Satellite observations of ice sheet velocity and grounding line dynamics: science goals, data continuity, and gaps.

Science questions.

- How fast are the glaciers and ice sheets contributing to sea level rise now and how fast will they contribute during the coming decades?

- What are the risks of collapse of the marine-based sectors of Greenland and Antarctica?

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Mass Balance = Surface_mass_balance – Ice_discharge

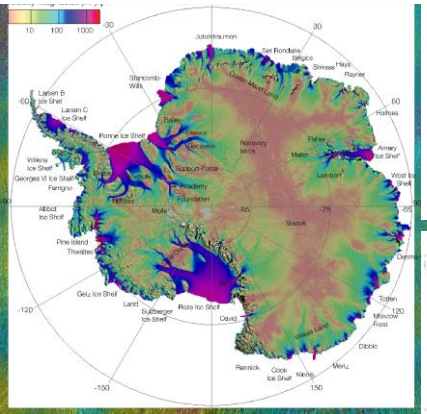
Ice_discharge = Integration of velocity and thickness at grounding line
Surface_mass_balance = Integration of SMB over drainage basin.

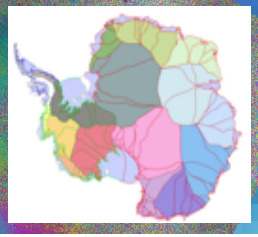
Velocity, grounding line: ERS-1, ERS-2, RADARSAT-1, RADARSAT-2, ENVISAT ASAR, ALOS PALSAR, ALOS-2 PALSAR-2, Copernicus SENTINEL-1a/b, Cosmo SkyMed, TerraSAR-X, TanDEM-X, LANDSAT-8, SENTINEL-2

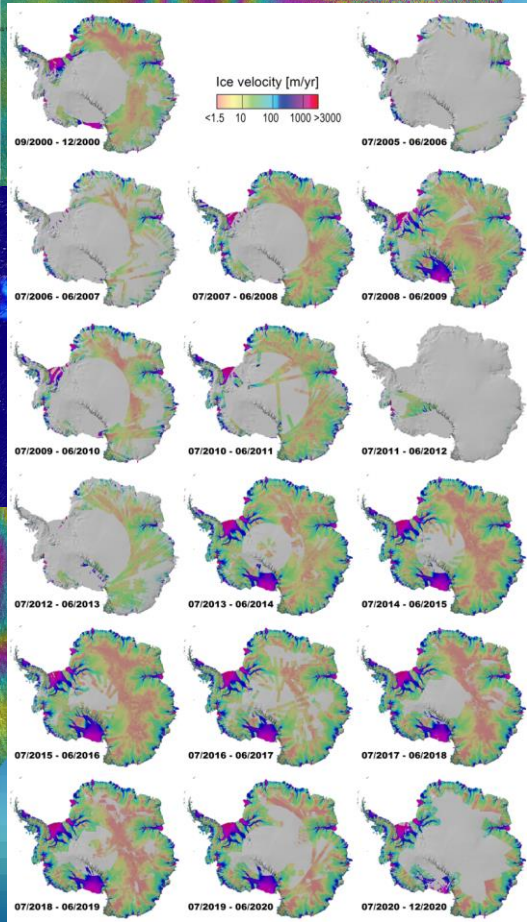
Surface topography: TanDEM-X DEM (Copernicus DEM), REMA DEM.

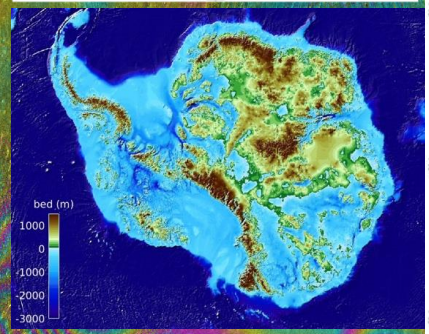
Ice_thickness: Bedmap, NASA Operation IceBridge, BedMachine Antarctica

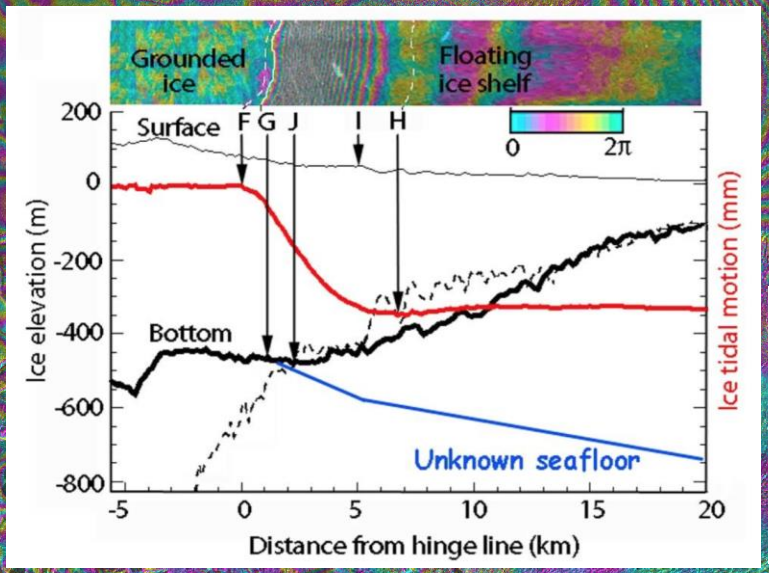
SMB: RACMO2.3p1 and 2.3p2 w. ERA5











- Velocity within 3-4 meters/year
- GL within a few 100 meters.
- Ice thickness within 10-60 meters
- SMB within a few % from RCMs + and re-analysis.

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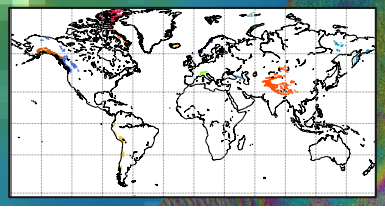
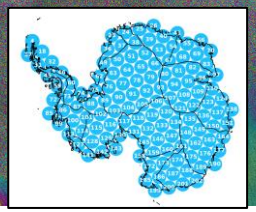
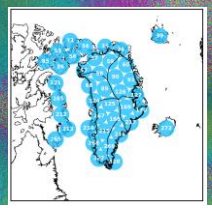
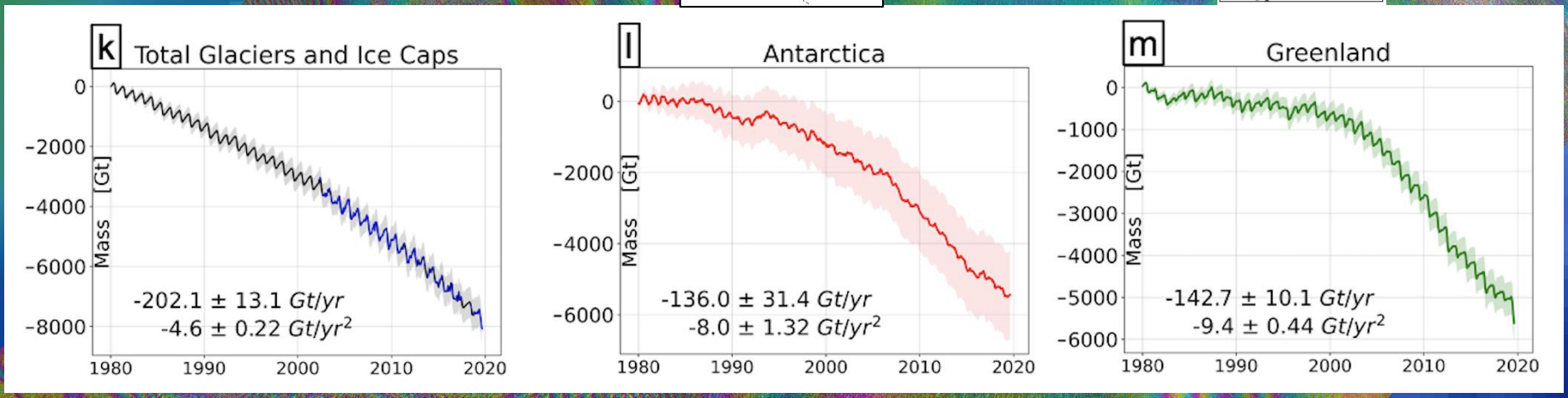


