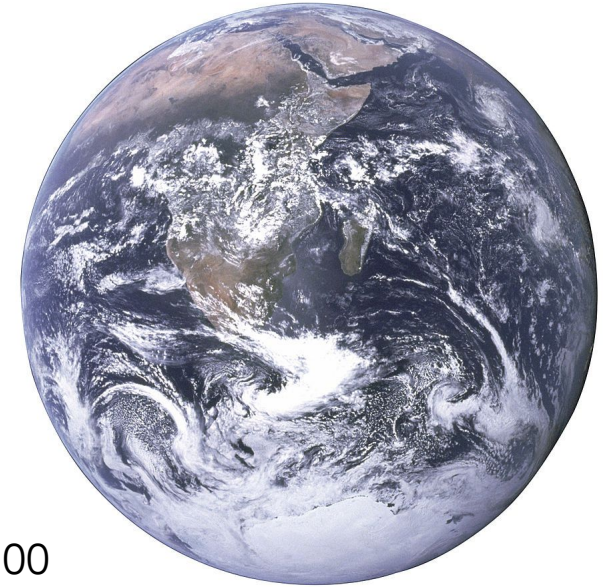
Remote Sensing 1: GEOG 4/585

Lecture 9.1.

Remote sensing of ice and snow



Johnny Ryan (he/him/his)
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Office hours: Monday 15:00-17:00
in 165 Condon Hall

Required reading:
Ryan (in press)

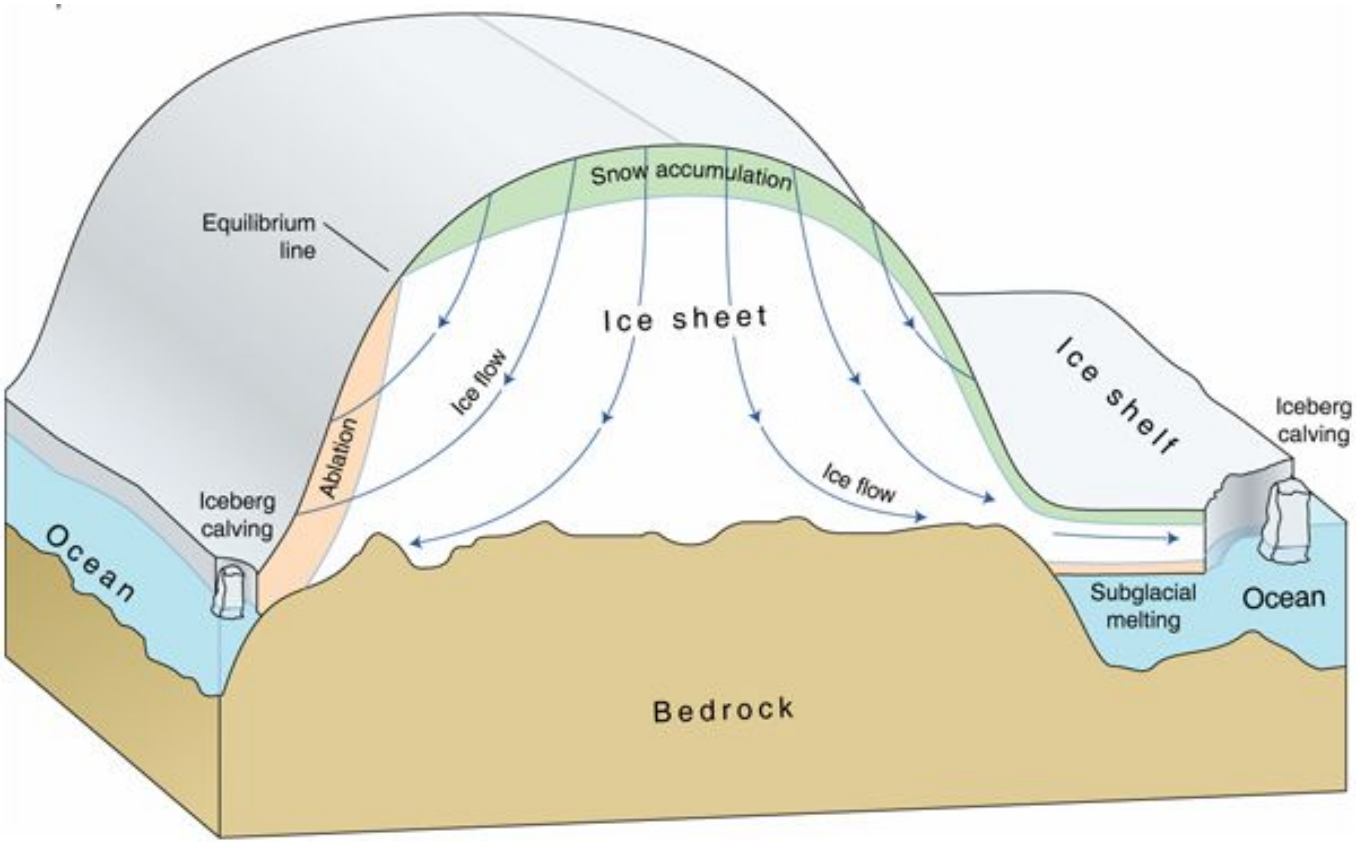
Overview

- What is a glacier, ice cap, ice sheet?
- Remote sensing the spectral properties of ice and snow
- Remote sensing the mass of ice sheets
- Remote sensing of snow water equivalent

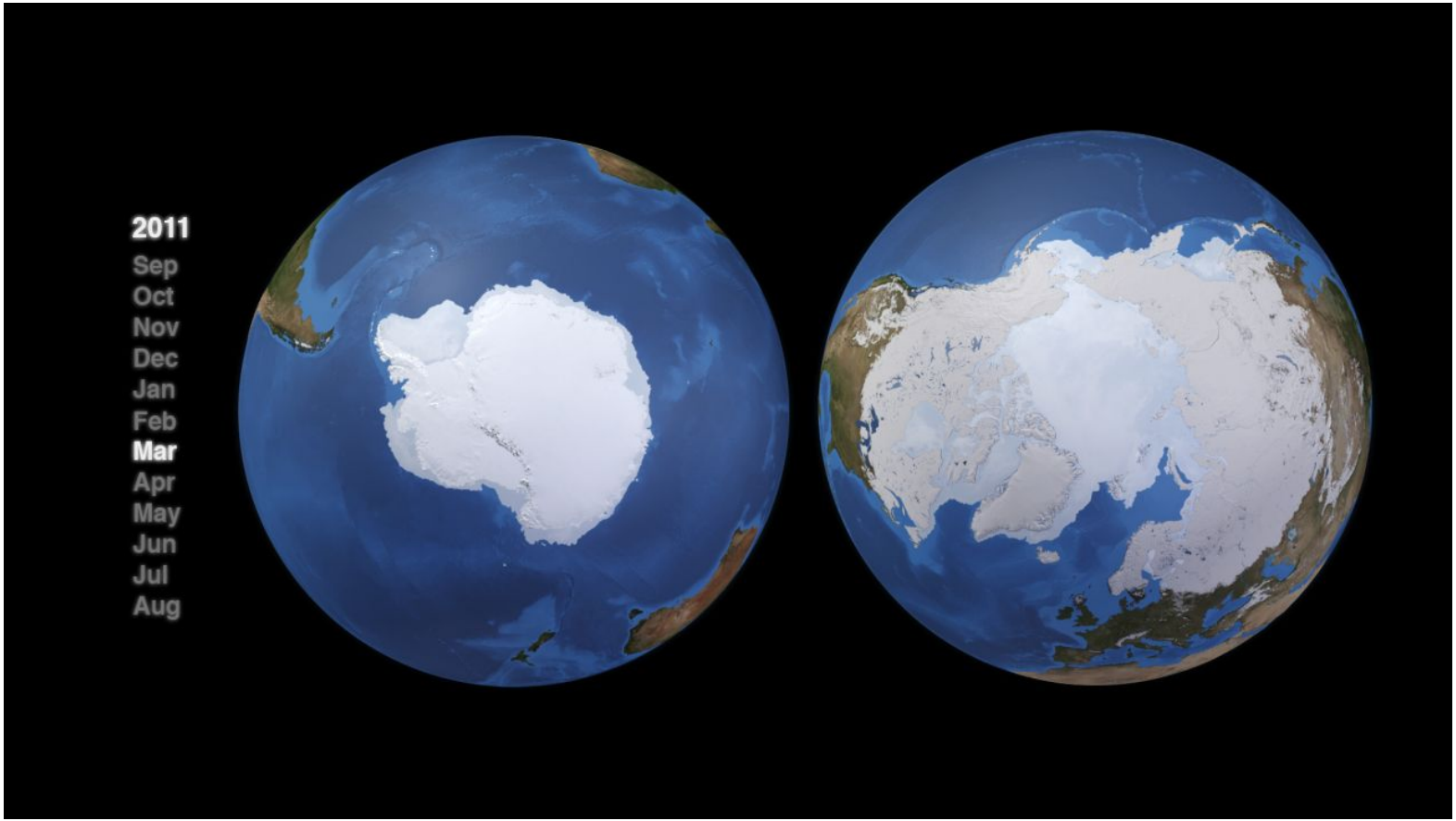
Snow, ice and glaciers

- Remote sensing the spectral properties of ice and snow
- Remote sensing the mass of ice sheets
- Remote sensing of snow water equivalent

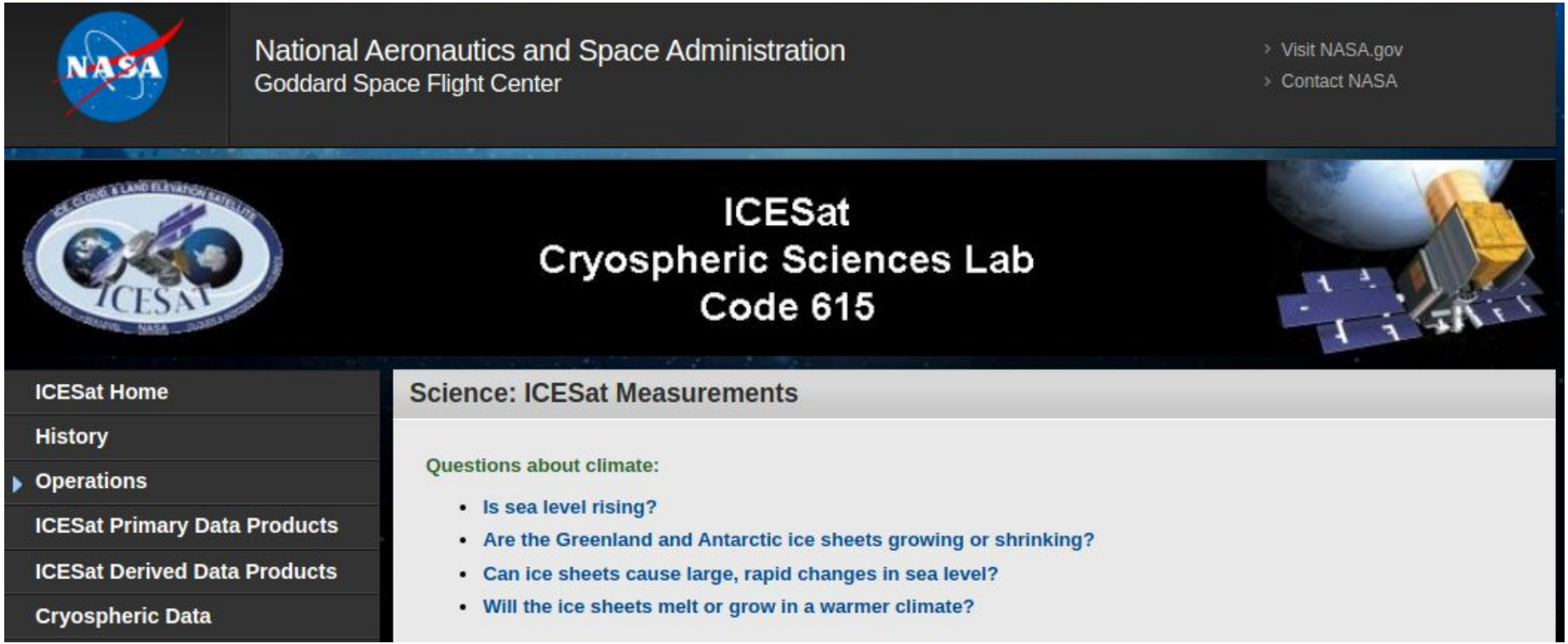
What is an ice sheet?



