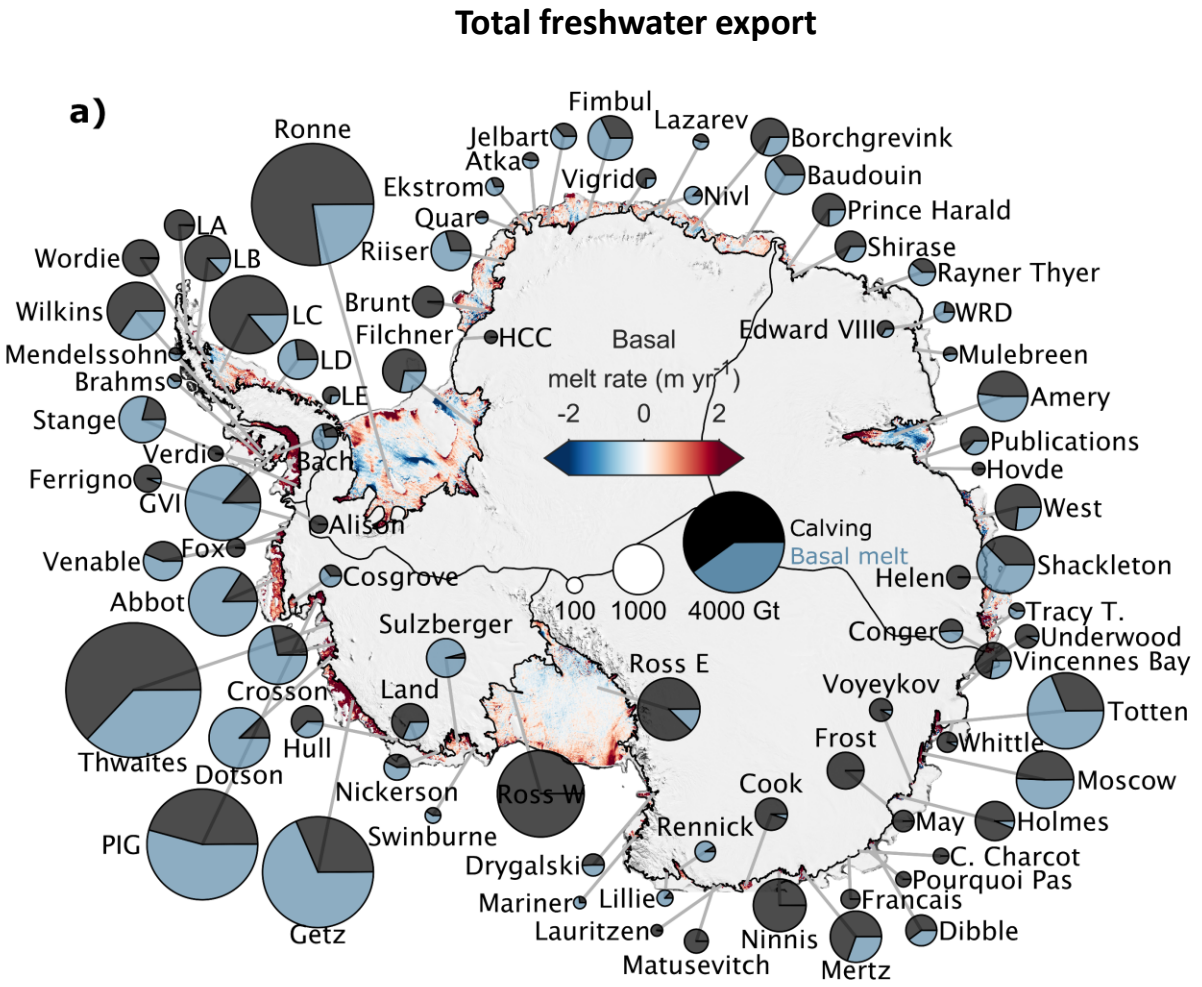
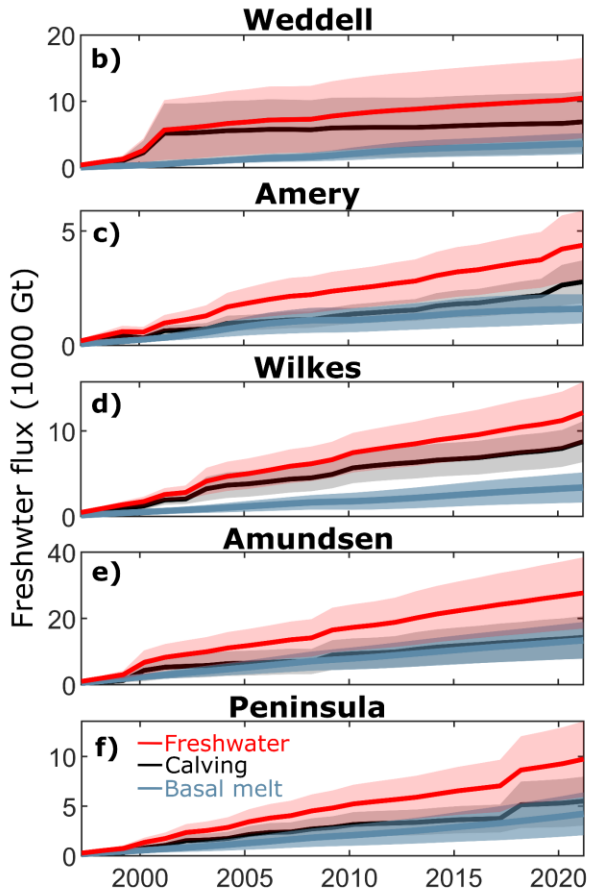
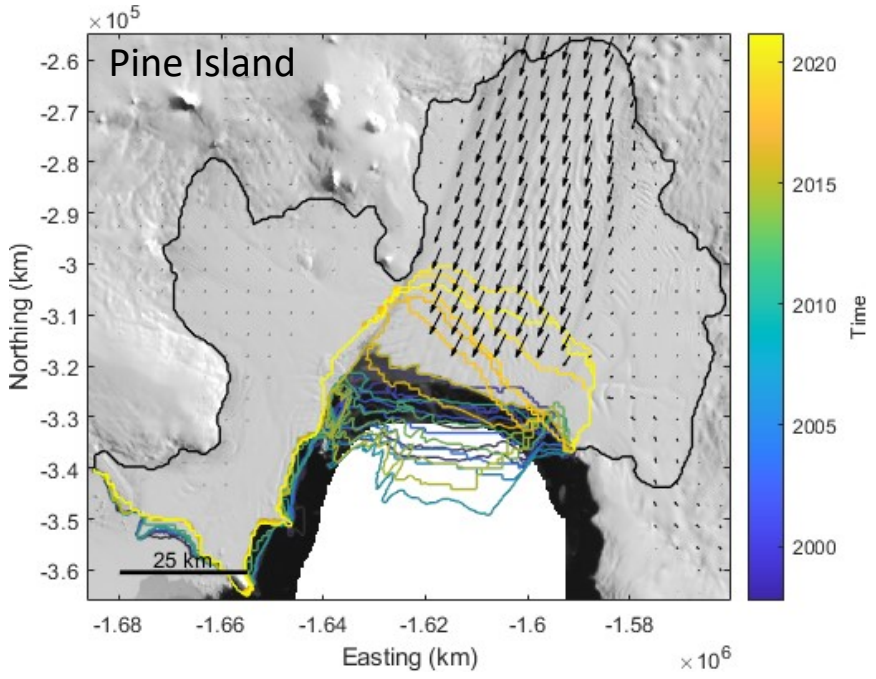
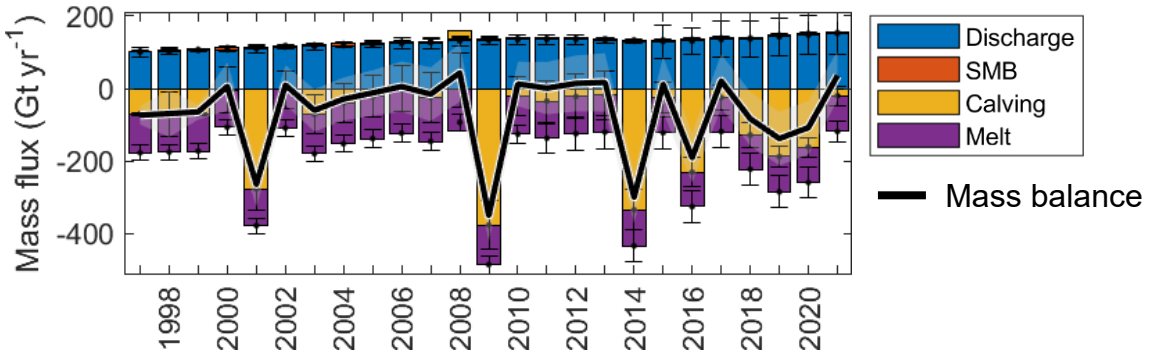
Generally steady freshwater export with intermittent calving spikes
- Weak negative trend of -50 Gt/yr total freshwater flux from Antarctica
- Positive melt flux trends of >2%/yr at 34 ice shelves