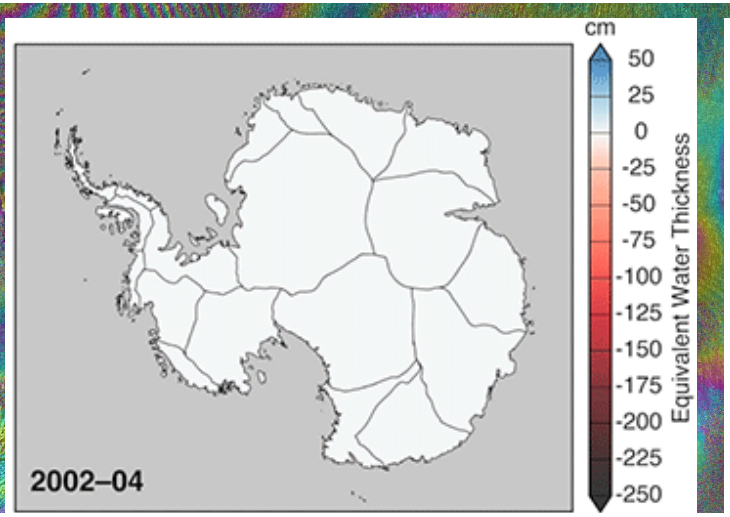


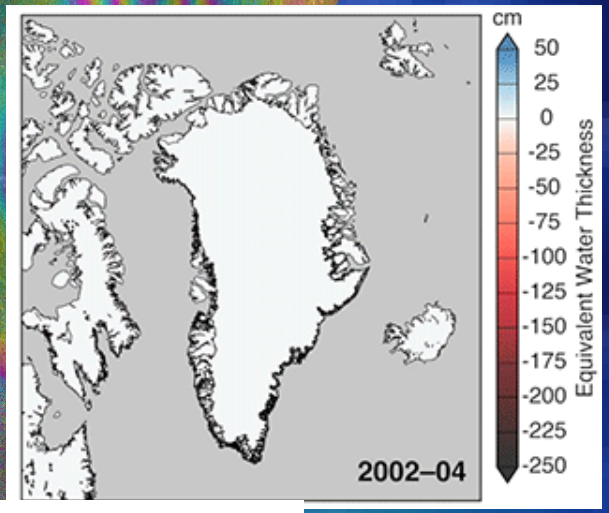




IMBIE-1-2-3 reports

Acceleration of
22 Gt/yr every year →
1 m SLR by 2100





Graphics from Rignot et al., 2019; Mouginot et al., 2019; Velicogna et al., 2022; Ciraci et al., 2023

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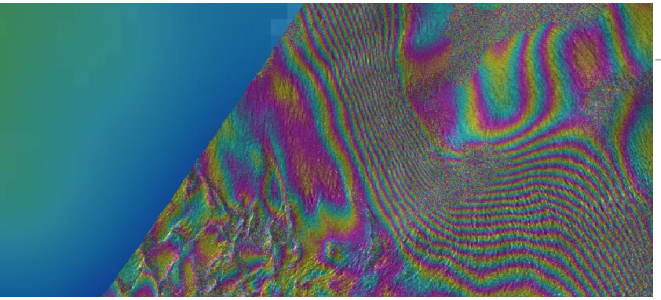
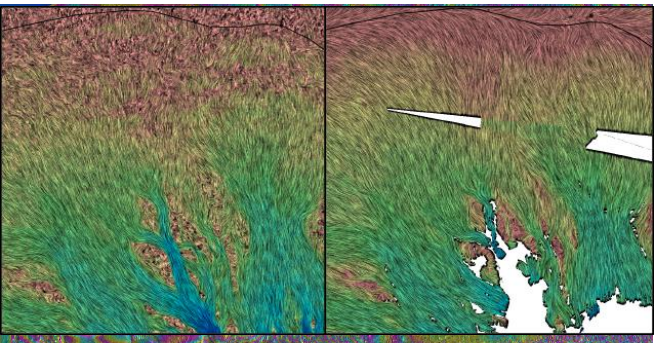
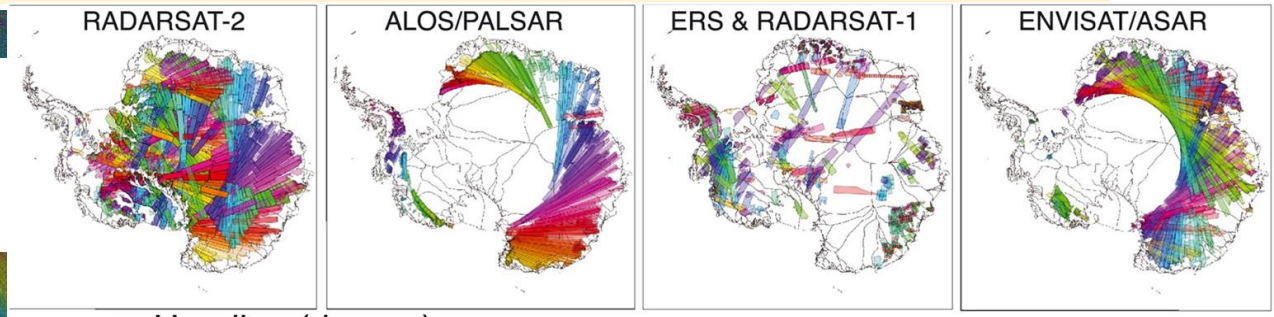
With phase only, velocity precision is 10-20 cm/yr versus 1-2 m/yr with speckle tracking

