School of Earth and Environment
INSTITUTE FOR CLIMATE & ATMOSPHERIC SCIENCE

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Increased variability in Greenland Ice Sheet runoff detected by CryoSat-2 satellite altimetry

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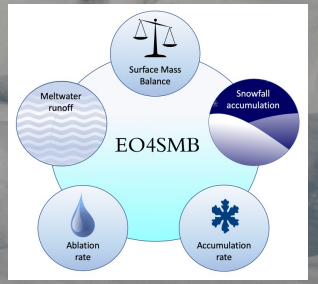

Outline

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- Introduction
- Partitioning CryoSat-2 elevation changes
- Seasonal cycle of melting and snowfall
- A CryoSat-2 record of Greenland runoff
- Increased variability in Greenland runoff from CryoSat-2 observations
- Key points

Image Credit: Ian Joughin

Greenland's contemporary mass balance

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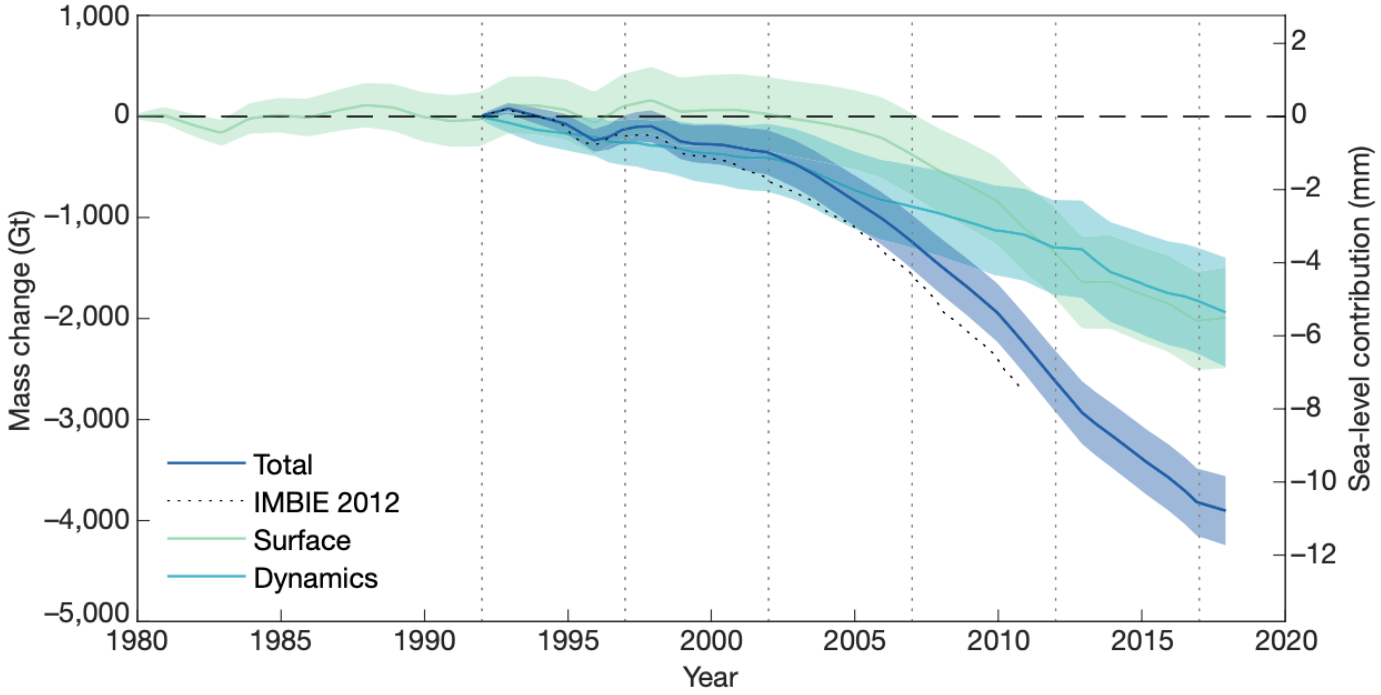
Greenland has contributed 11 mm to global sea level since 1992