Ice shelf mass balance: Pine Island





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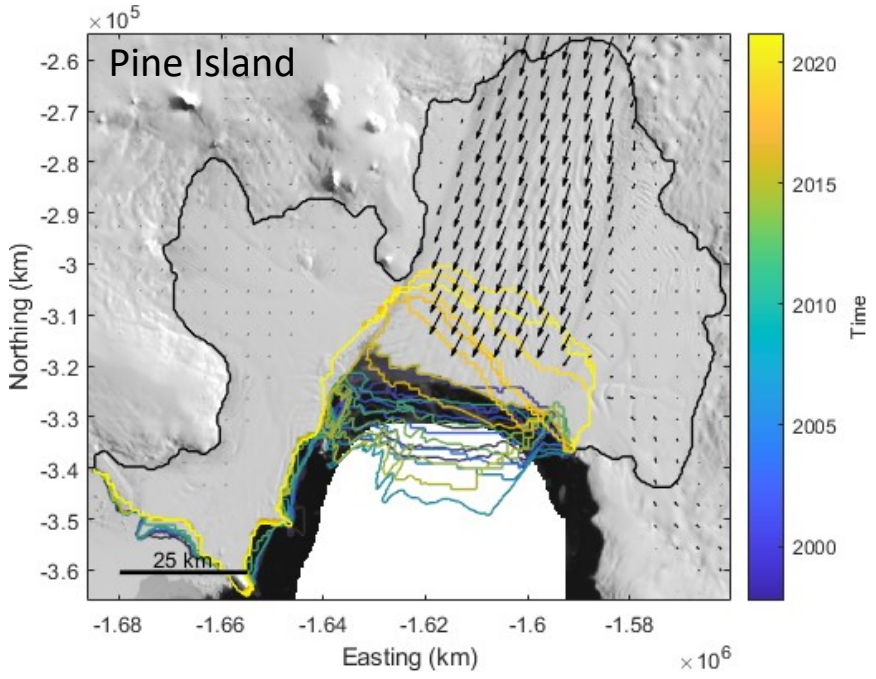
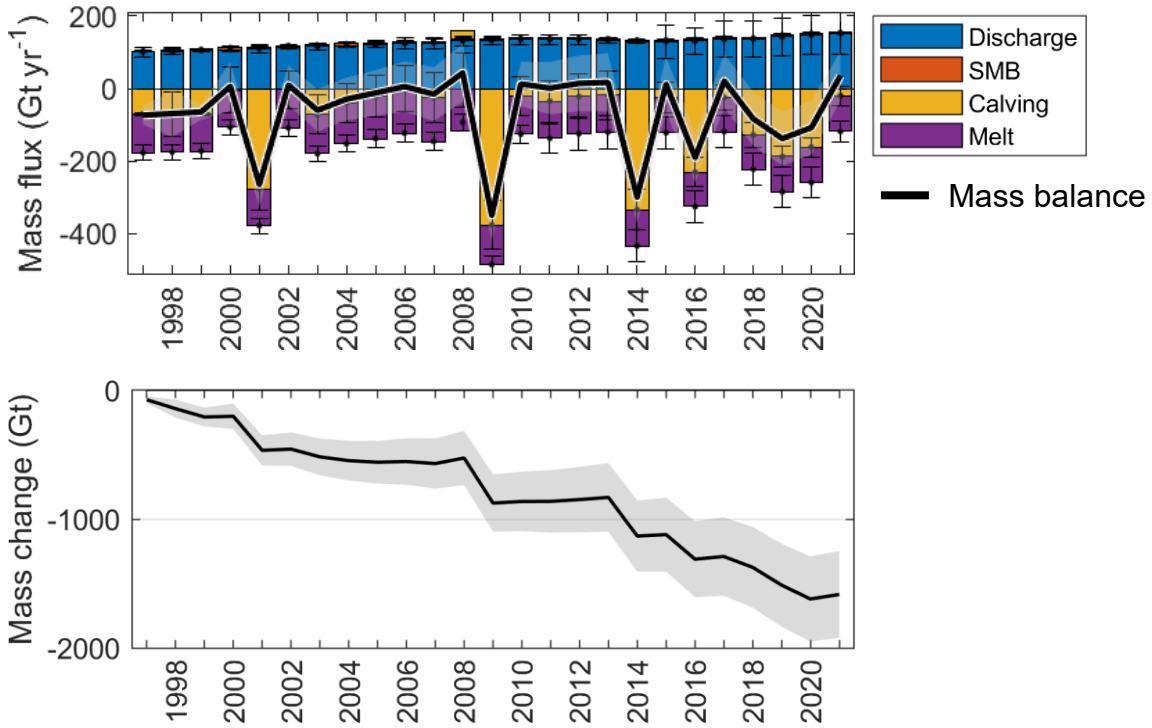




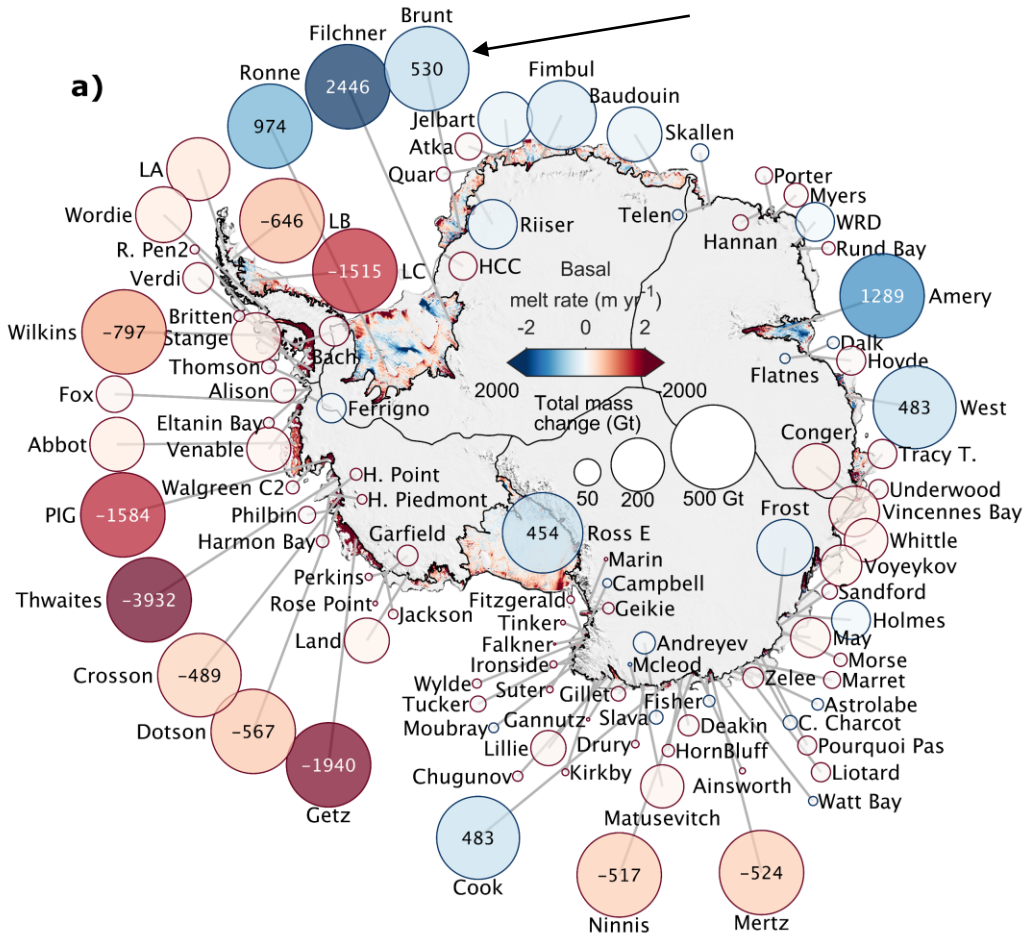
Ice shelf mass change: overview

Total ice shelf mass change

- 103 ice shelves have lost mass
- Net reduction in ice shelf mass of 6,600 ± 1,500 Gt 1997-2021

Total mass change

Nb: I've capped the circle size at 500 Gt



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Large ice shelves are the principal contributors to overall ice shelf mass change:

- 5 ice shelves contribute >50% of gross mass loss: Wilkins, Larsen C, Pine Island, Getz, Thwaites
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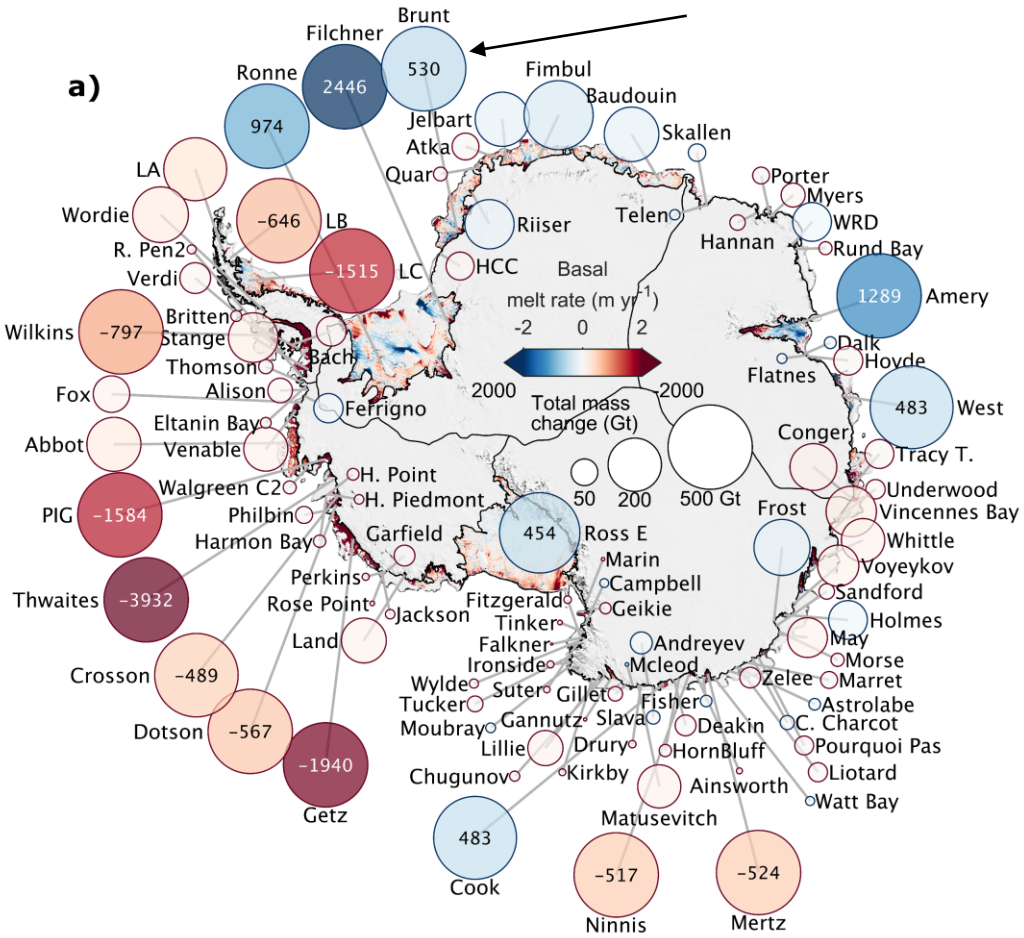

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Gradual ice shelf deterioration is widespread

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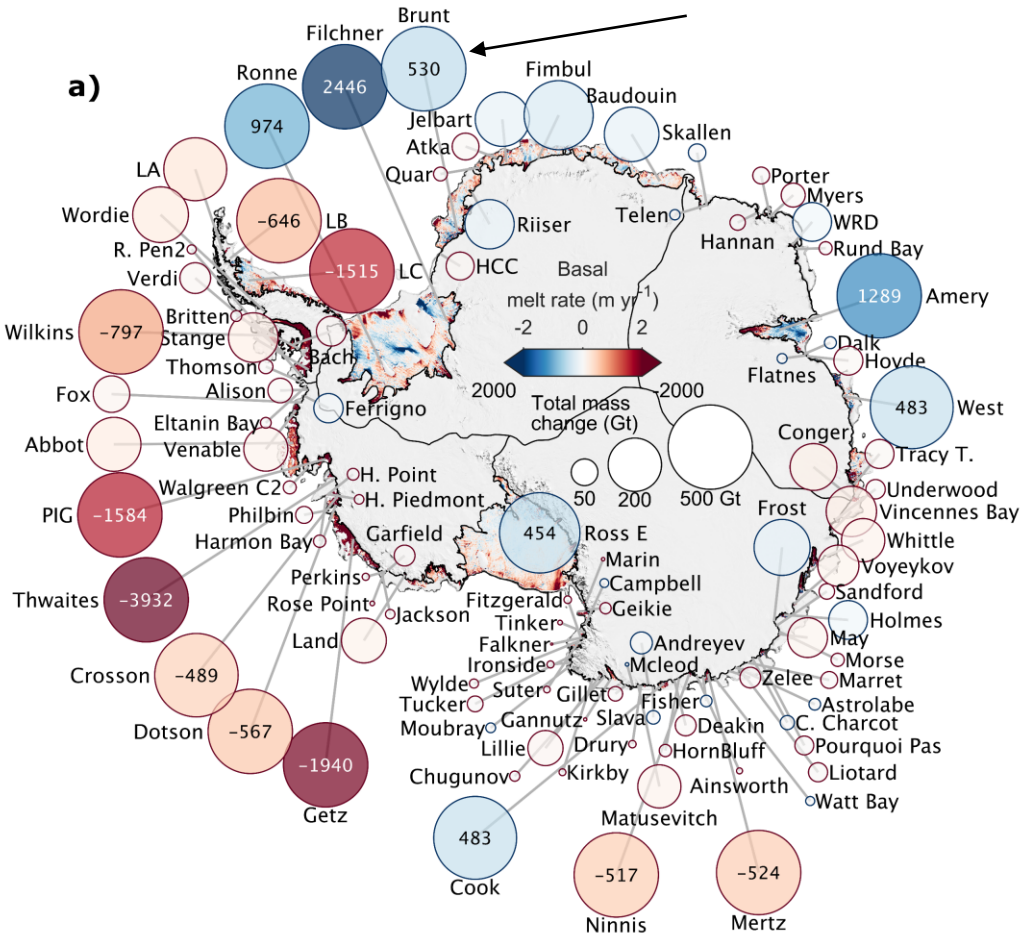
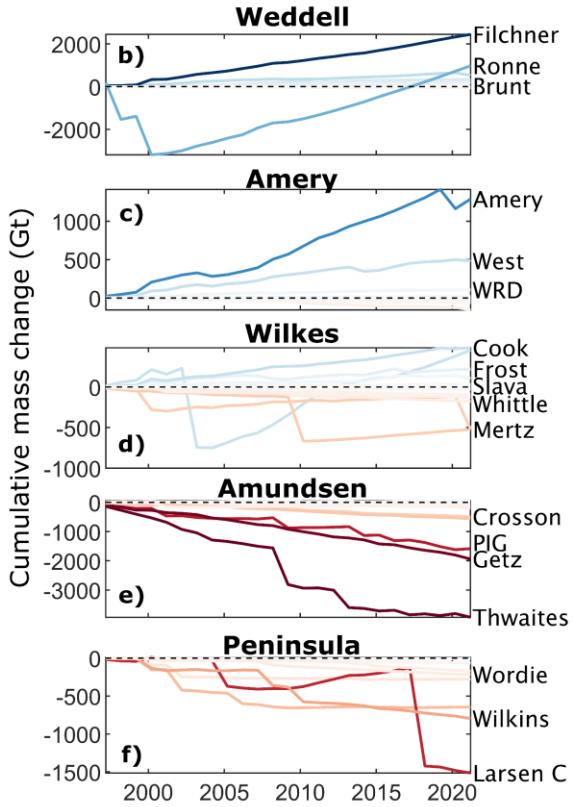