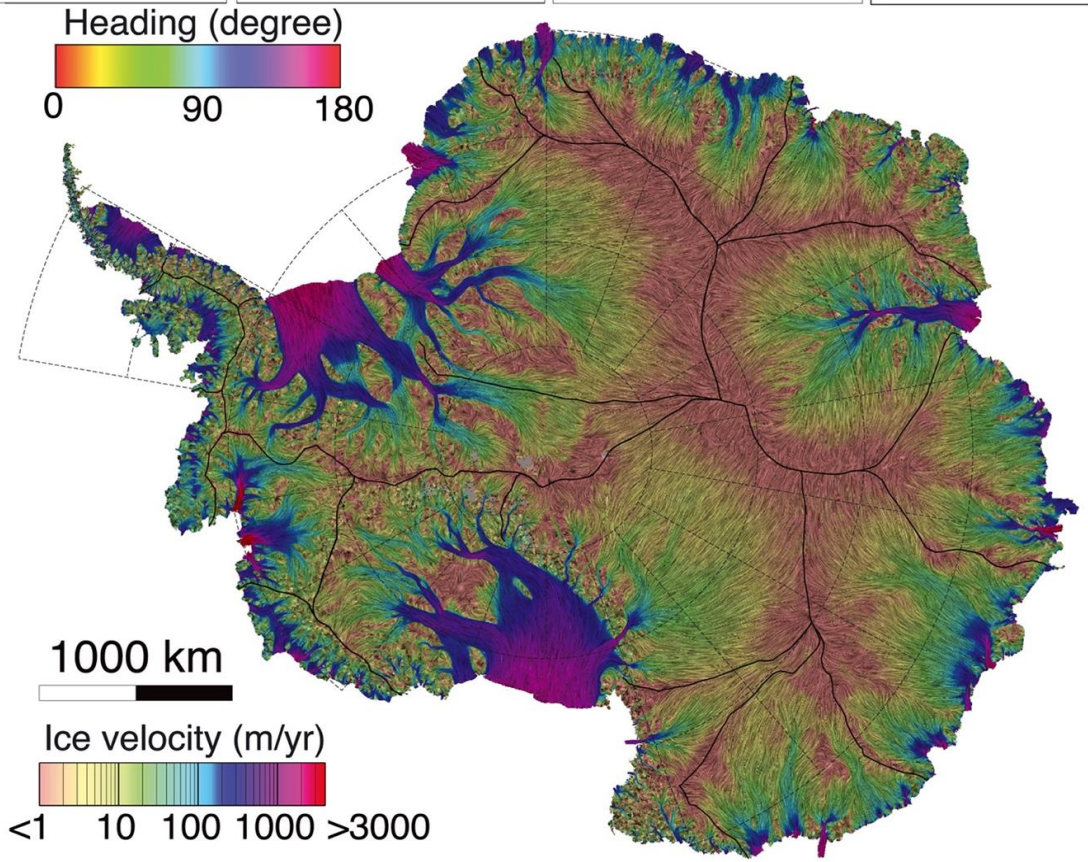


Speckle tracking vs Phase



Better delineation of ice divides with velocity direction, detect of subglacial events, grounding lines, speed up, rifting, etc.





Graphics from Mouginot et al., 2019; 10 years of data, six sensors

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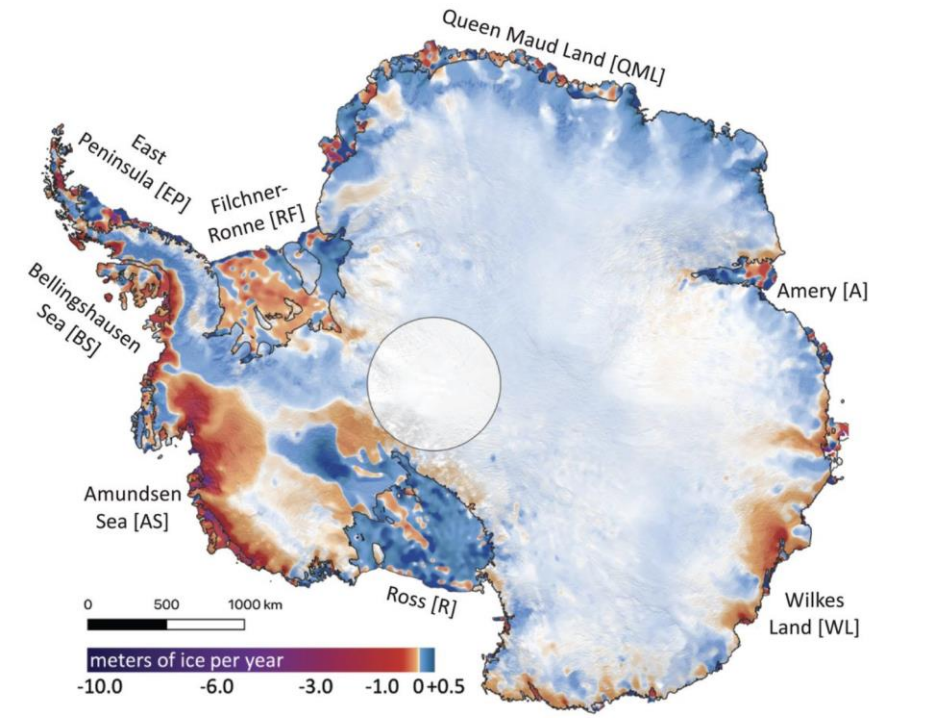
Geophysical Research Letters
10.1029/2022GL100141



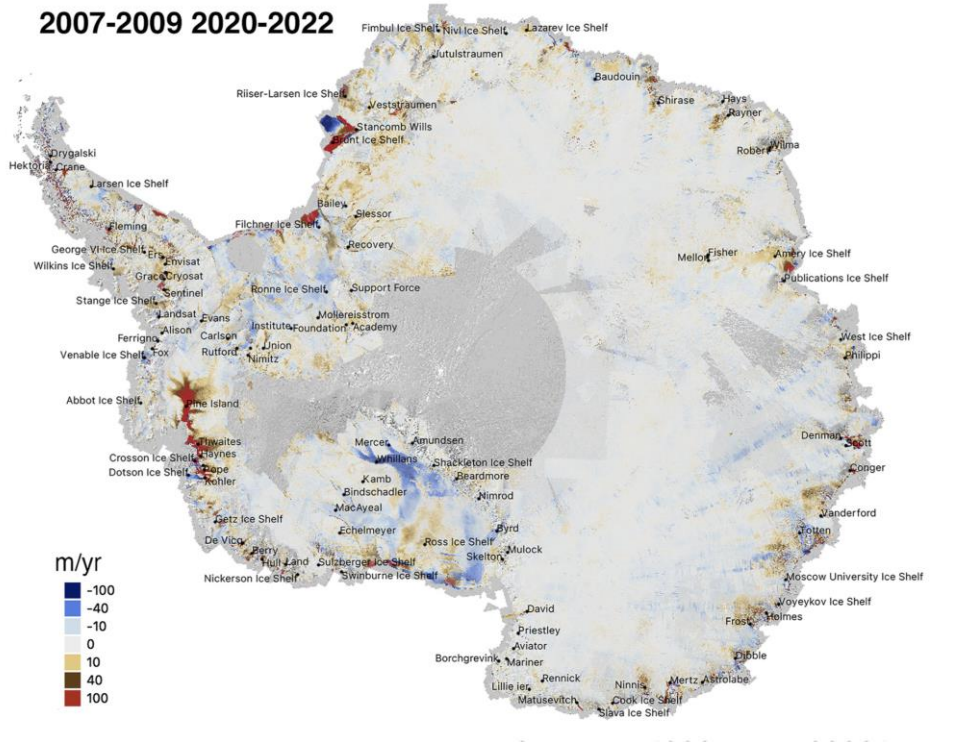
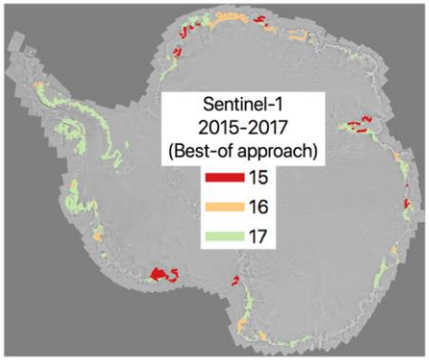