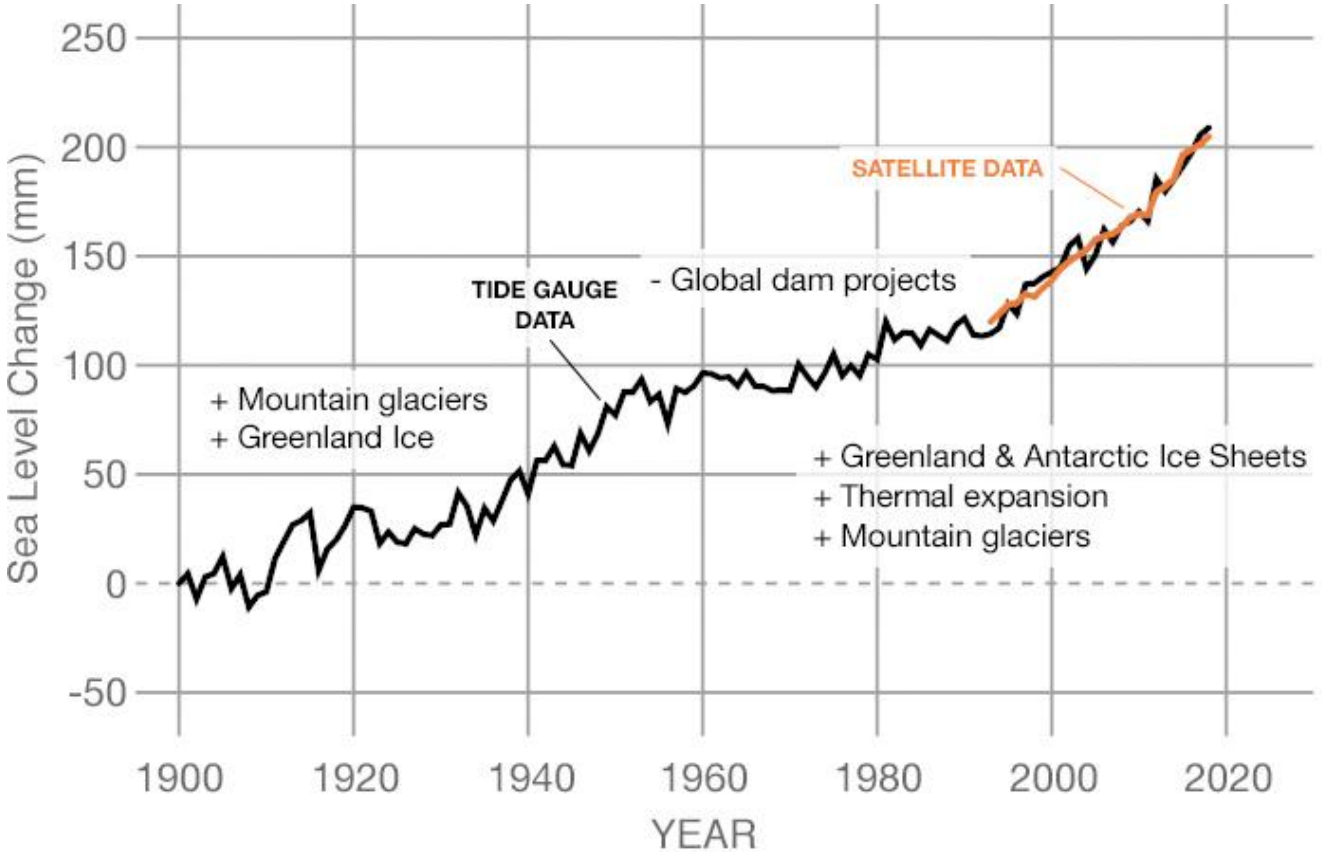
What is an ice sheet?



Scientific questions twenty-years ago

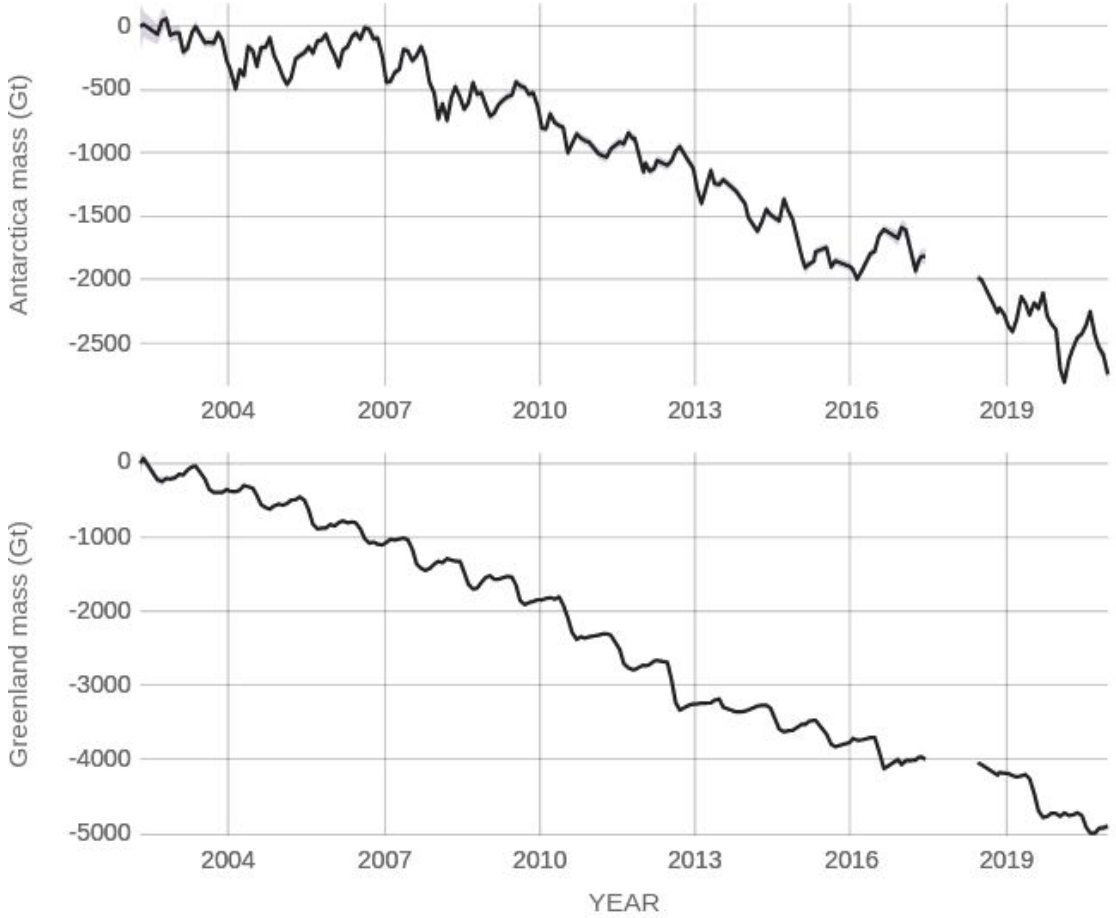


Global sea levels are rising



Credit: Frederikse et al. (2020)

Antarctic and Greenland Ice Sheets are losing mass



Credit: NASA

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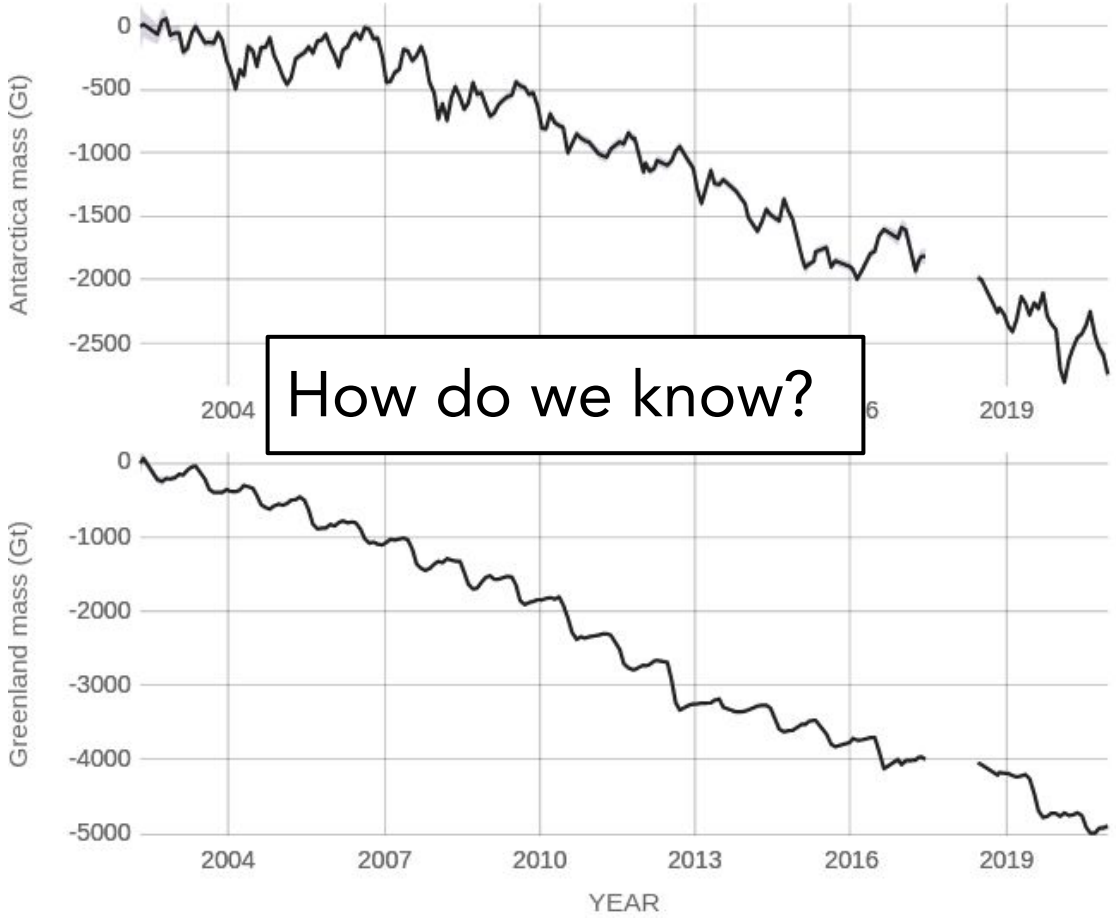


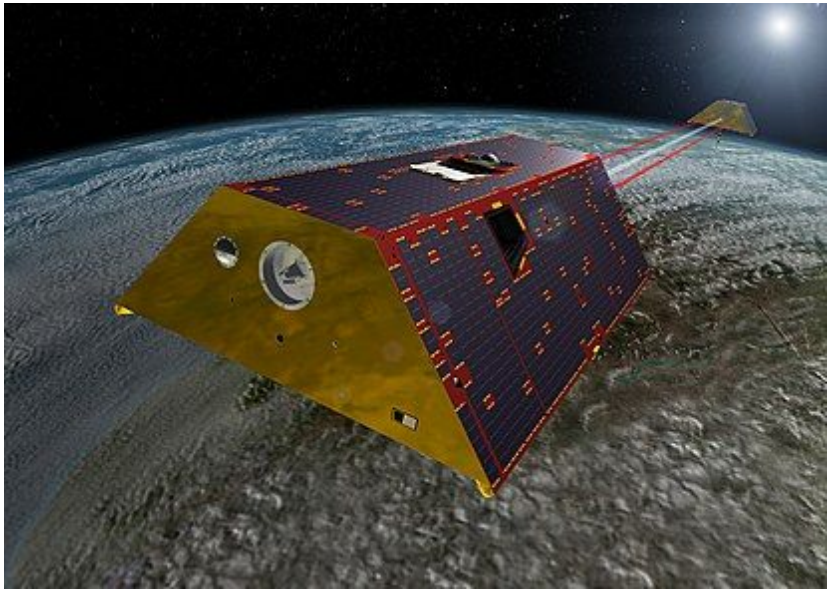
Credit: NASA

Gravity Recovery And Climate Experiment (GRACE)