Recent imbalance driven by decline in net surface mass balance (SMB) as regional climate has warmed



Cumulative Greenland mass anomalies. The IMBIE Team, 2020

Greenland's surface mass balance

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Surface mass balance (SMB) net balance between gains (snowfall, rainfall) and losses (runoff, sublimation drifting snow erosion) at ice sheet surface…

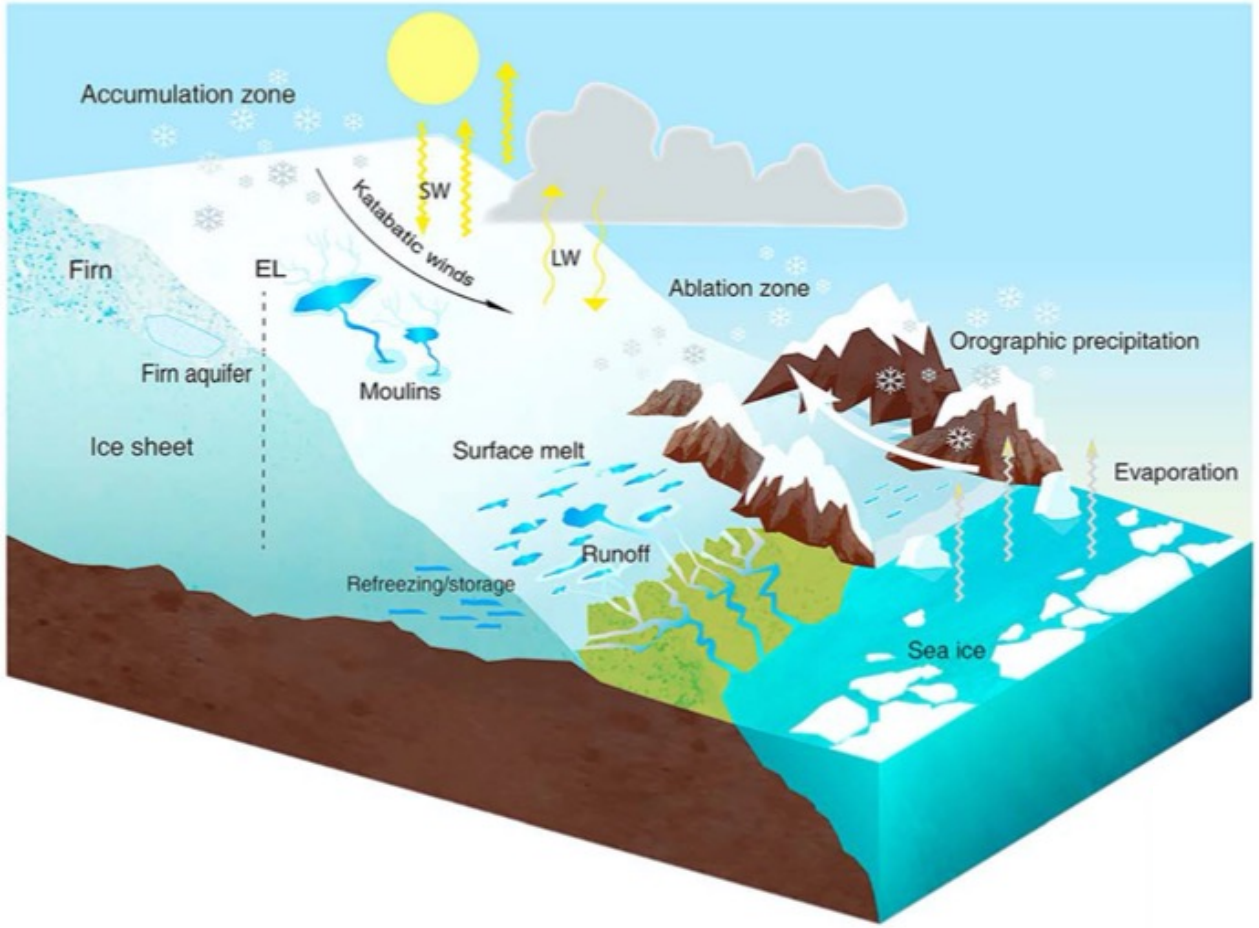

Illustration of processes contributing to Greenland SMB. Lenaerts et al., 2019