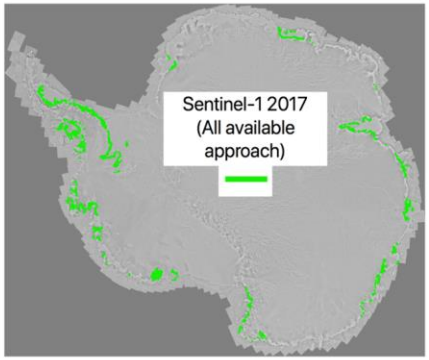
Figure 3. Multi-year mosaic of change in ice motion from 2007–2009 to 2020–2022. Color coding is the same as Figure 2.

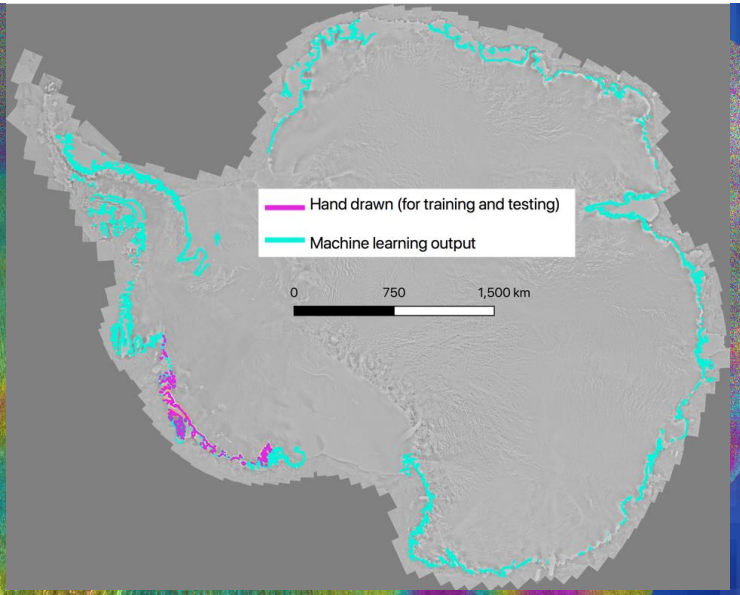
How far and how fast do changes in ice velocity propagate inland?

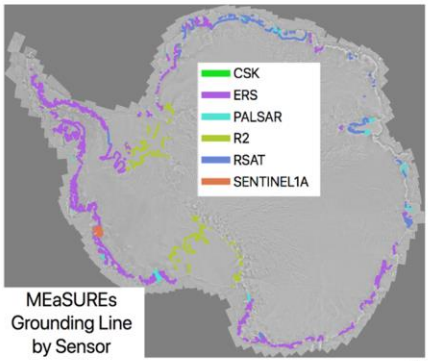
An answer helps constrain basal conditions (sliding laws) (Kahn et al., Nature 2023).

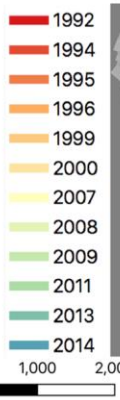
Satellite observations of ice sheet velocity and grounding line dynamics: science goals, data continuity, and gaps.