- Joint NASA and German DLR satellite mission launched in March 2002 and ended October 2017
  - Follow-on mission (GRACE-FO) launched in May 2018

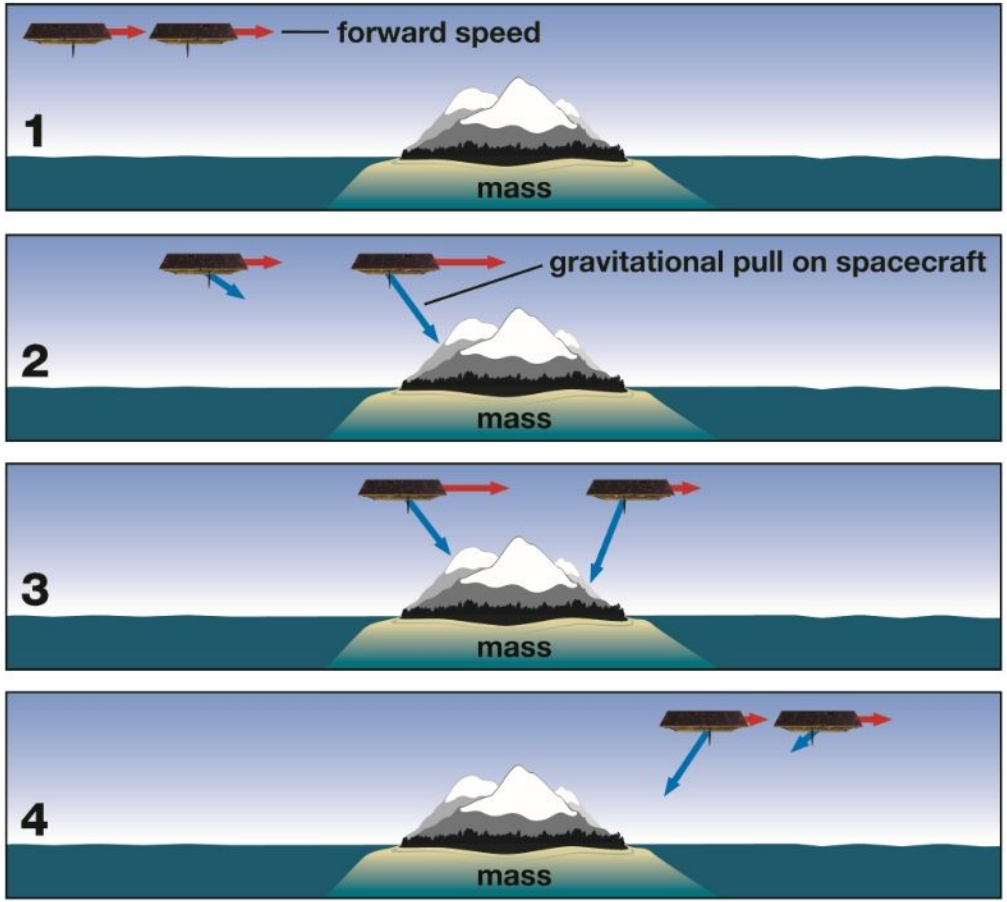
- Twin satellites in similar low Earth orbits (~500 km altitude, ~220 km apart)
  - Microwave ranging instrument
  - Satellite positions mapped very accurately with GPS and star tracker