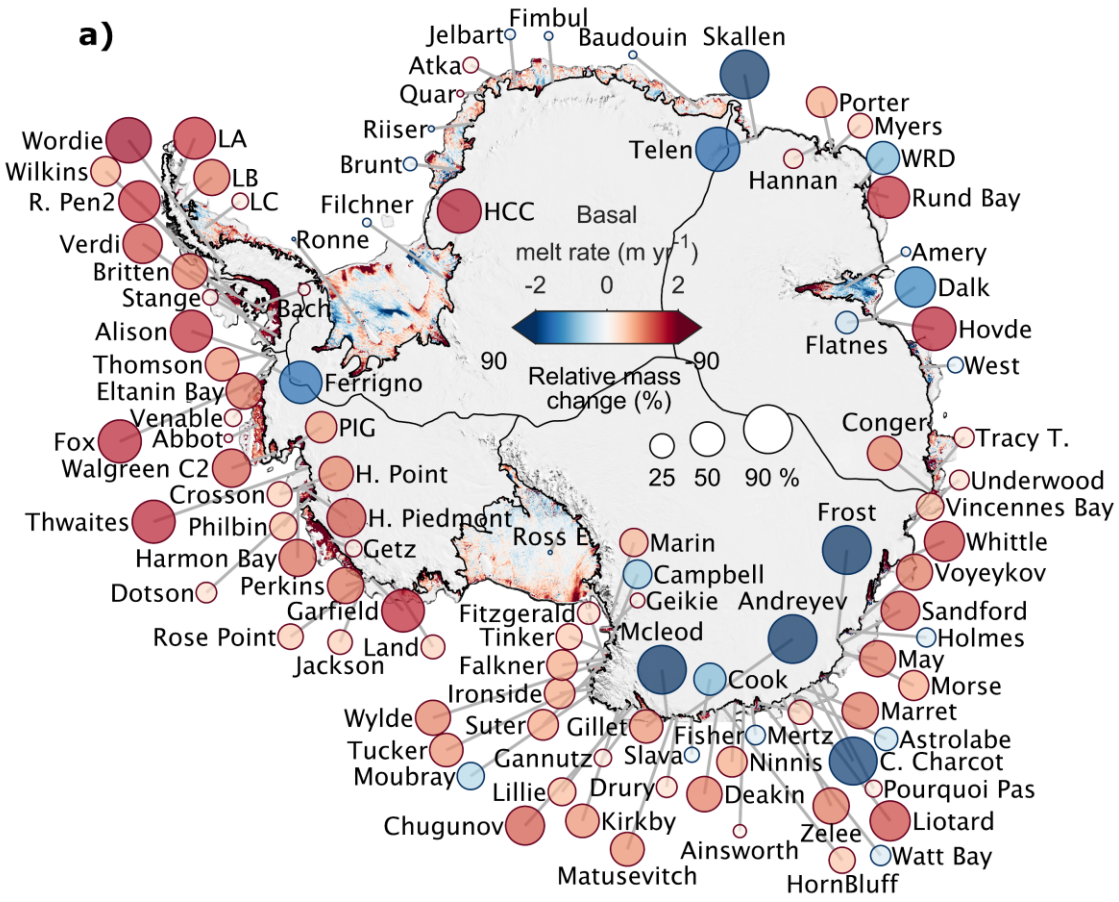


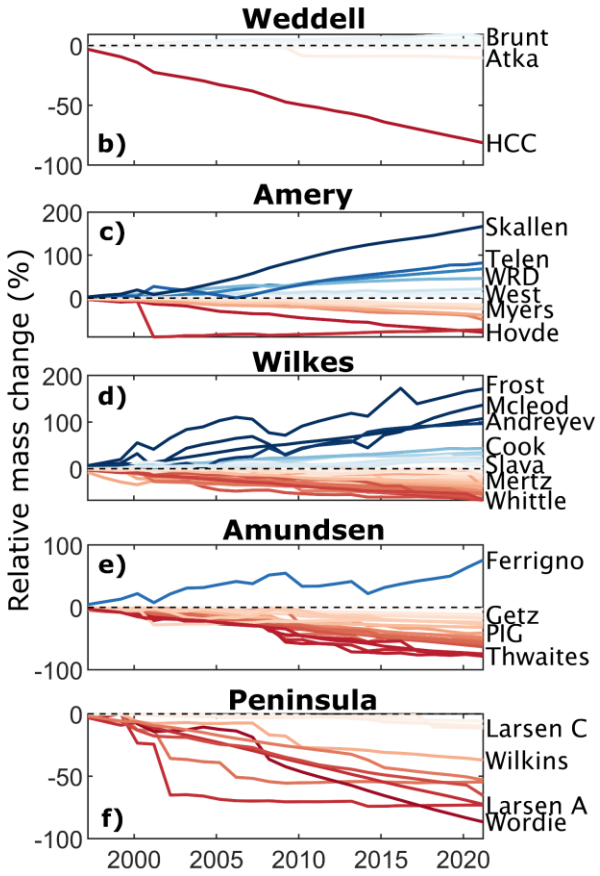
Ice shelf mass change: overview

Relative ice shelf mass change

- 101 ice shelves have a significant trend for mass loss
- 80 ice shelves have reduced in mass by more than 10%

Relative mass change





Ice shelf mass change: overview

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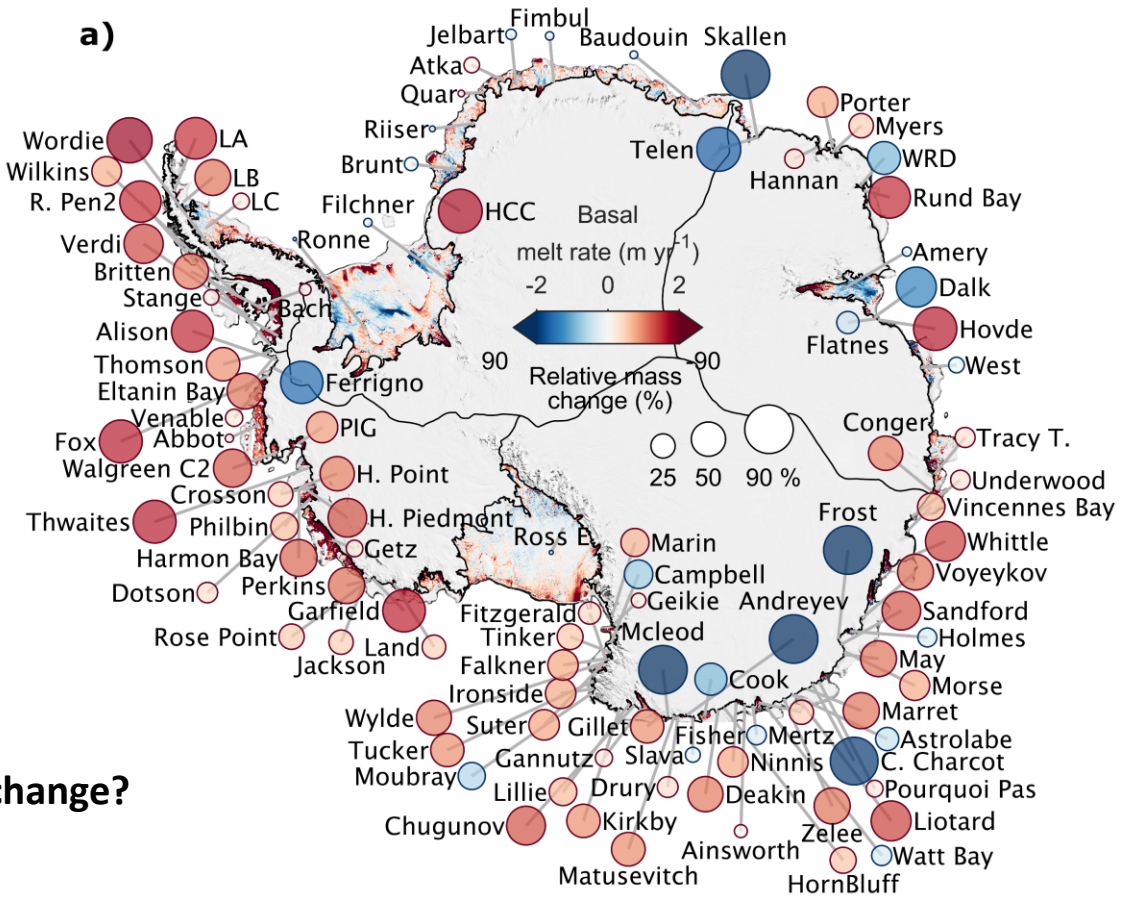
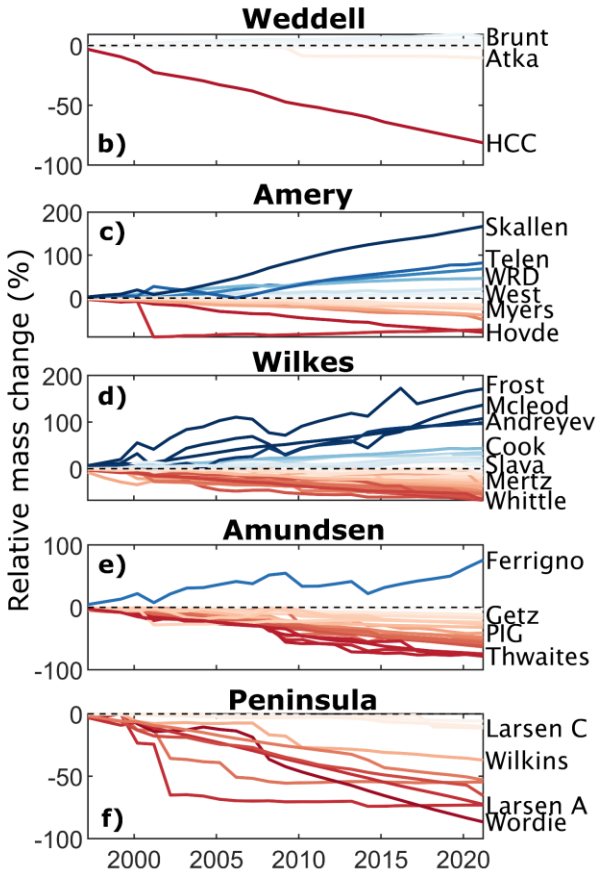
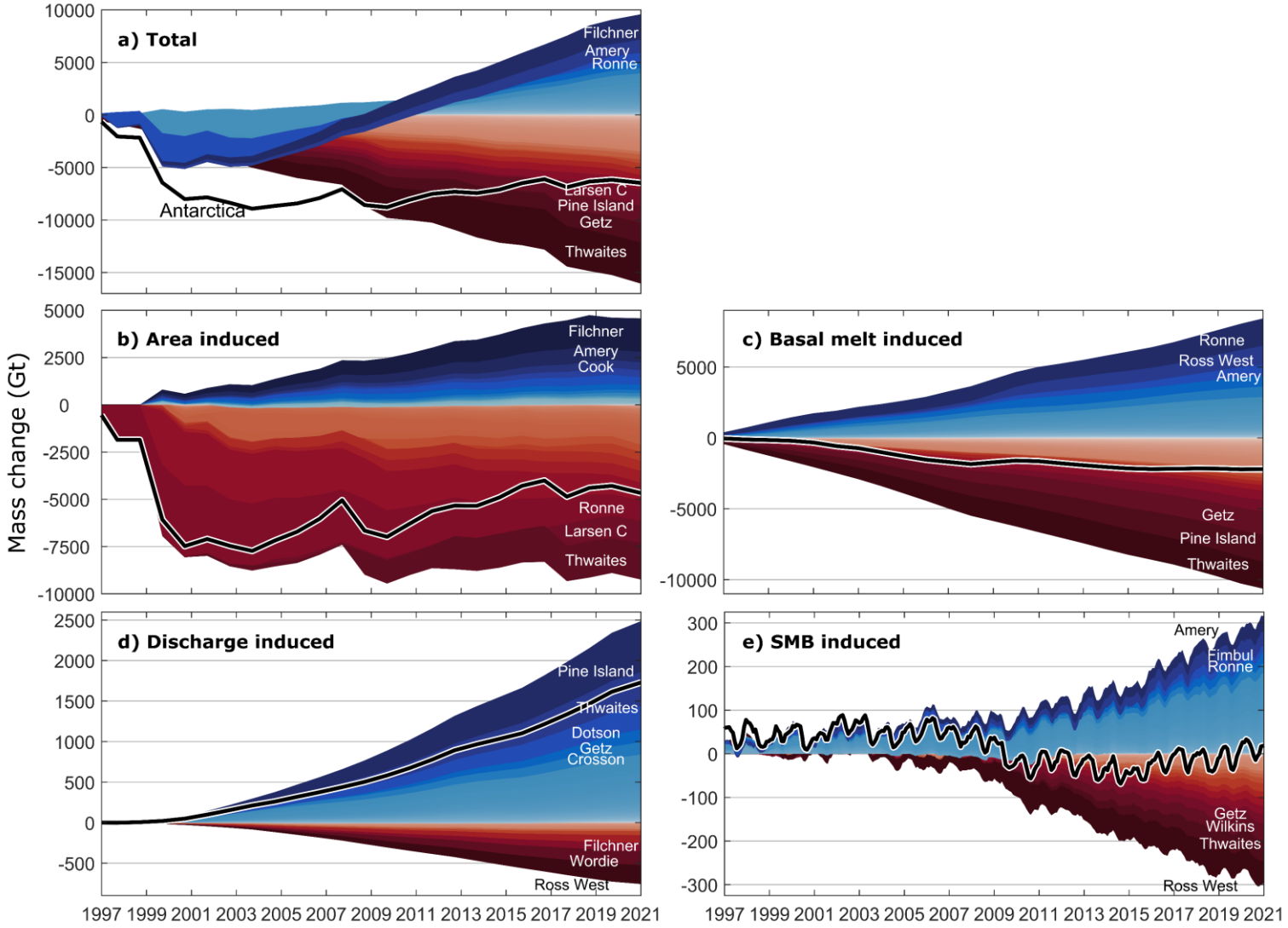
What are the drivers of ice shelf mass change?