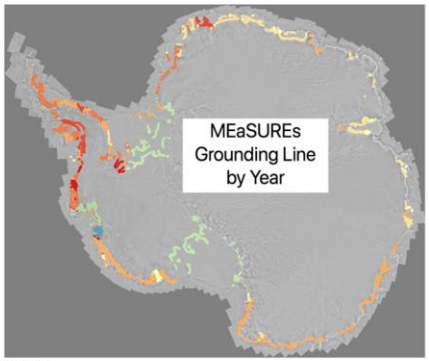


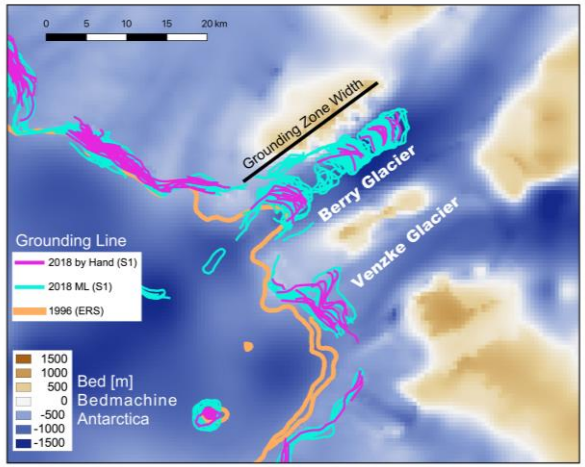




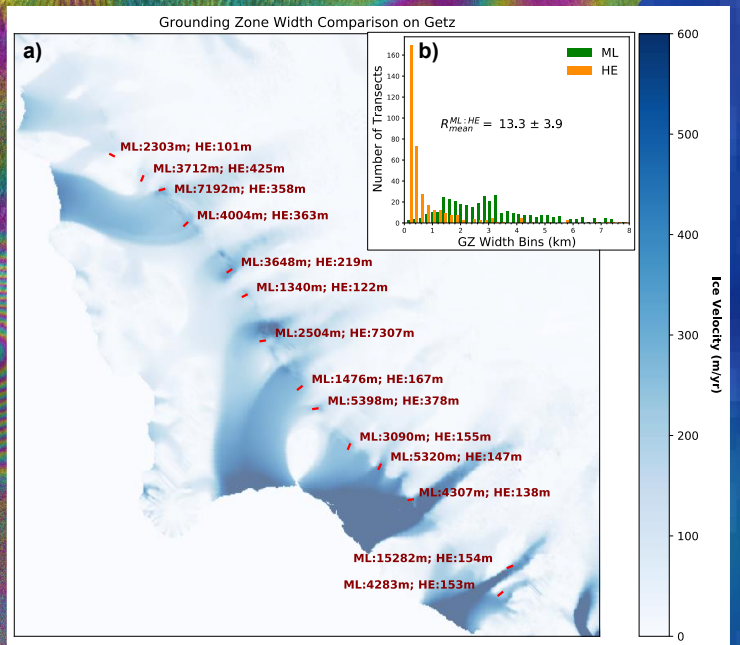






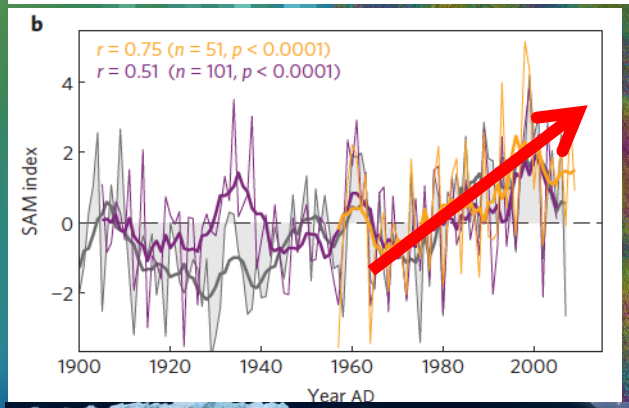


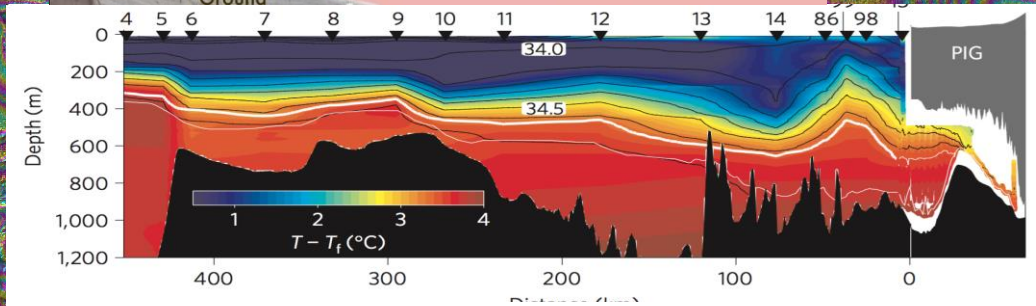
ML tools to map grounding lines repeatedly using multiple SAR sensors (Mohajerani et al., 2021).

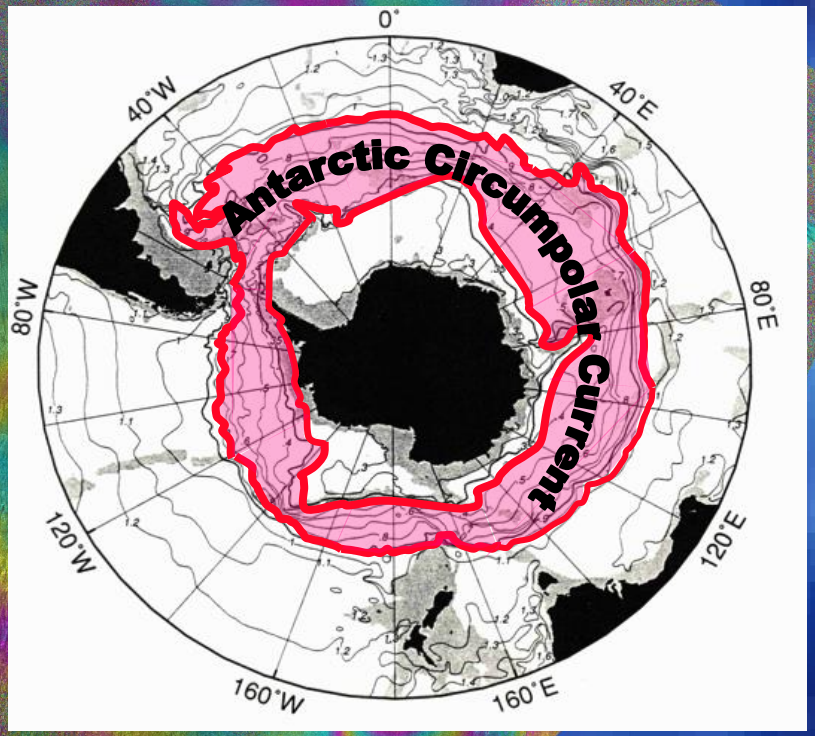


Satellite observations of ice sheet velocity and grounding line dynamics: science goals, data continuity, and gaps.

Major advance of the last 20 years ..







CDW pushed by enhanced westerlies (GHG / O_3) melt glaciers faster.

To get it right, we need bathymetry and ocean state on CS/IS.

Ice shelf bathymetry unmapped.

Graphics from D. Thompson et al., 2002; Abram et al., 2014; Spence et al., 2014; Mayewski et al., 2013, and Martinson, 2011.

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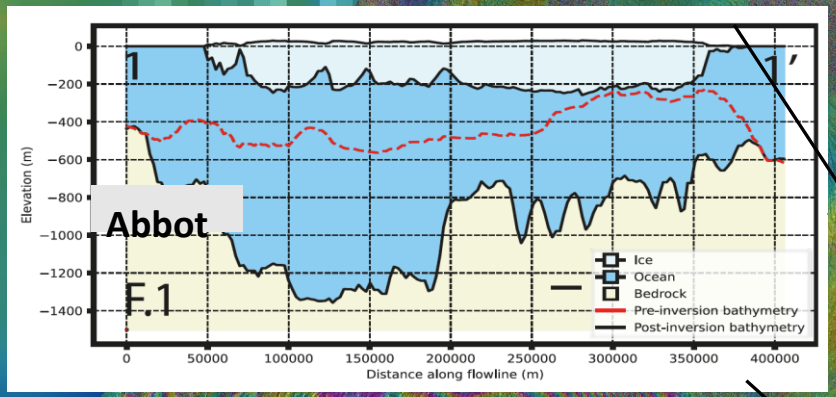
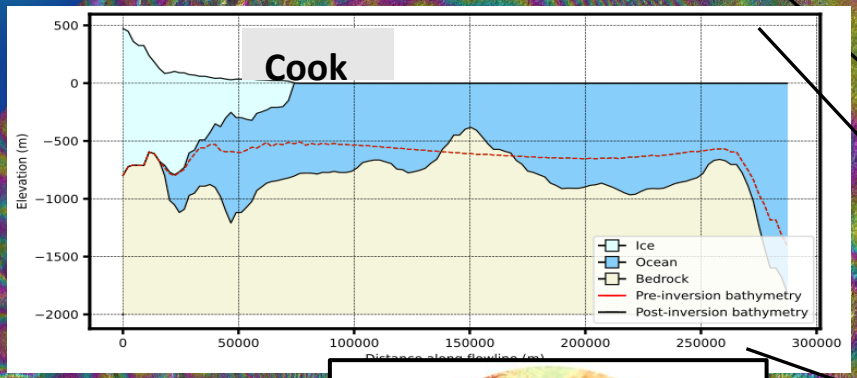
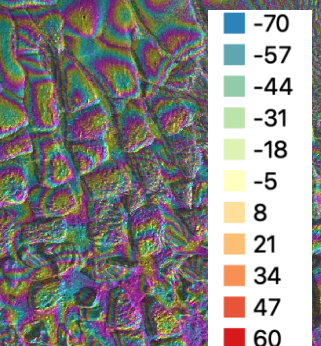
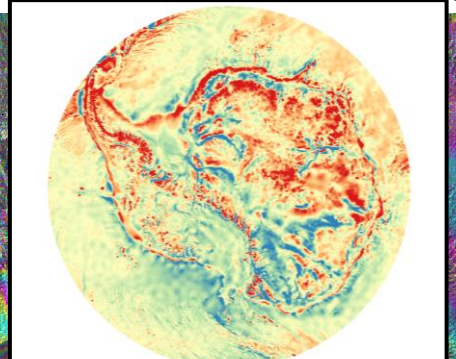
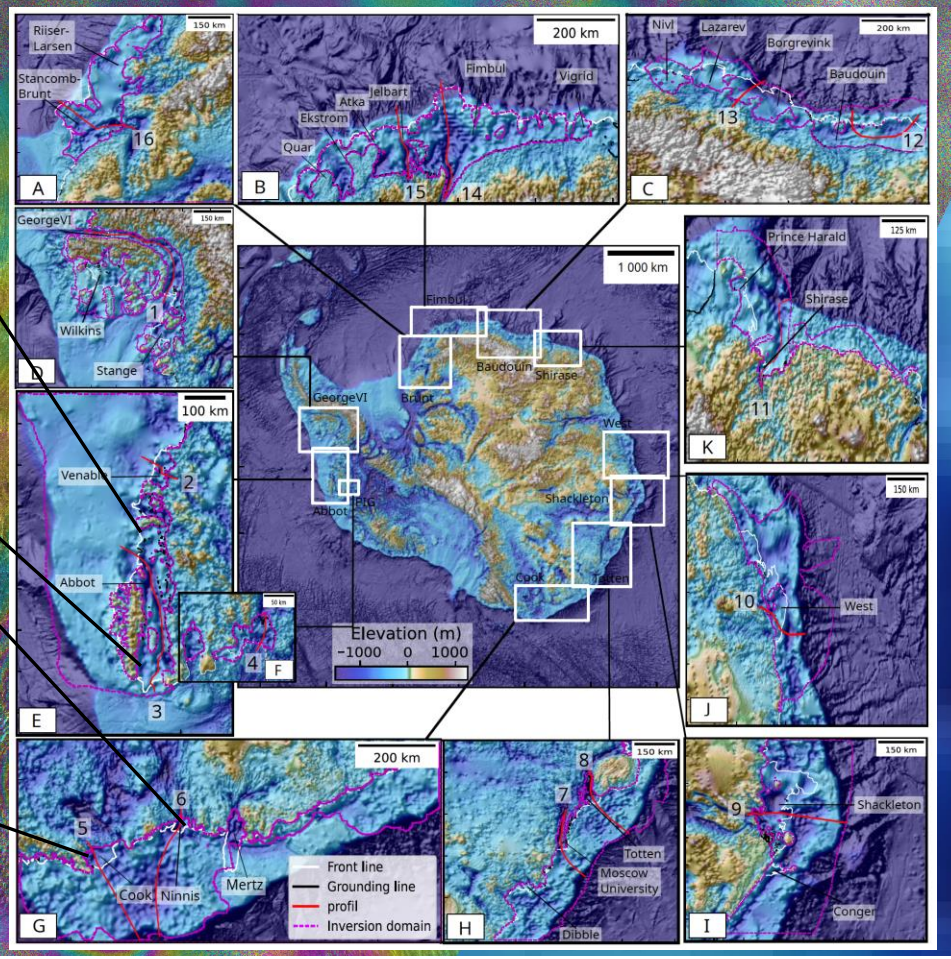
Antarctic ice shelf bathymetry