- Measures the Earth's static and time-variable gravity field



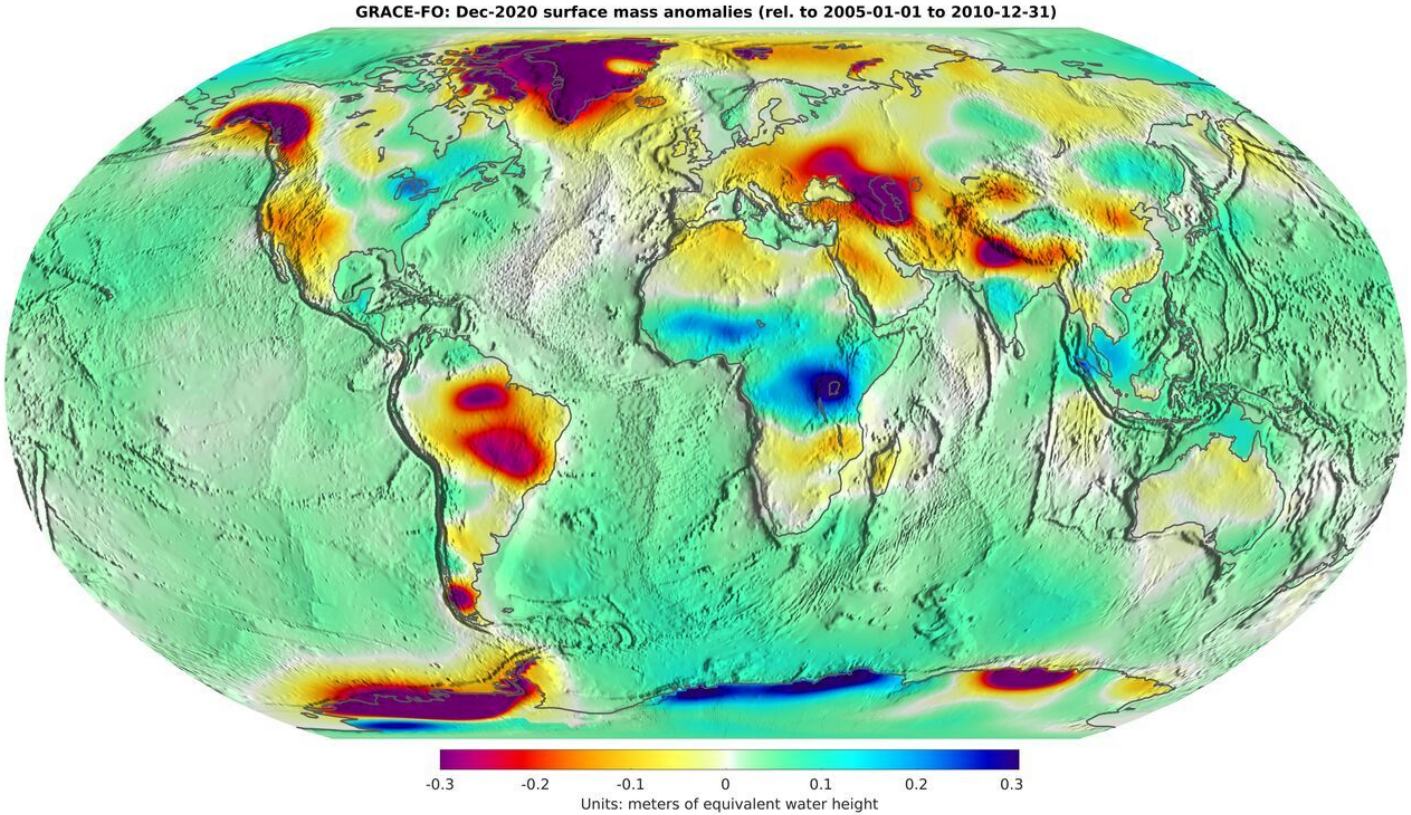
Credit: NASA/JPL-Caltech

How GRACE and GRACE-FO works



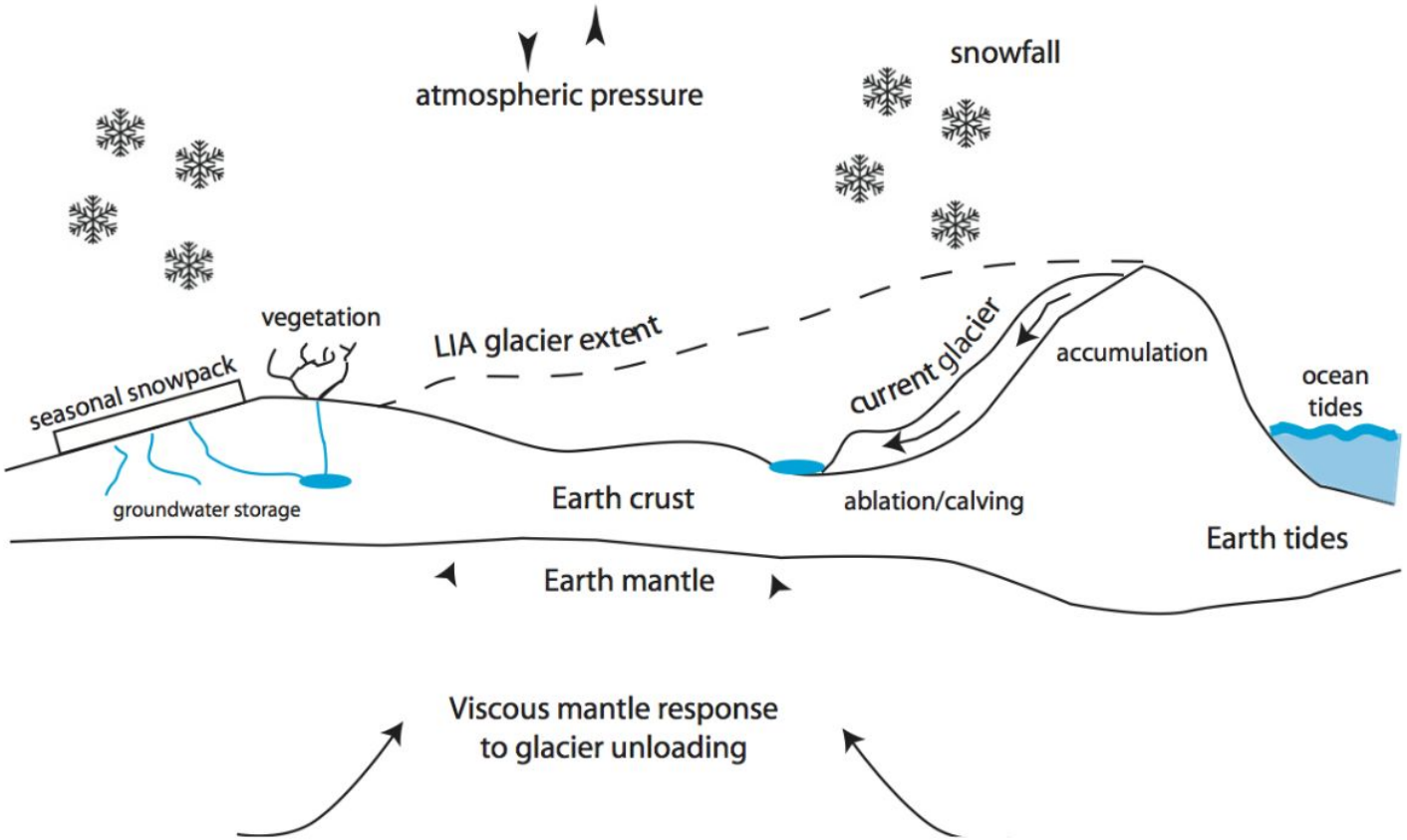
Credit: NASA

GRACE and GRACE-FO products



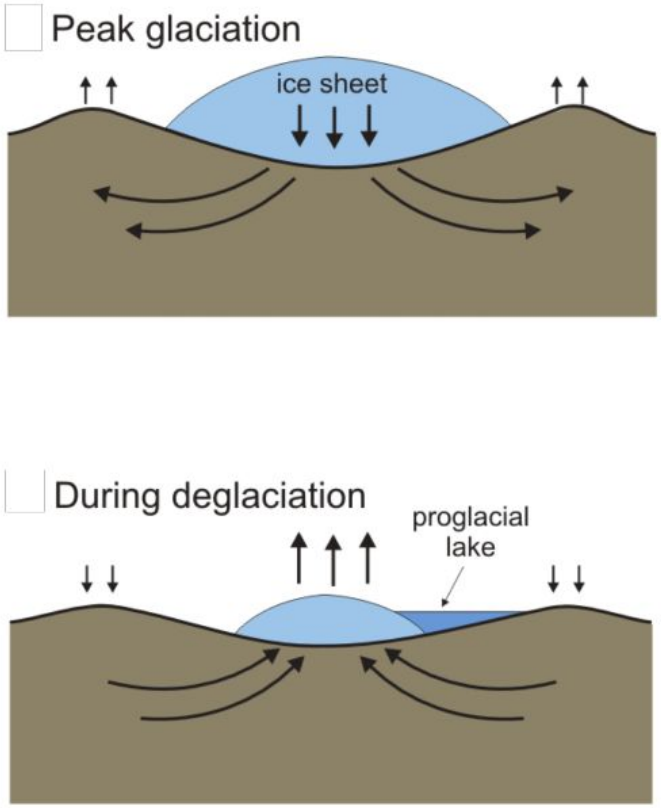
Credit: NASA

Complications in GRACE/GRACE-FO data



Credit: A. Arendt

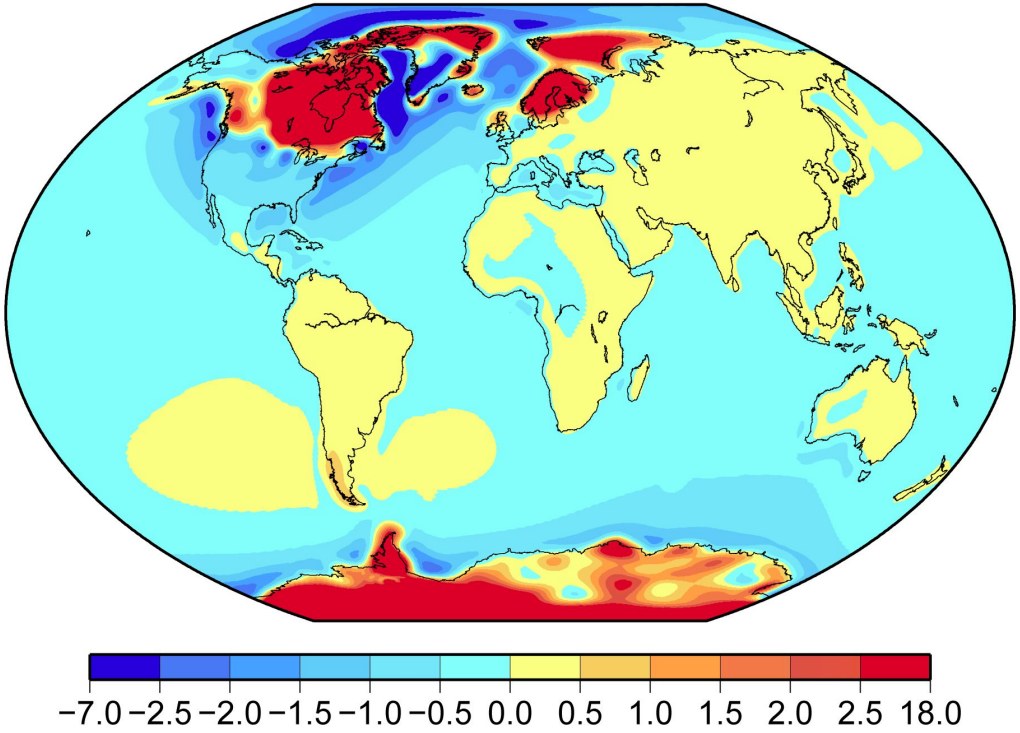
Glacial isostatic adjustment



- Weight of the ice sheets induces flow in underlying mantle
- Areas depressed by the paleo-ice sheets are gradually uplifting
  - Affects both surface elevation and the gravitational field
  - Apparent in GRACE as a long-term secular signal
- Viscoelastic response of the solid Earth depends on:
  - Lithospheric Thickness
  - Mantle viscosity structure
  - History of deglaciation

Credit: T. James (NRC)

Glacial isostatic adjustment



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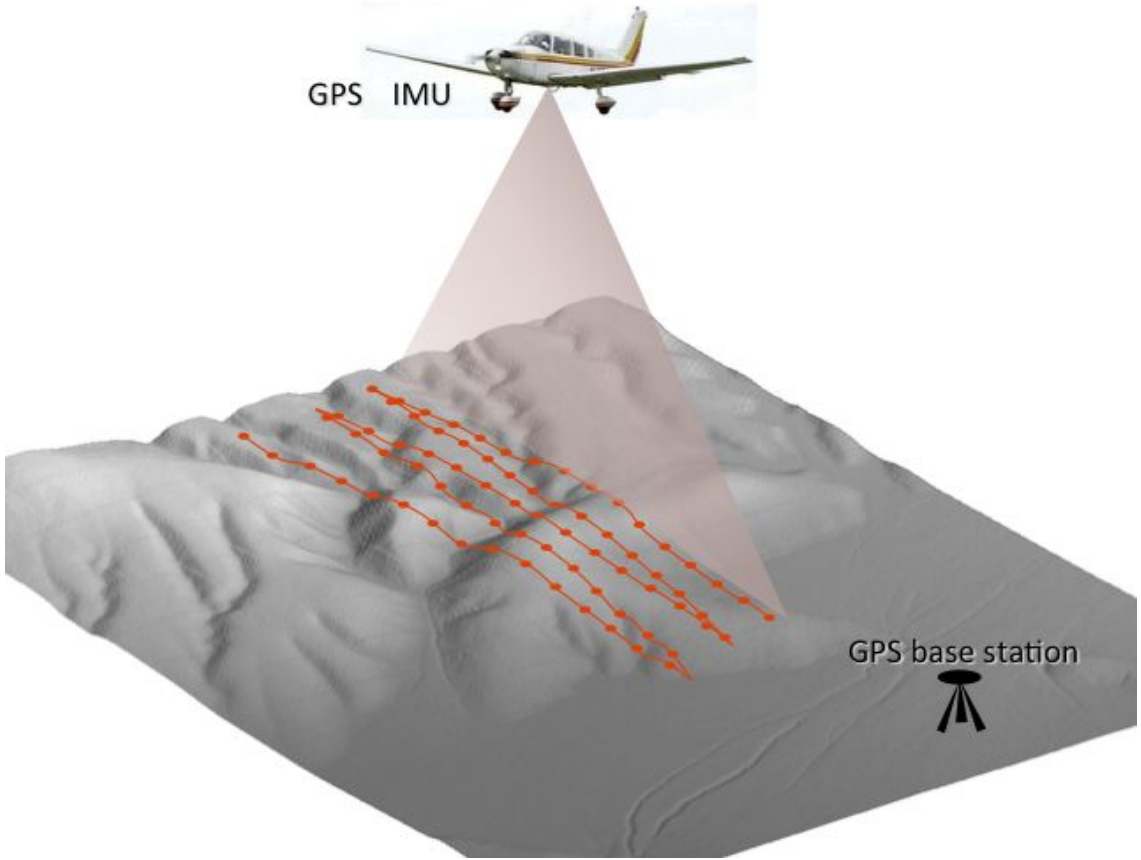
Credit: G. Milne (Encyclopedia of Quaternary Science)

Laser altimetry: measuring ice sheet volume changes

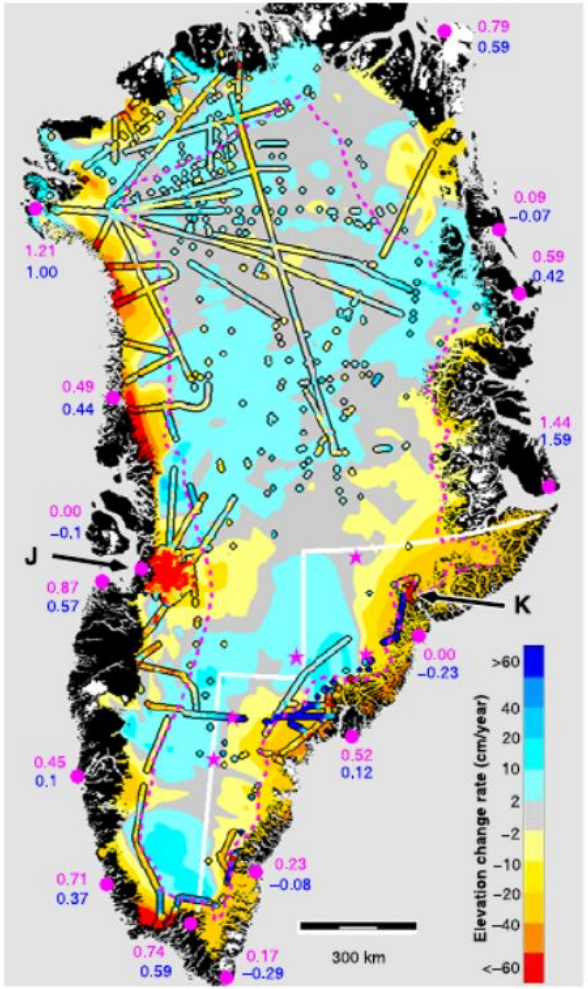


NASA airborne program (1990s)

Credit: NASA

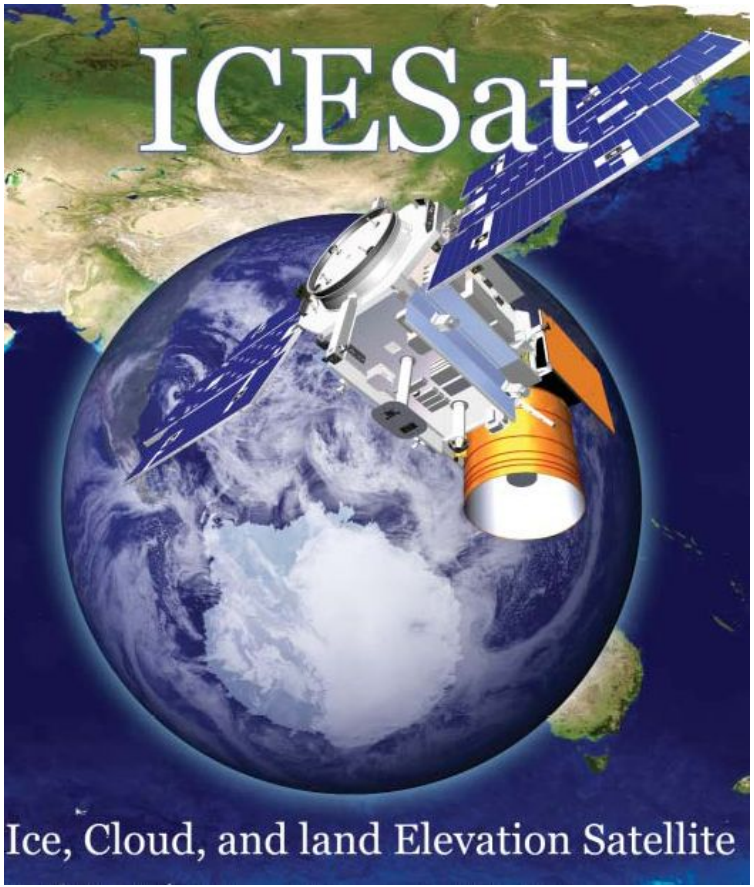
Airborne altimetry measurements of Greenland Ice Sheet thinning

- Rates of elevation change during 1997-2003, superimposed on a map of elevation-change rates resulting from the 1993/94 and 1998/99 surveys.
- High rates of ice sheet thinning at the margins provided first indication that ice sheet was responding to a warmer climate.
- This research, amongst others, motivated the requirement for a satellite laser altimeter.