Relative mass change





Drivers of ice shelf mass change



Net mass change

- Antarctic wide, majority of mass loss occurs from 1997-2002 because of icebergs A38/39 and A43/44 (Ronne Ice Shelf)
- Net mass gain after 2002 because of growth of Amery and Filchner

Partitioned mass change

- Calving: 4800 ± 700 Gt mass loss
- Basal melt: 3500 ± 1400 Gt mass loss
- SMB: 23 ± 80 Gt mass loss
- Discharge: 1800 ± 800 Gt mass gain

Drivers of ice shelf mass change

Pine Island:

- Net mass change: -1580 Gt
- Net thickness change due to basal melting: -1769 Gt (111% of the total mass change)
- Net area change: -450 Gt (28% of the total mass change)

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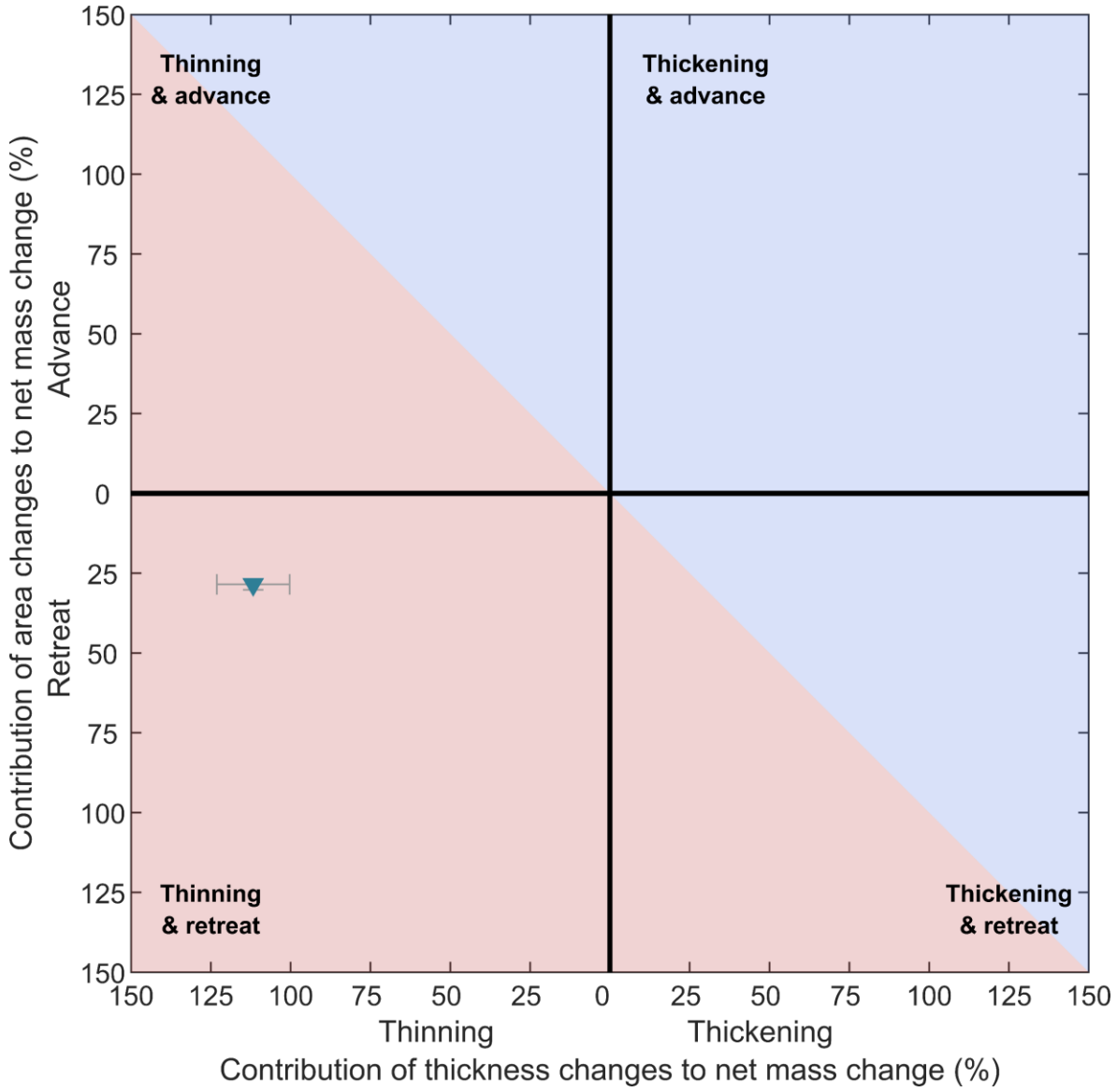