With ANTGG2022, a new bathymetry of Antarctica with all ice shelves (Charrassin, Millan, et al., 2024), merged with BedMachine and IBCSOv2 (Dorschel et al., 2023).

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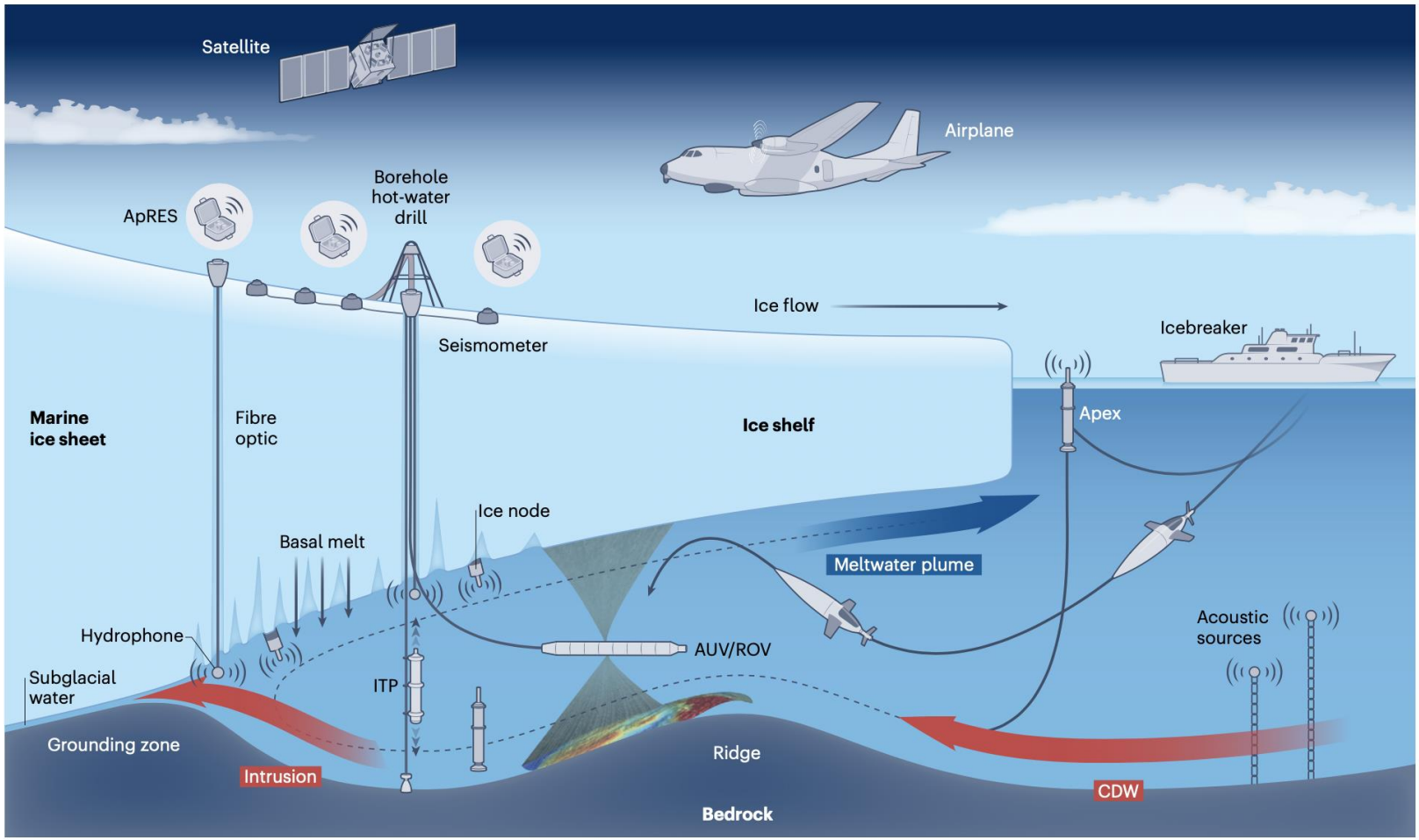

Ice shelf cavities and grounding zones are at the corner stone of marine ice sheet evolution. If we don't observe them, we won't model them right.

This effort will require a swarm of robots with autonomous navigation, docking, recharge, and data transmission.