Credit: Krabill et al. (2004)

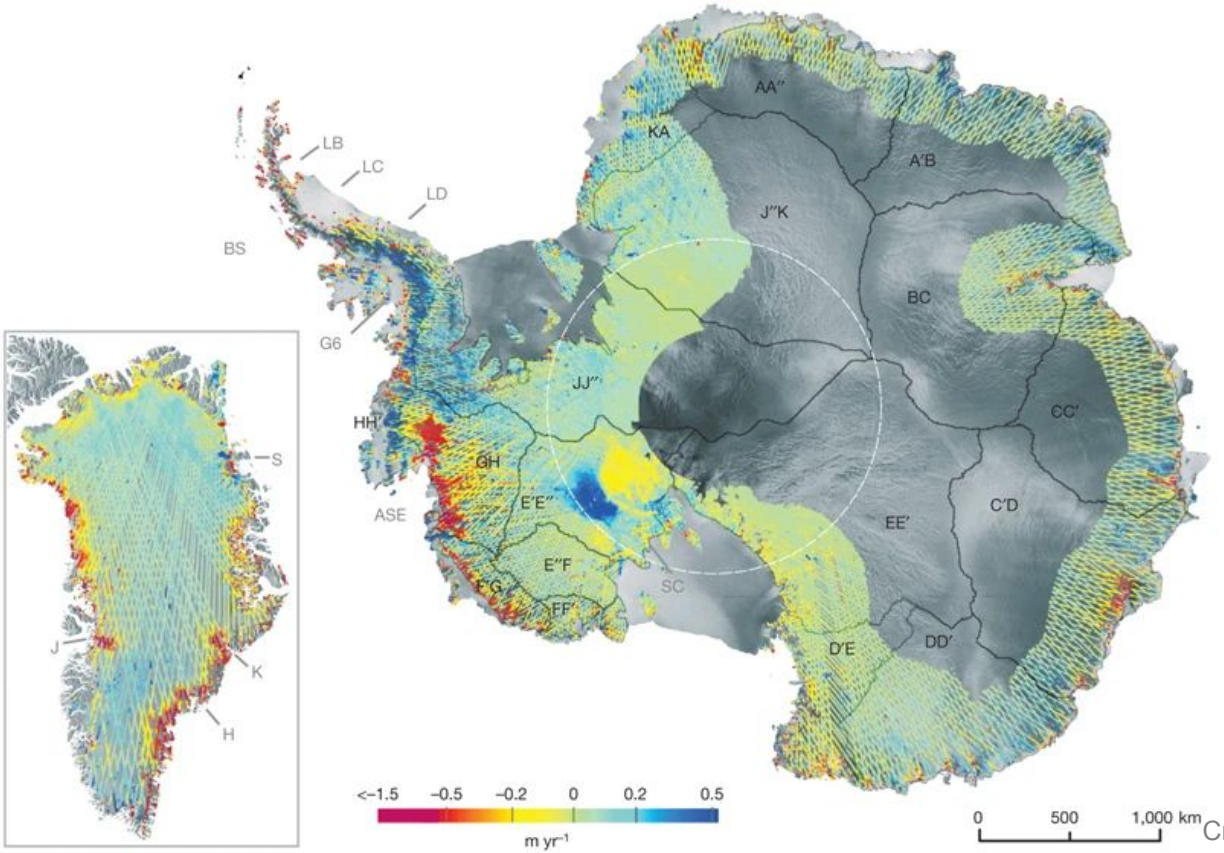
ICESat



- Carries the Geoscience Laser Altimeter System (GLAS)
- System includes:
  - a laser system to measure distance
  - a Global Positioning System (GPS) receiver a star-tracker attitude determination system
- The laser transmits short pulses of infrared (1064 nm) and visible green light (532 nm)
- Laser pulses at 40 times per second will illuminate spots (footprints) 70 meters in diameter, spaced at 170-meter intervals along Earth's surface.

Credit: NASA

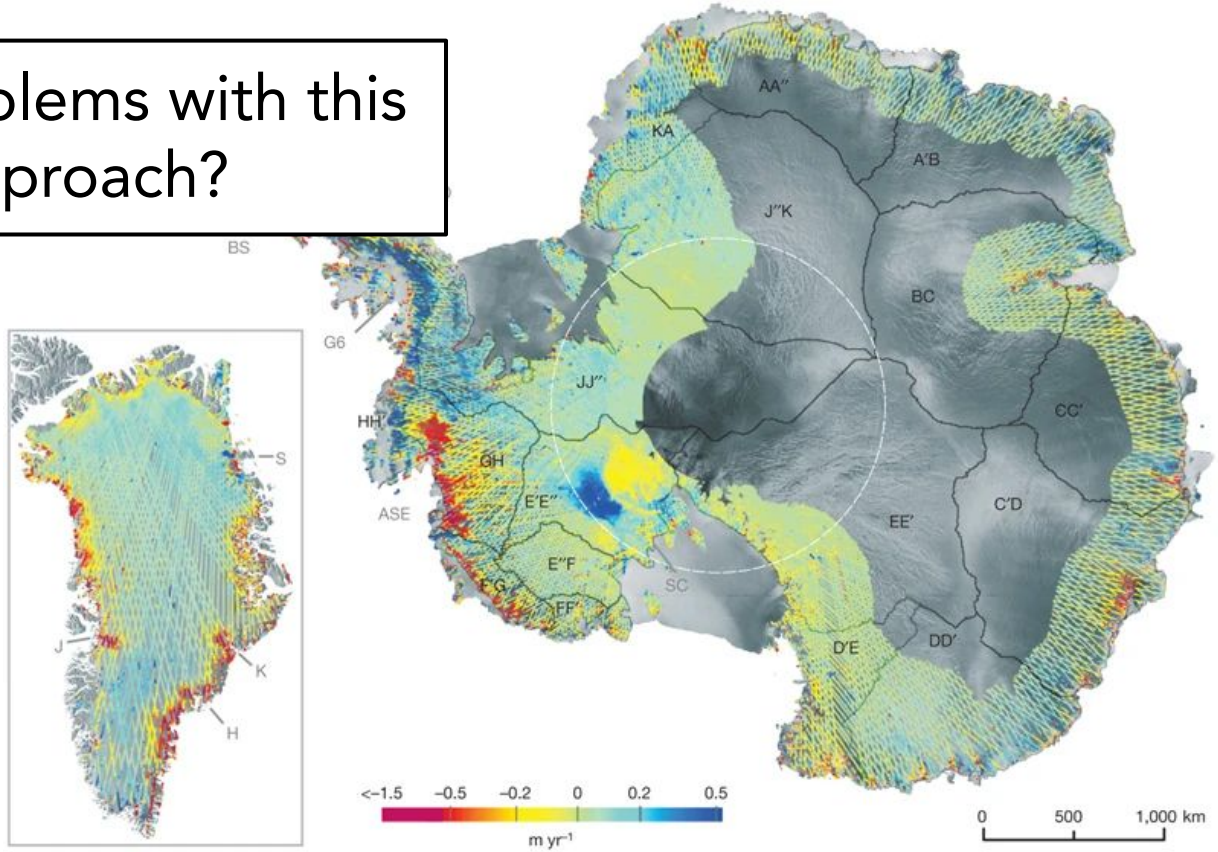
Extensive dynamic thinning on the margins of the Greenland and Antarctic ice sheets



Credit: Pritchard et al. (2009)

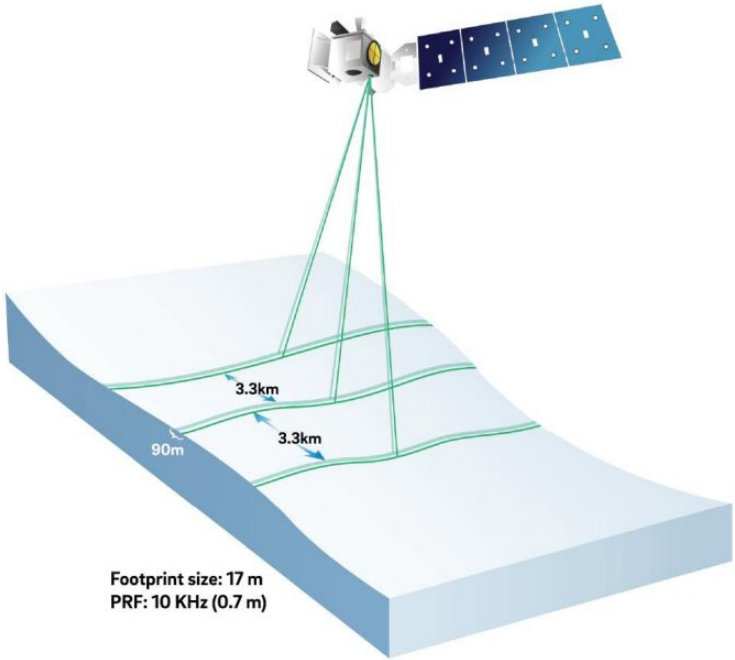
Extensive dynamic thinning on the margins of the Greenland and Antarctic ice sheets

Any problems with this approach?



redit: Pritchard et al. (2009)

ICESat-2



- Launched September 15, 2018
- Carries the Advanced Topographic Laser Altimeter System (ATLAS) a photon-counting LiDAR
- The laser emits pulses at 532 nanometers (green on the visible spectrum) 10,000 pulses per second
- Footprint size of ~17 m

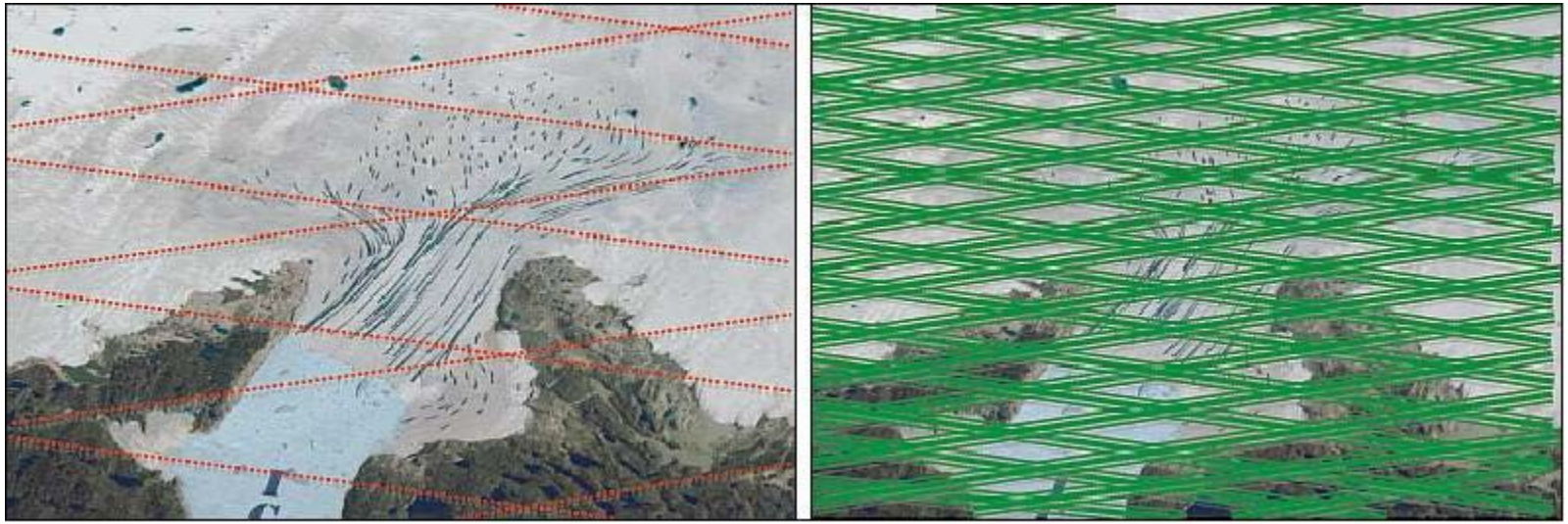
ICESat-2

ICE, CLOUD, AND LAND ELEVATION SATELLITE-2

Credit: Smith et al. (2020)