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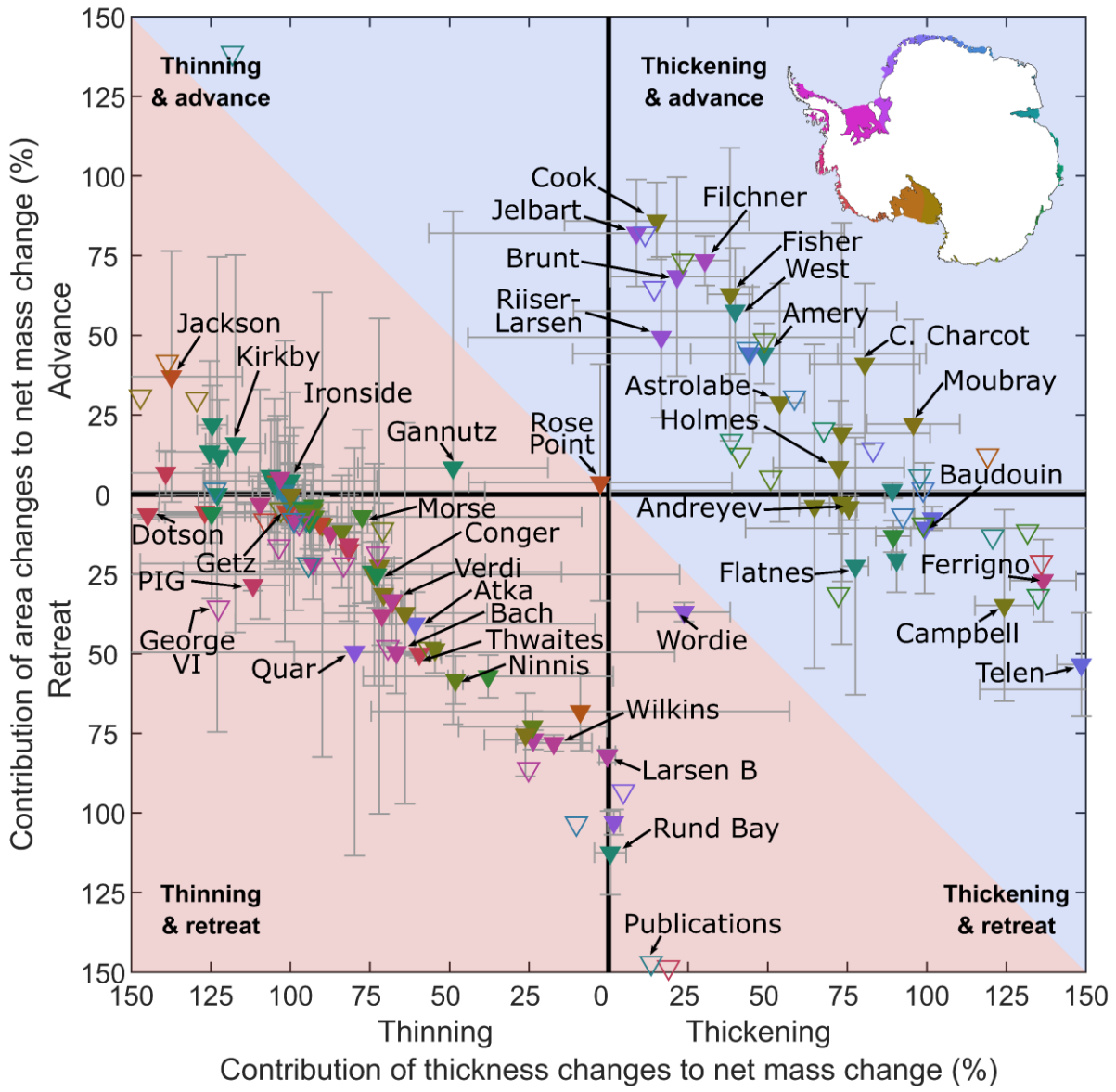
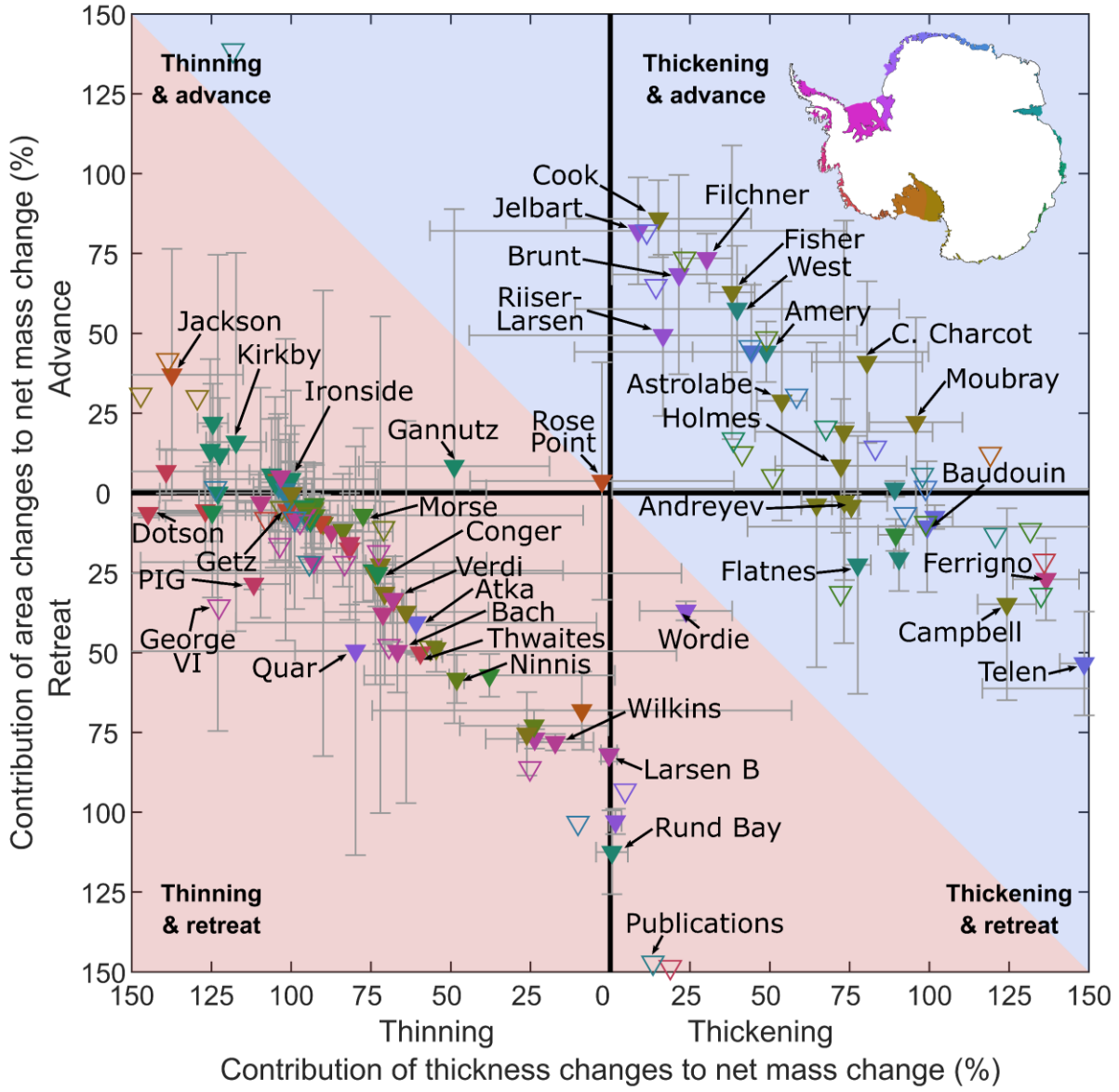


Drivers of ice shelf mass change

Basal melting is principal contributor to mass change of individual ice shelves

- Basal melting dominates mass loss for 80% of shelves

Basal melting dominant in the Amundsen/Bellingshausen sea, Princess Elizabeth Land and parts of Dronning Maud Land



Summary

Large Antarctic ice shelf freshwater export:

- 66,000 ± 13,500 Gt 1997-2021

Many Antarctic ice shelves deteriorated from 1997 to 2021

- Net reduction in ice shelf mass of 6,600 ± 1,500 Gt
- 103 ice shelves have lost mass
- 80 ice shelves have reduced in mass by more than 10%

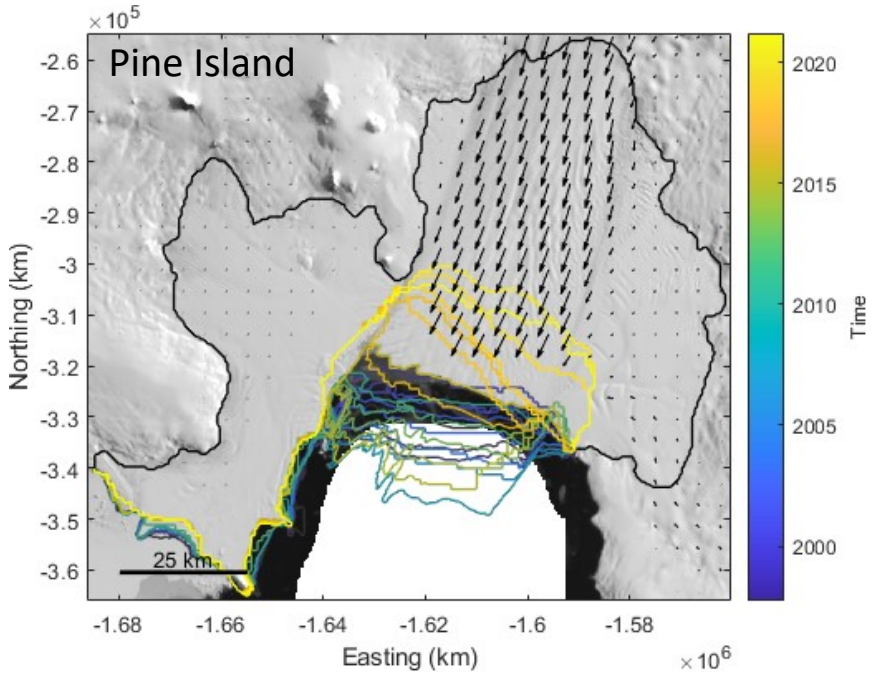
Many Antarctic ice shelves are *deteriorating*

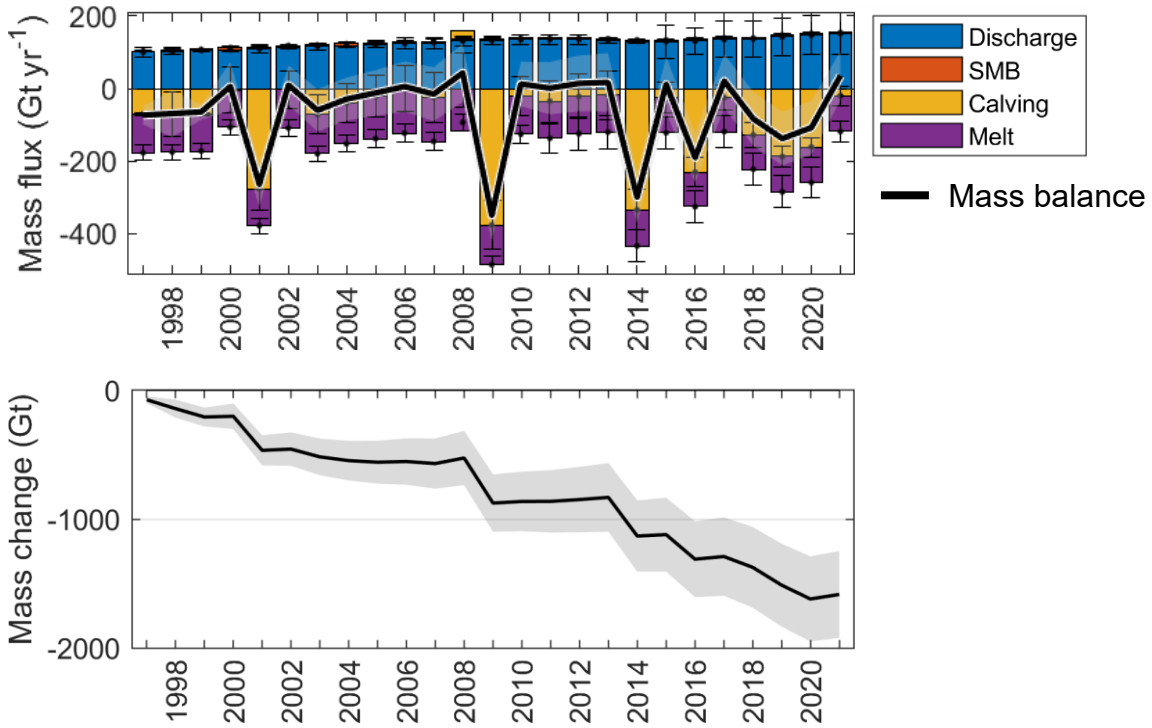
- 101 ice shelves have a significant trend for mass loss