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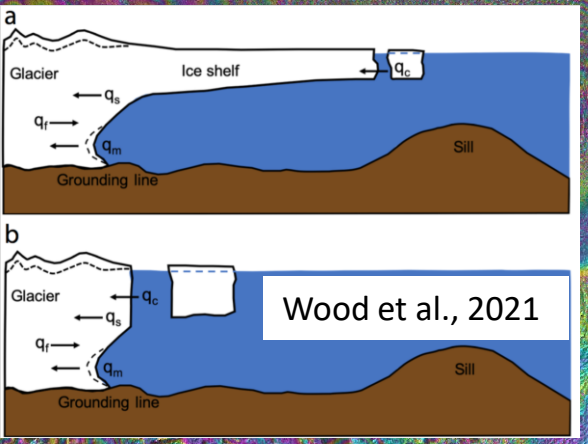
Km-sized seawater intrusions yield the highest melt rates in the ice shelf system. Their inclusions in ice sheet models result in projections x 2 (Parizek et al., 2013; Seroussi and Morlighem, 2018; Robel et al., 2022)

Ice shelf

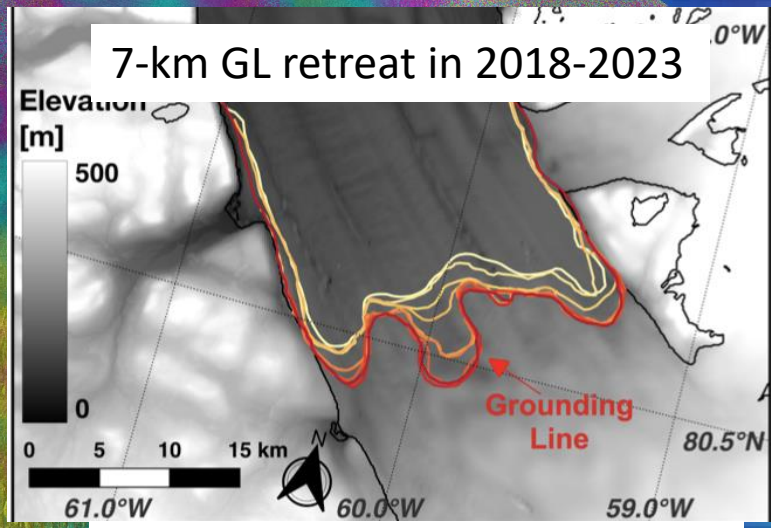
Grounded ice

Intrusions

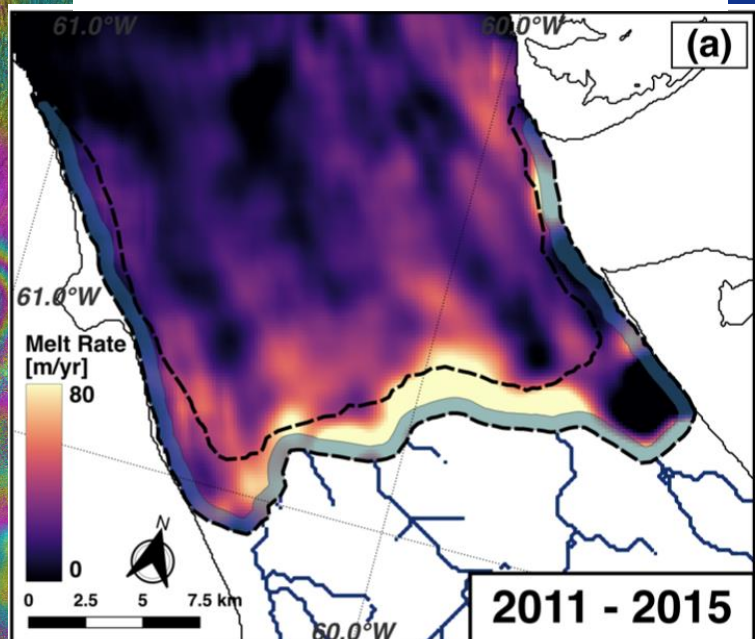


Wood et al., 2021

7-km GL retreat in 2018-2023



Millan et al, 2021; Ciraci et al., PNAS 2023



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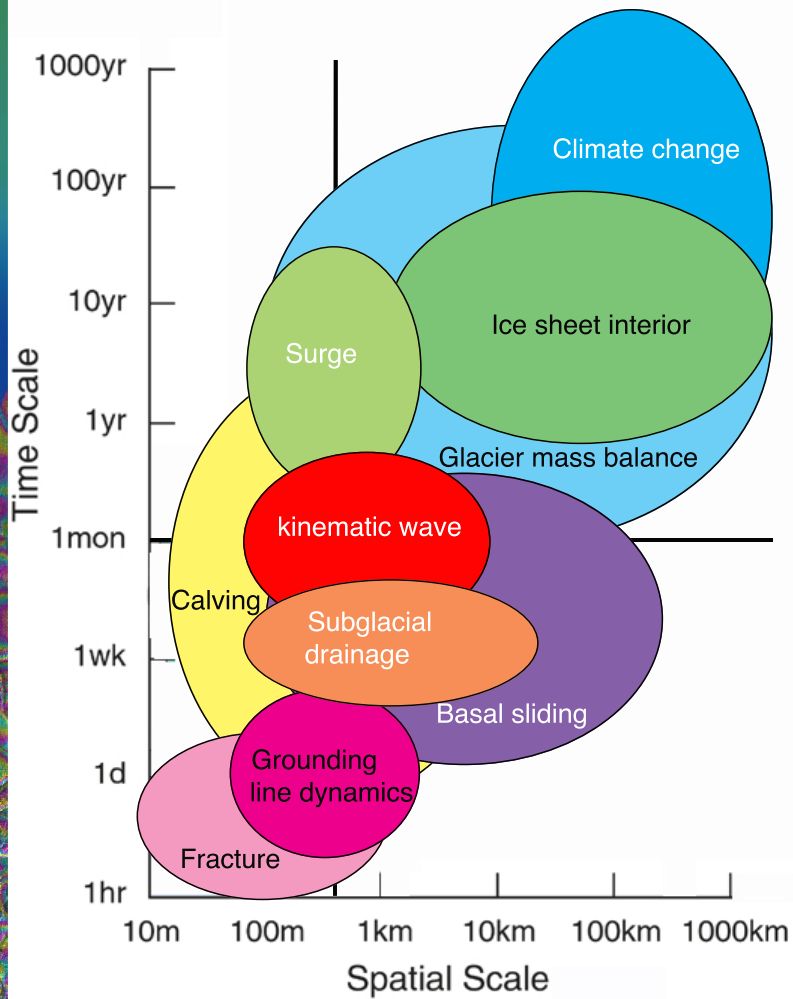
Requirements for satellite missions to look at glaciers.



TIME SCALE AND SPATIAL SCALE OF MAJOR PHYSICAL PHENOMENA DRIVING THE MASS BALANCE OF ICE SHEETS AND GLACIERS

- EARLY MISSIONS ADDRESSED MONTHLY & 10 KM SCALES.
- NEW MISSIONS WILL ADDRESS 100 M AND 1 WEEK SCALES.
- FUTURE MISSIONS WILL TARGET 10 M AND DAILY SCALES FOR RAPID CHANGES: GROUNDING ZONE DYNAMICS, FRACTURE MECHANICS, AND CALVING.
- BIG SCIENCE: EVALUATE RISK OF FAST CHANGES IN ICE SHEETS AND REVISE SEA LEVEL RISE PROJECTIONS.