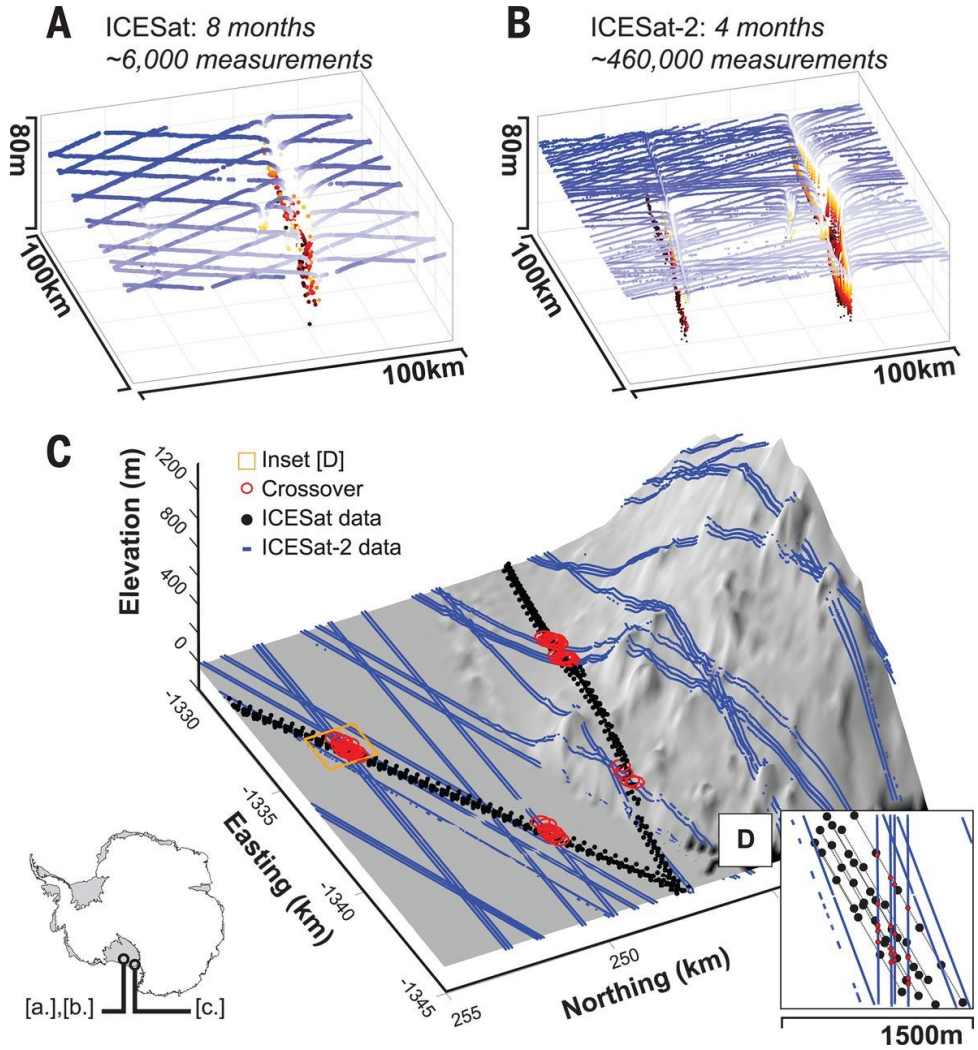
ICESat-2 continued

- ATLAS has six beams provided much denser coverage than its predecessor (ICESat)



ICESat single-beam

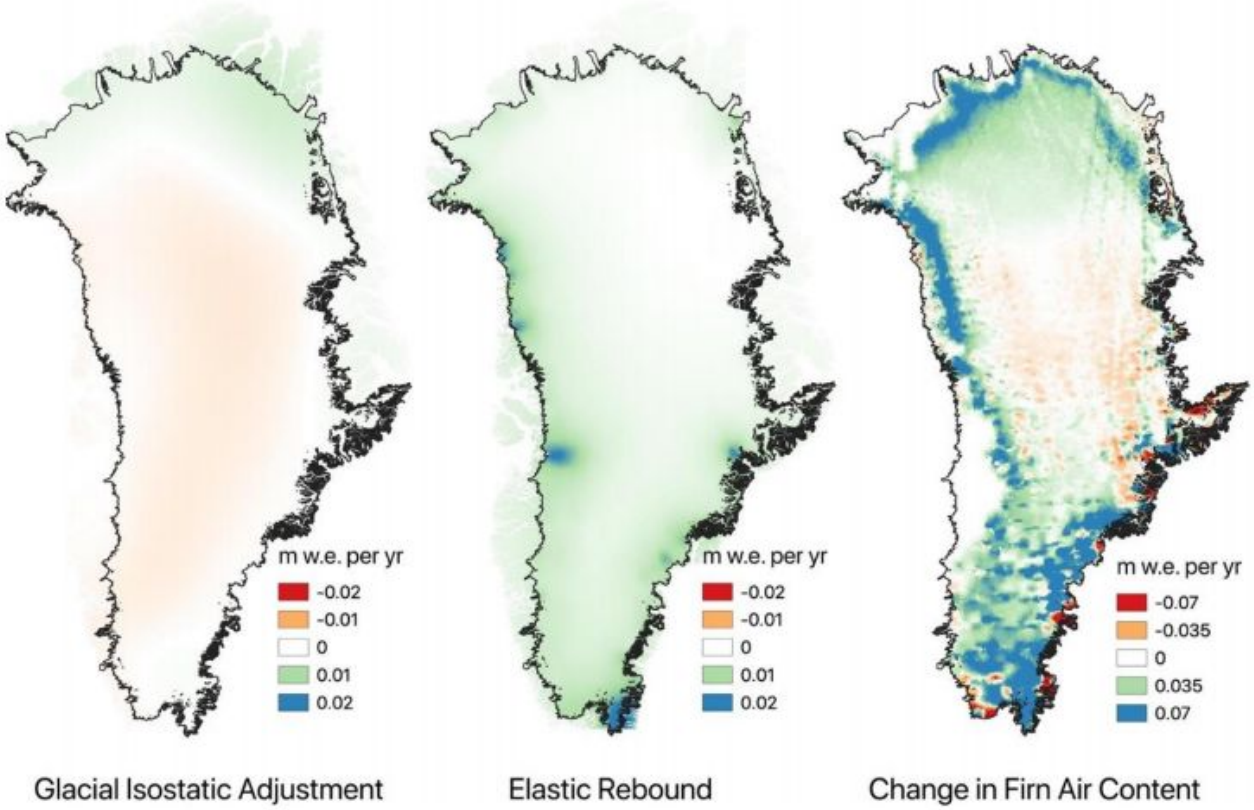
ICESat-2 six beams



Pervasive ice sheet mass loss reflects competing ocean and atmosphere processes

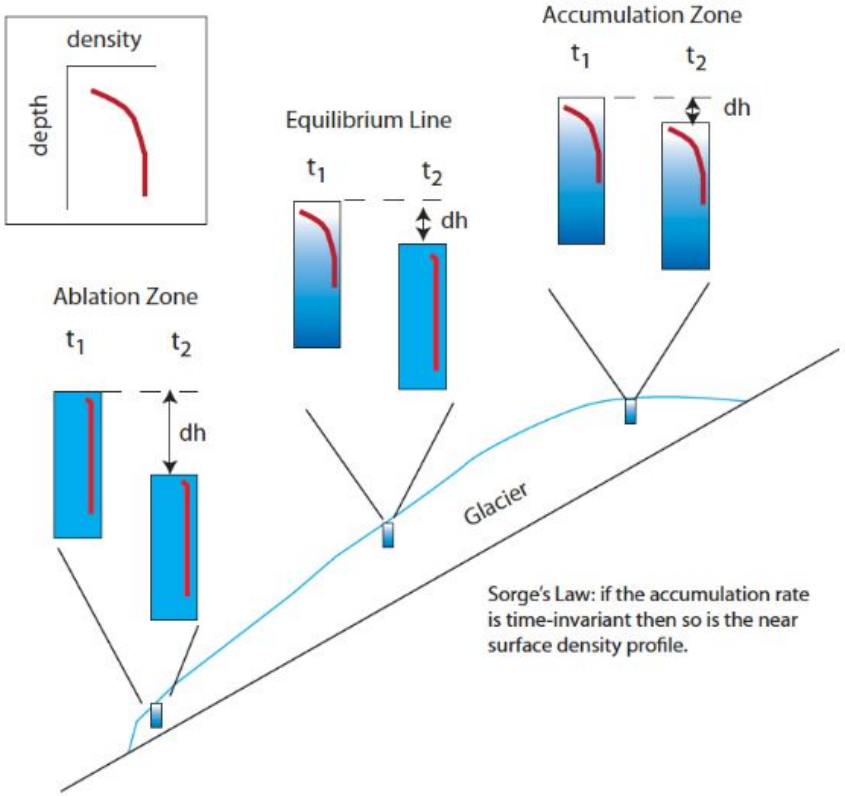
Credit: Smith et al. (2020)

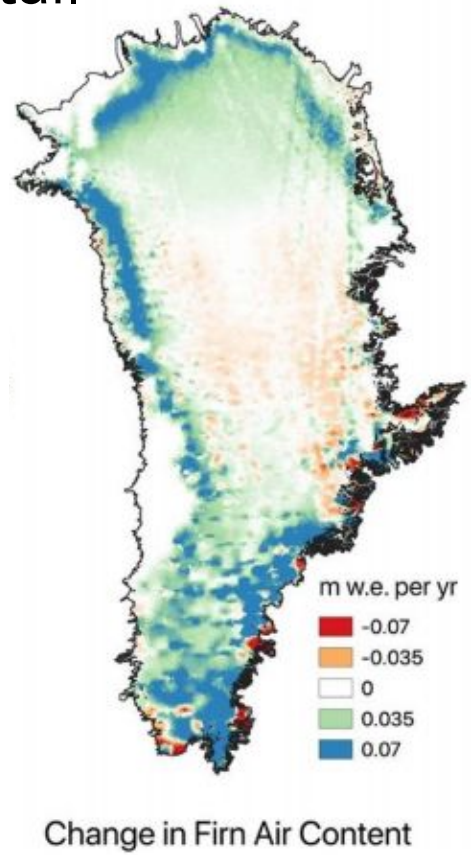
Corrections applied to surface elevation changes



Credit: Smith et al. (2020)

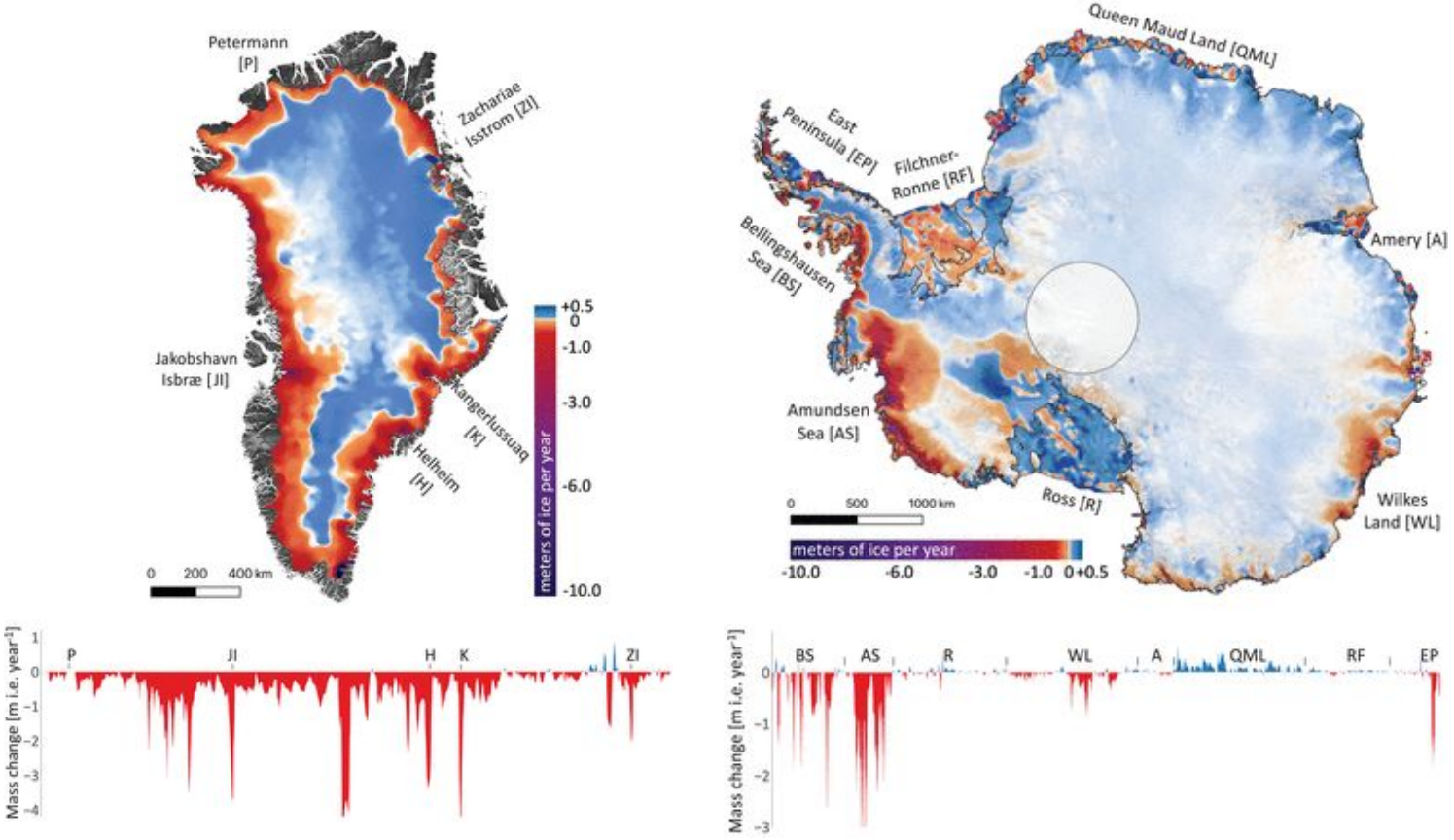
Density correction in more detail





Credit: Smith et al. (2020)