Basal melt appears to be driving the majority of deterioration for individual ice shelves

Large range of observed discharge responses to a given increase in basal melting or calving

Ice shelf mass balance: Pine Island





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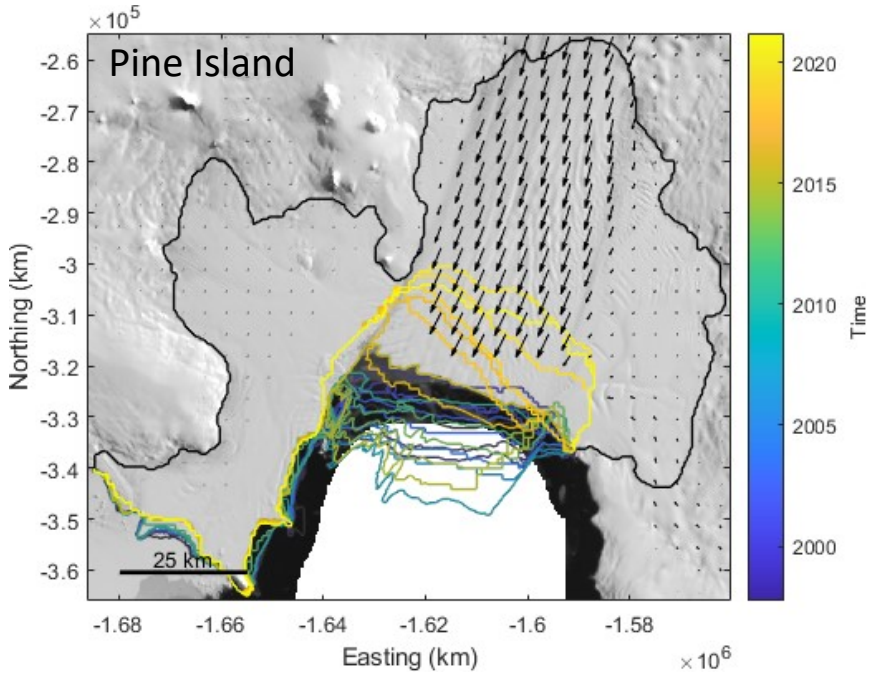
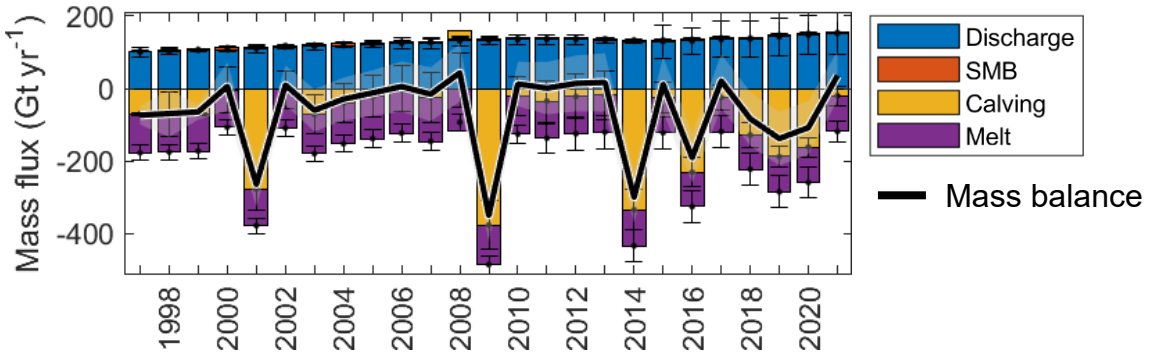
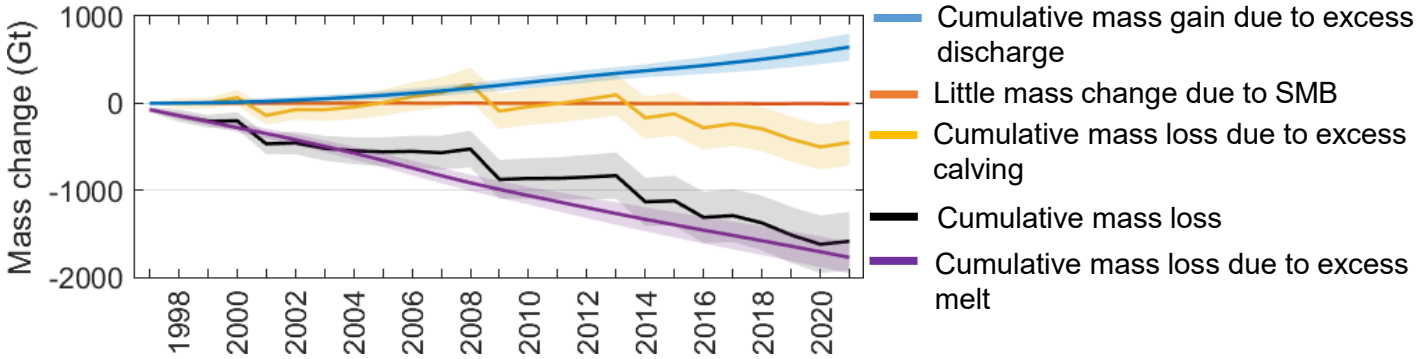
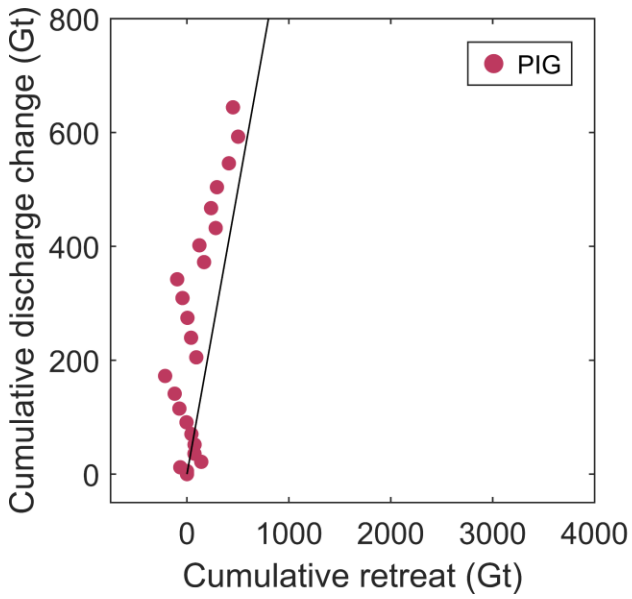
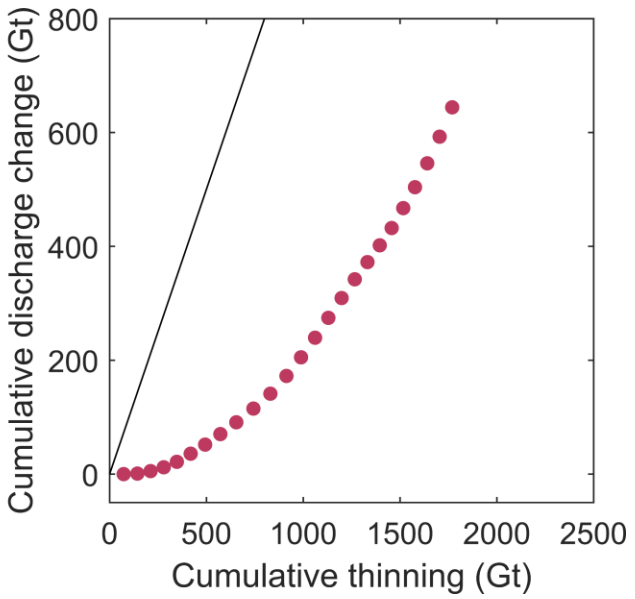