SATELLITE MISSIONS TO BE COMPLETED WITH (MORE/NEW) IN-SITU OBSERVATION NETWORKS.

OBSERVATIONS MORE TIGHLY COUPLED WITH MODELS

MODELS CAPABLE OF RESOLVING HIGH RESOLUTION PROCESSES WITH HEAVY DATA ASSIMILATION

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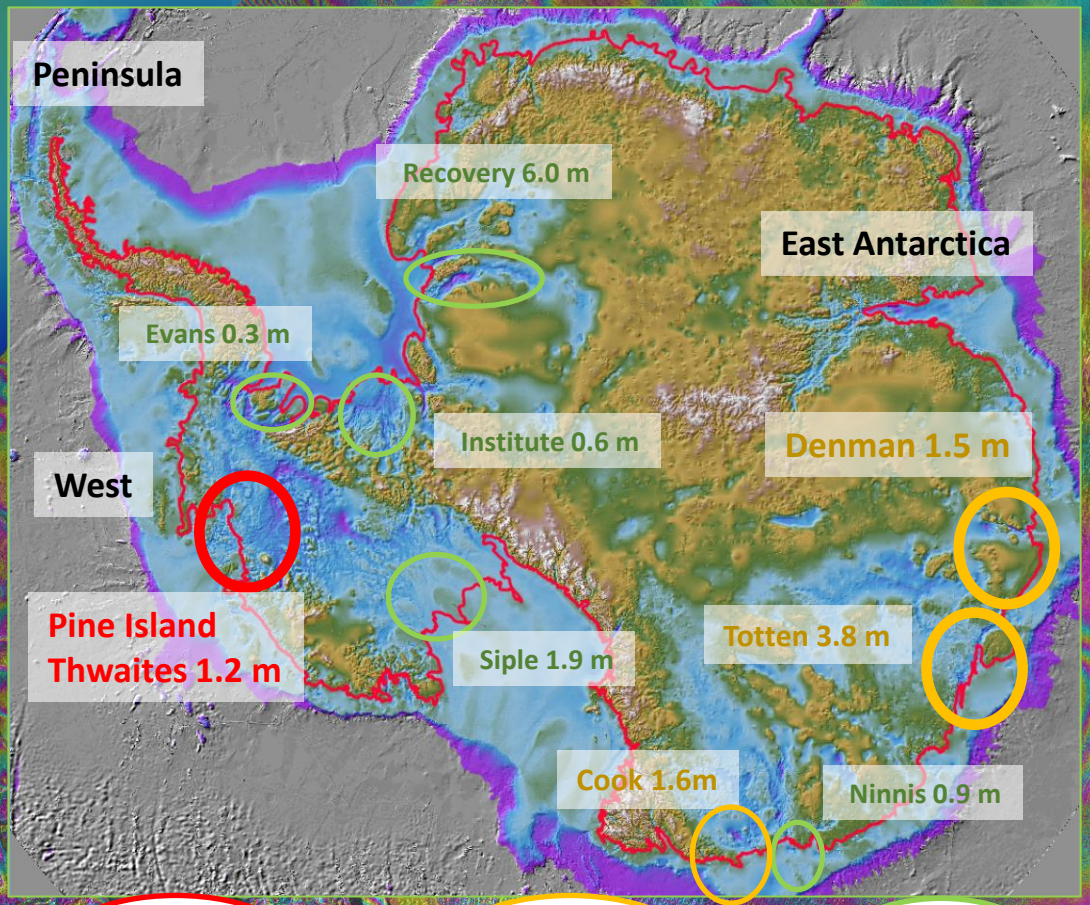
Rapid sea level rise: Where? When ?

Marine: 3 m SLR West; 19 m SLR East

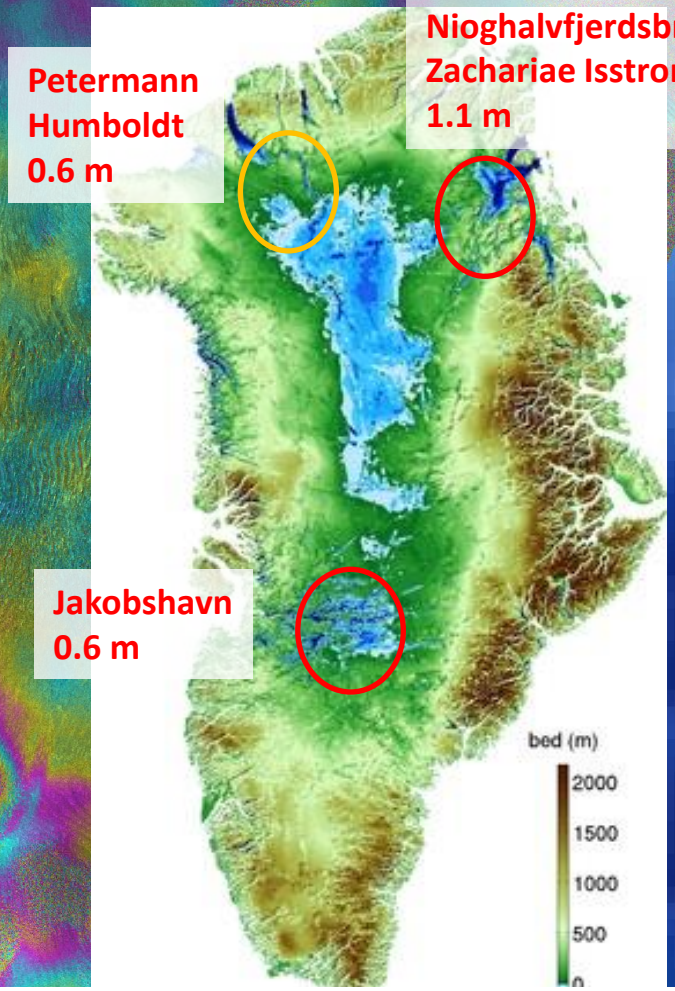


Collapse

Retreat

Stable

Marine: 3 m SLR GrIS



Marine retreat: 0.5-2.5 km/yr

Non-marine retreat: km/decades.

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A new way to conduct Polar Science

- Satellites have revolutionized the study of polar regions, but cannot measure everything, hence the critical need to in-situ data to be collected by robots (e.g., ocean state), drones (e.g., ice thickness), automated stations (ApRES, AWS, GNSS, etc.), and icebreaking ships.

- Budget and staffing of polar science have not changed in the last decades while the importance of polar science has increased tremendously (tipping points).

- A step up will require international collaboration (IPY4ever), no countries working in parallel or compete, especially in Antarctica, and low-carbon signature observation networks. Collaboration must involve everyone and be completely apolitical.

- Adaptation to SLR will cost billions for any city and trillions worldwide. Policy makers need to have better informed science to make the right decisions. We have major observational gaps.

- If better science saves 10% of the cost of adaption, the extra cost will more than repay itself.

- ITGC used $50M for 5 years to study the collapse of WAIS but mostly explored the Eastern Ice Shelf; new programs now aim to study East Antarctica; we should not limit ourselves to a few areas, for a few years, and take decades to make it happen. We need an ambitious, comprehensive network of polar observations.

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