Mass loss from Greenland and Antarctic ice sheets (2003 to 2019)

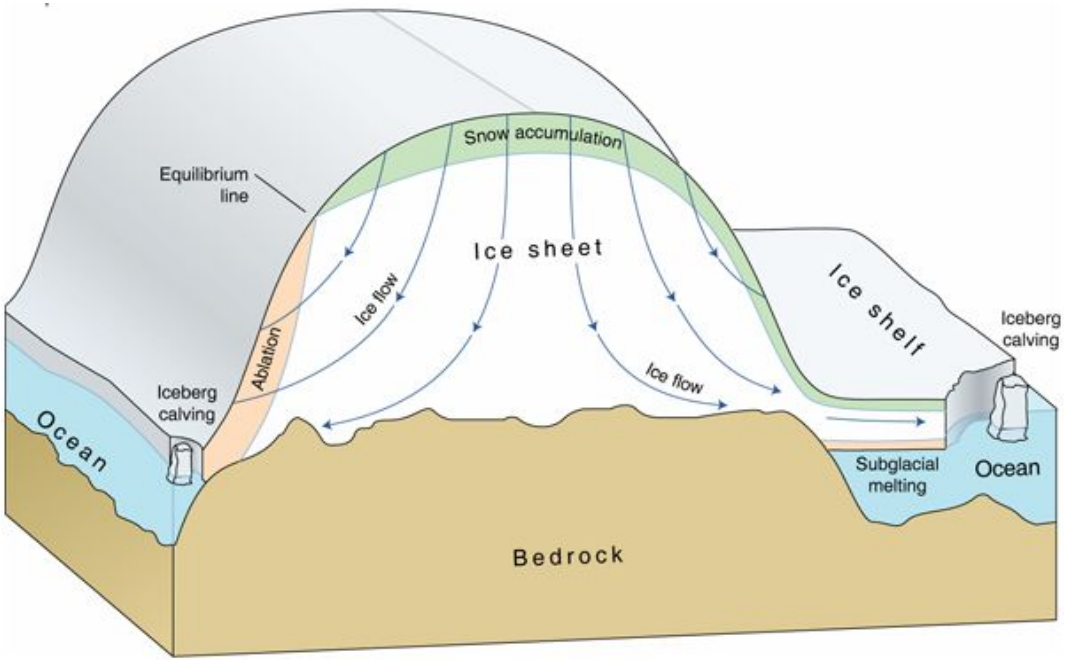


Credit: Smith et al. (2020)

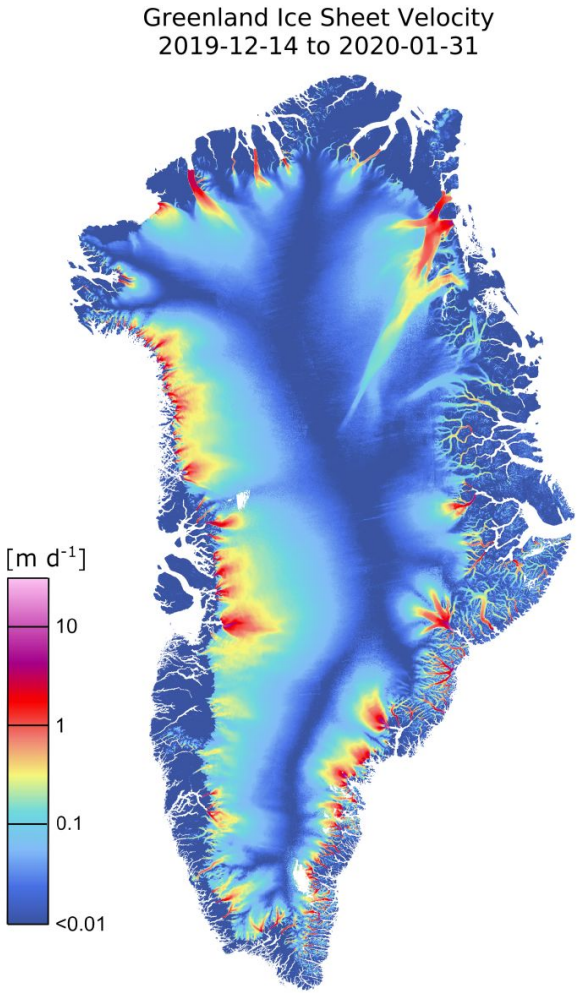
Processes of ice sheet mass change

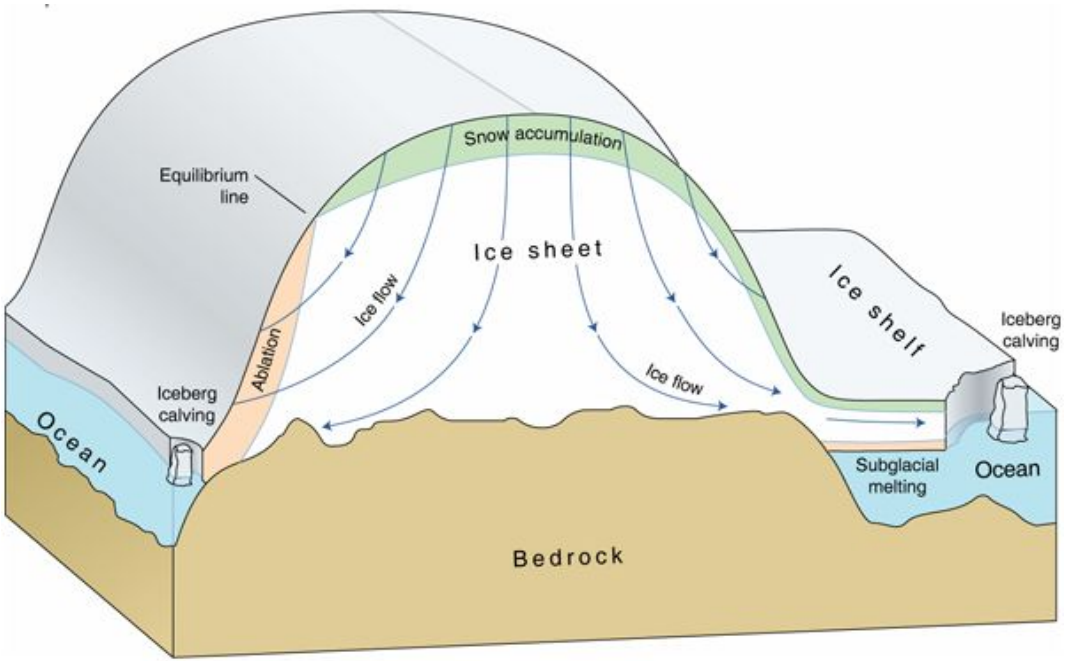
*"In Greenland… the low-elevation thinning is associated with… an increase in **surface melt**… At the same time… glacier termini… have **increased glacier velocities and ice discharge** into the ocean."* Smith et al. (2020)

*"In Antarctica, we see broad-scale patterns that are the fingerprints of two competing climate processes: **snow accumulation** and **ocean melting**."* Smith et al. (2020)