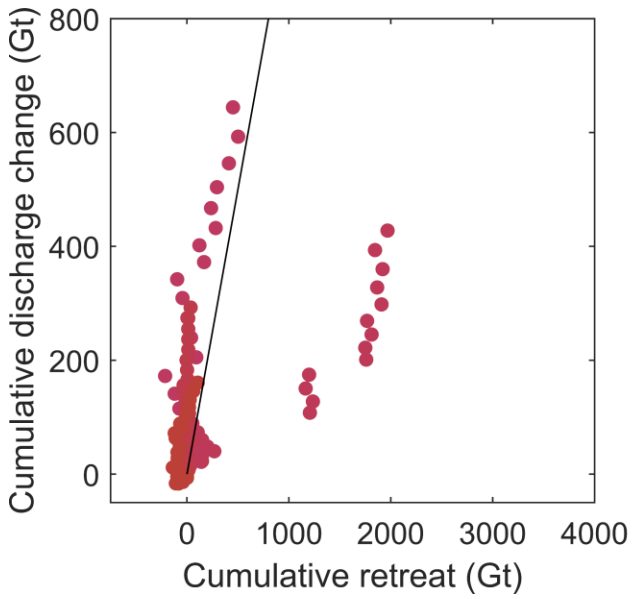


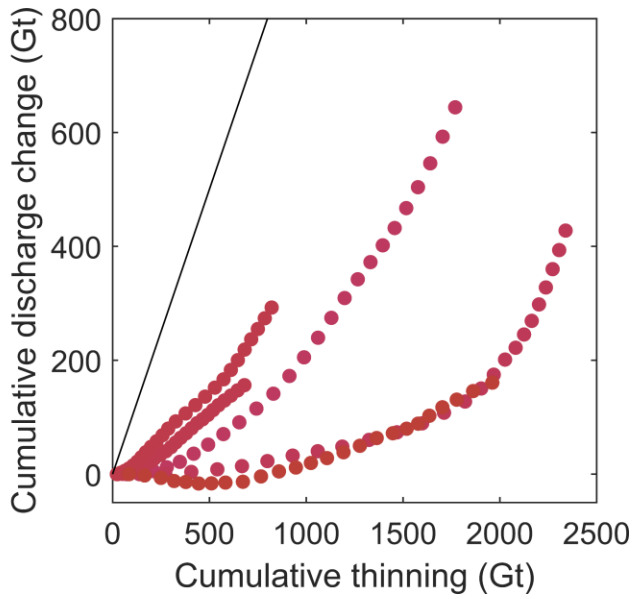
Impact on grounded ice – Pine Island Glacier



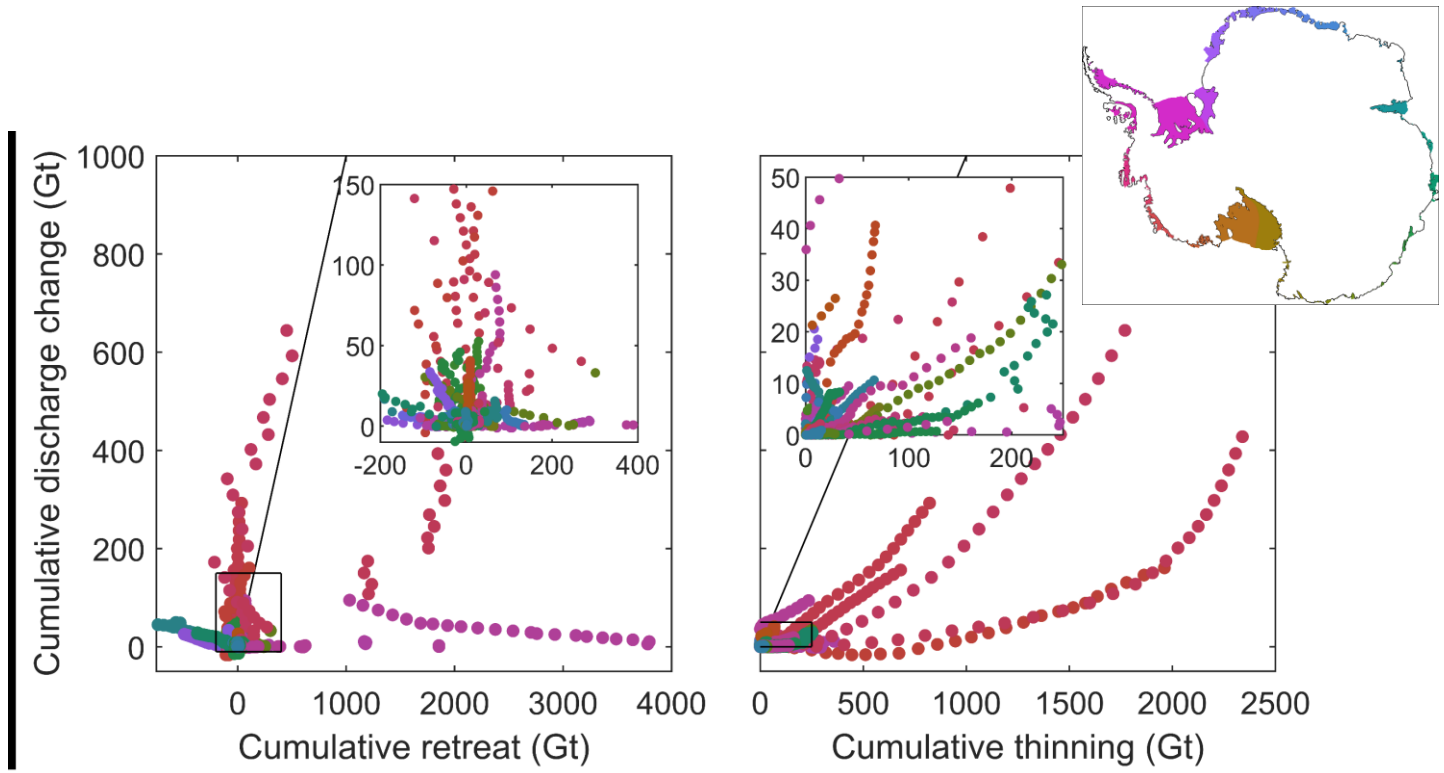


Impact on grounded ice – Amundsen Sea Embayment





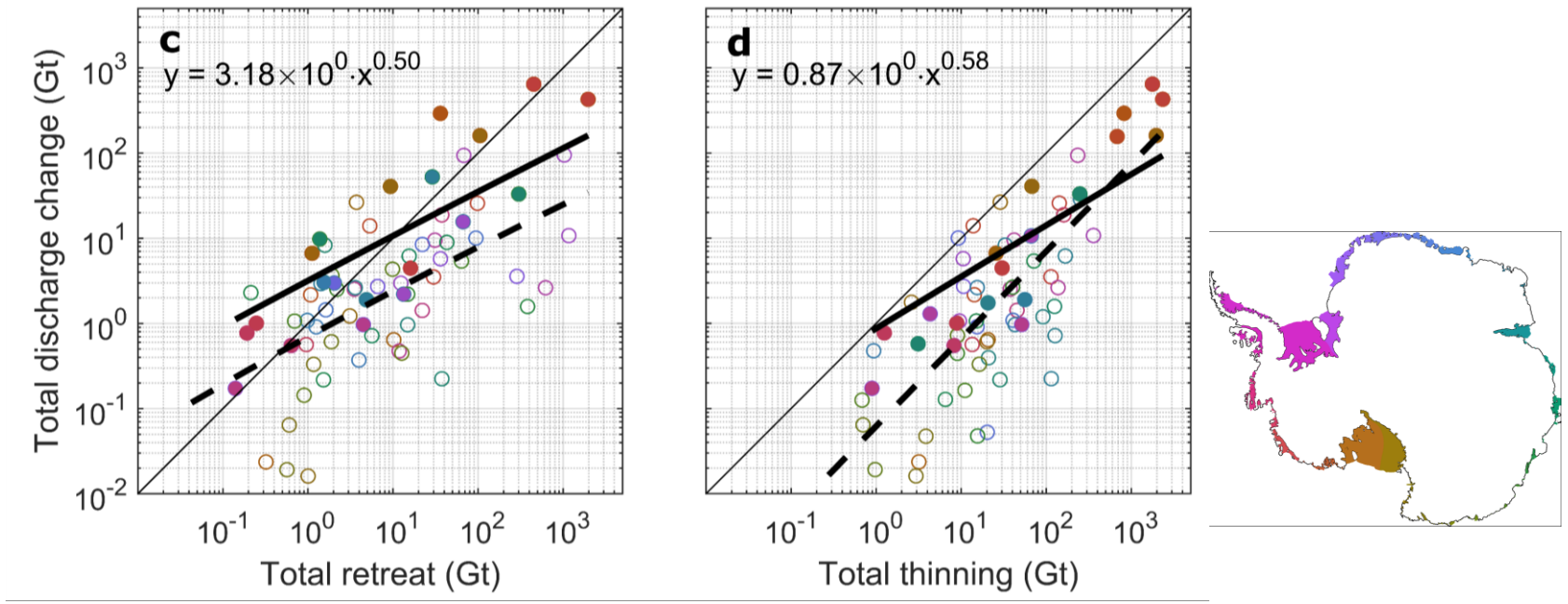
Impact on grounded ice – Antarctic perspective



Individual ice shelves

- Retreat & discharge: highly variable relationship
- Thinning & discharge: generally positive relationship
- Large spread in strength of relationship

Impact on grounded ice – Antarctic perspective



Antarctic-wide

- Overall relationship: discharge increases by about 10% of the observed thinning or retreat
- But very large spread and ambiguous timescale