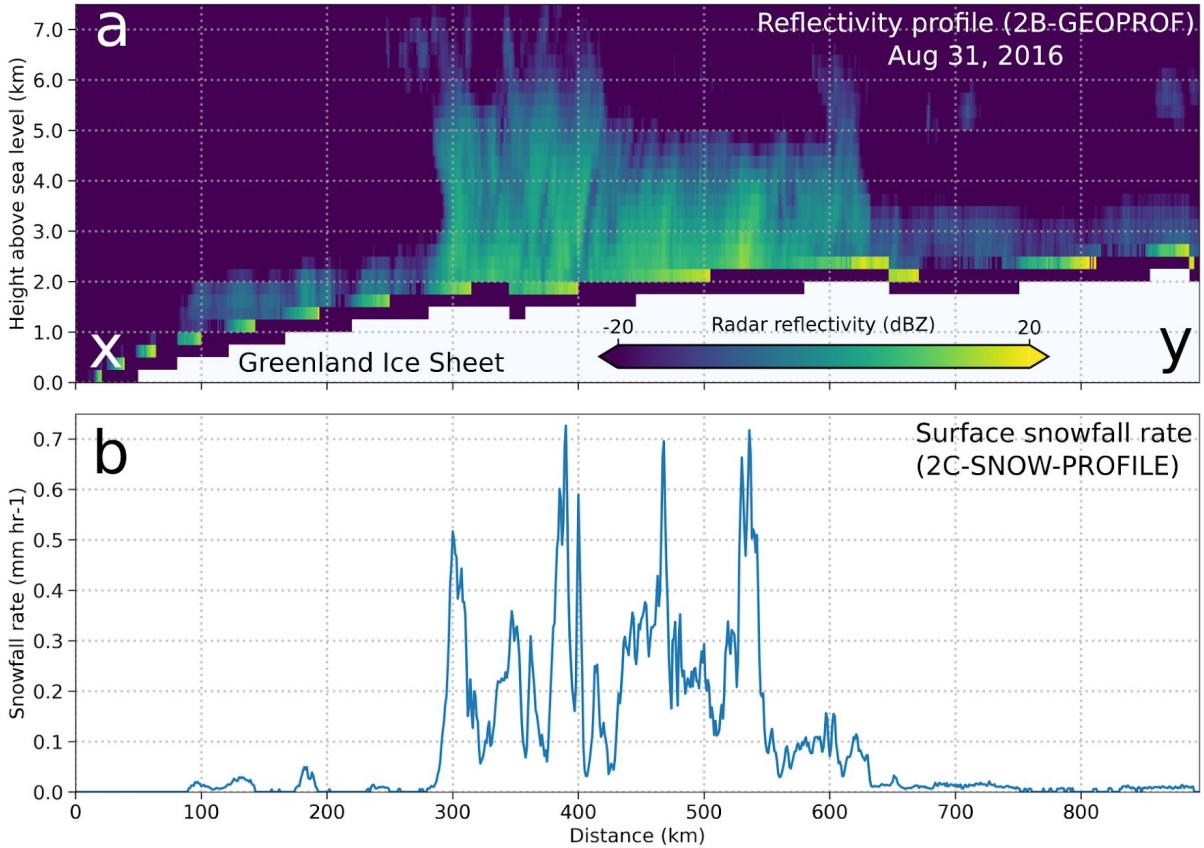


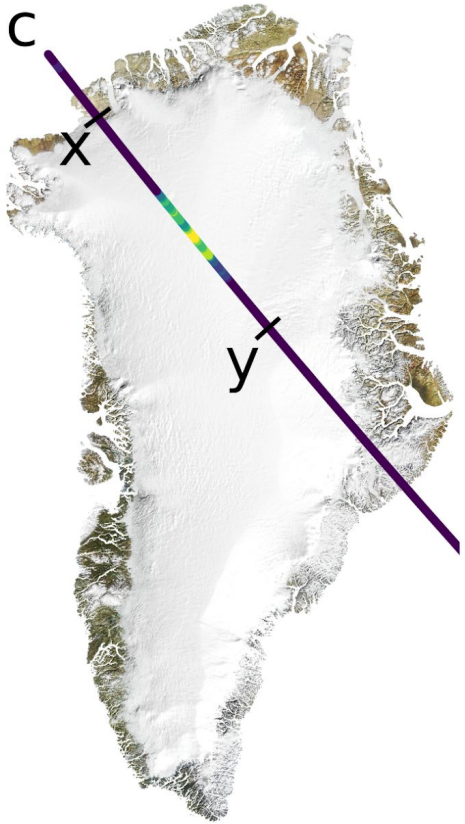
Remote sensing of glacier velocities





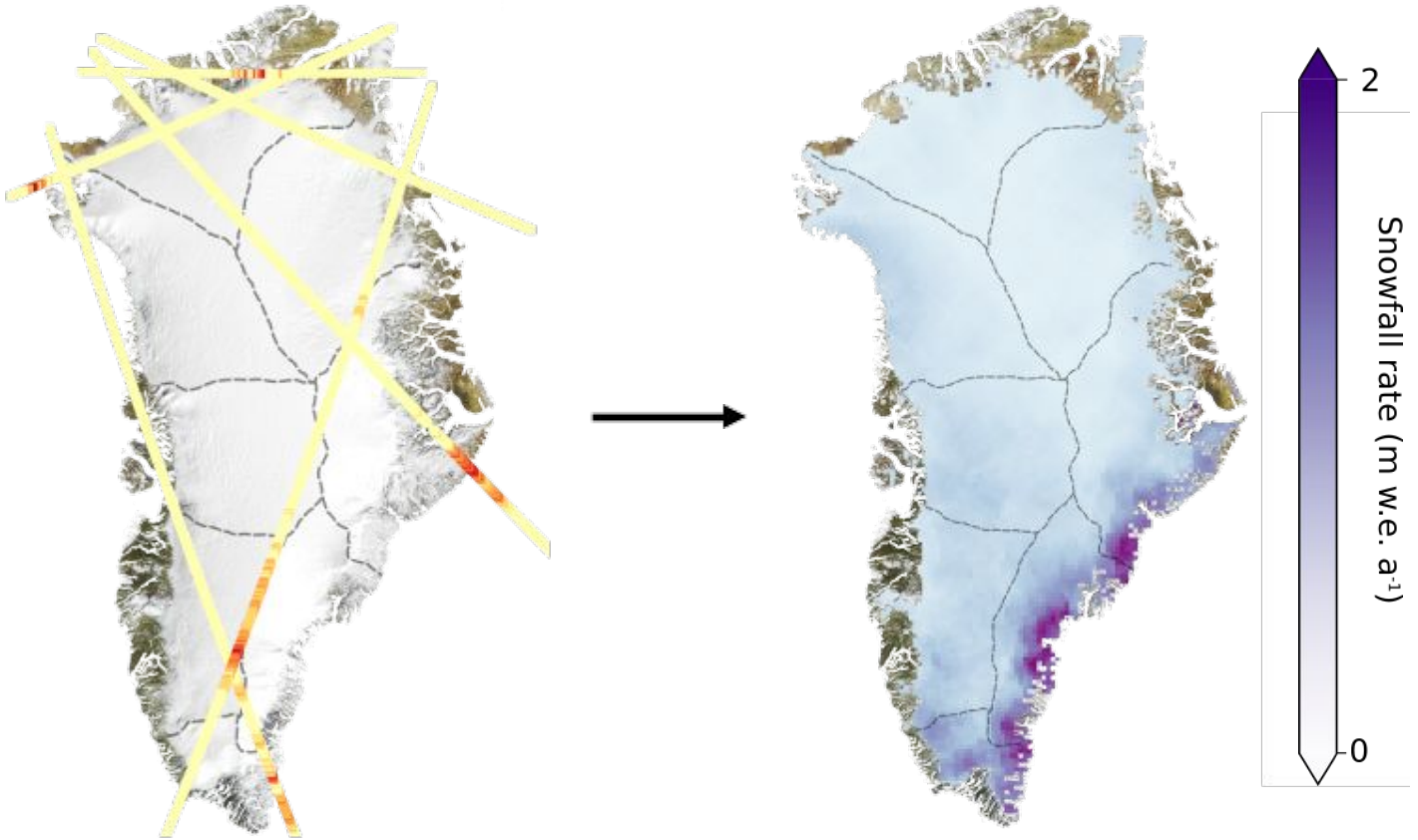
Remote sensing of snow accumulation



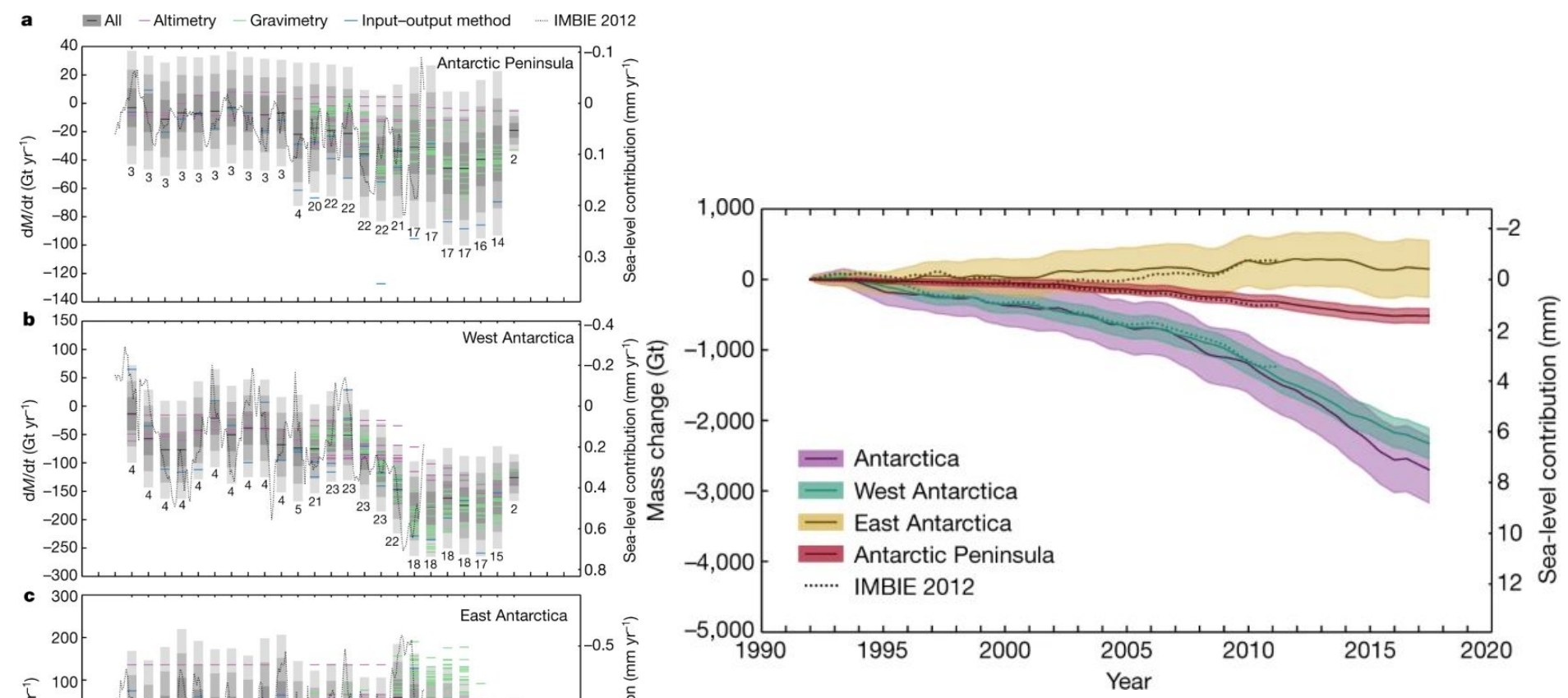


Credit: Ryan et al. (2020)

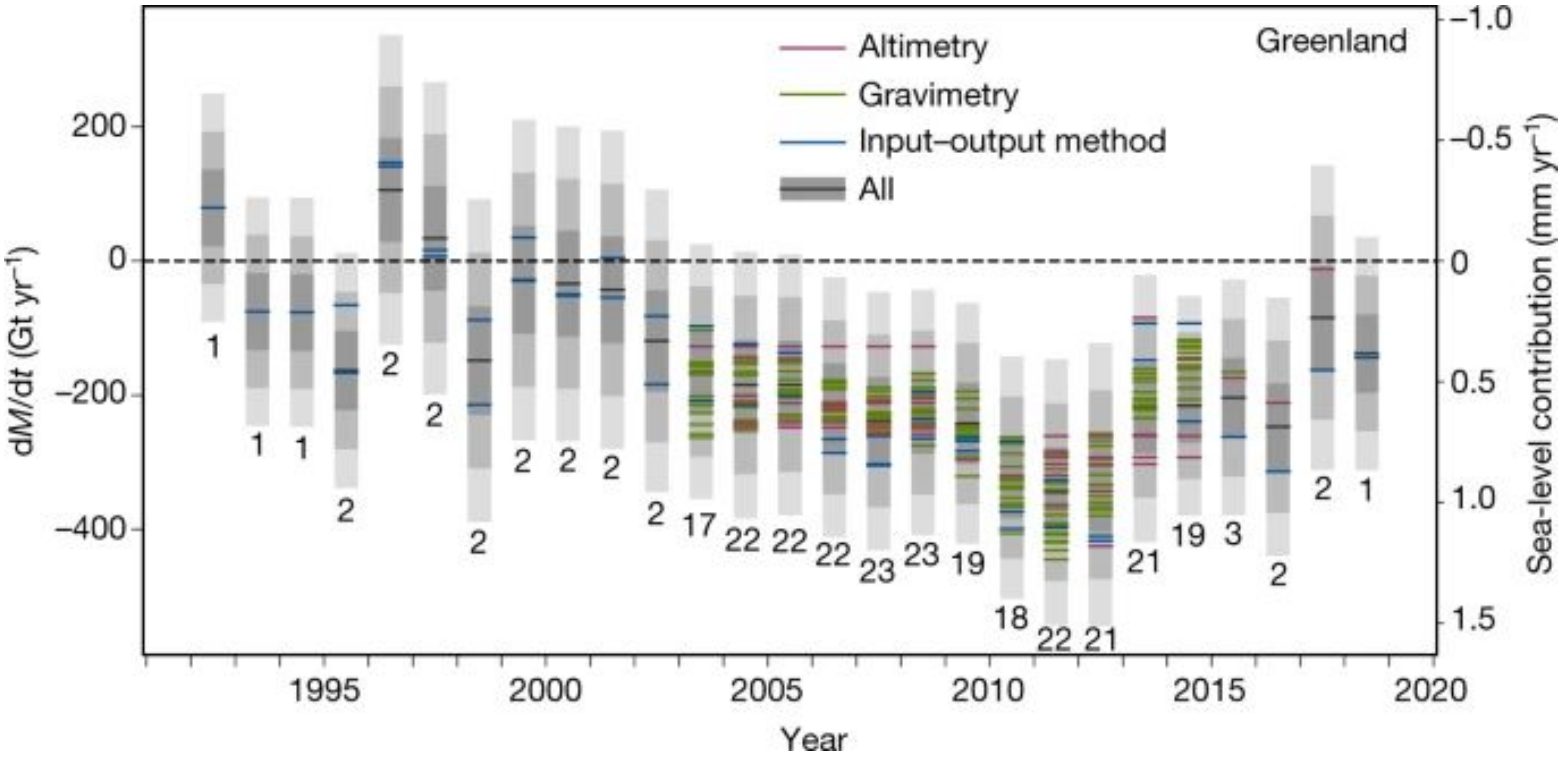
Remote sensing of snow accumulation



Credit: Ryan et al. (2020)



Credit: Shepherd et al. (2018)



Credit: Shepherd et al. (2020)