Greenland's surface mass balance

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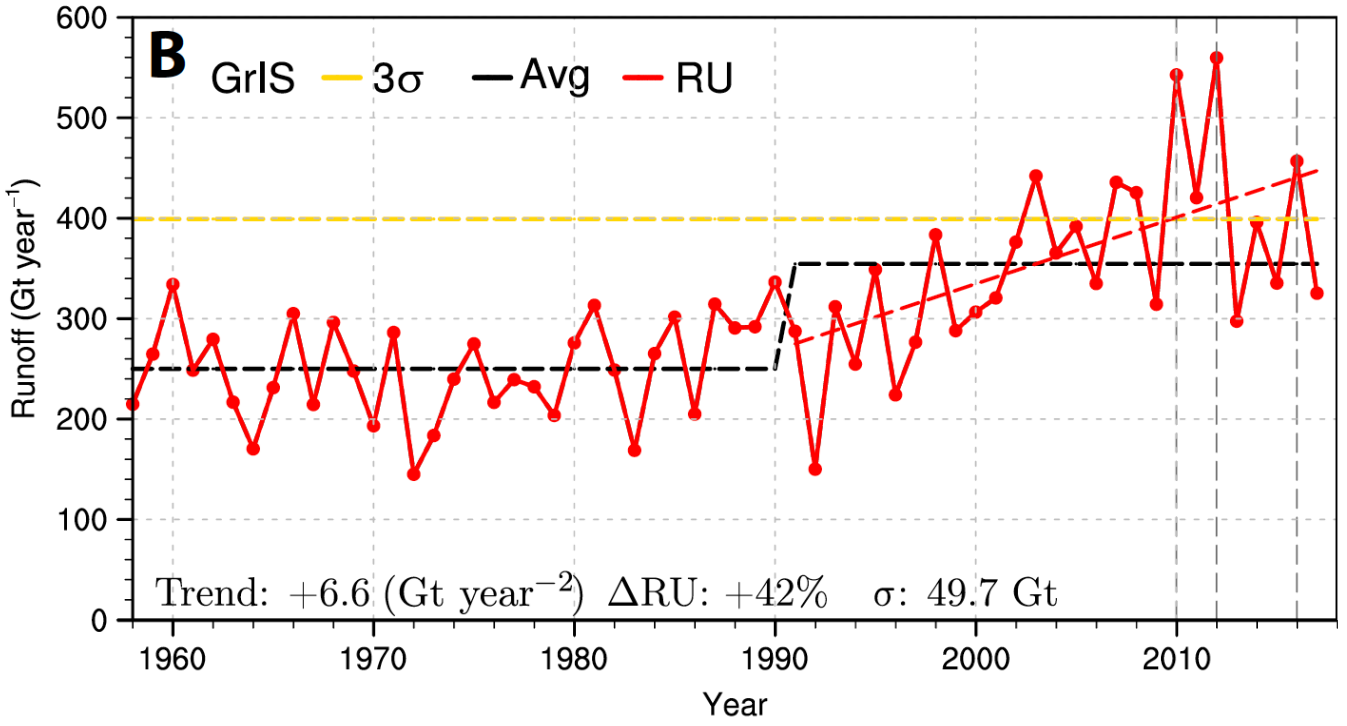
Surface mass balance (SMB) net balance between gains (snowfall, rainfall) and losses (runoff, sublimation drifting snow erosion) at ice sheet surface…

… the recent decline has primarily been driven by increased runoff.



Annual runoff modelled by RACMO. Noël et al., 2019

Greenland runoff

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Video Credit: UCLA; Smith el al., 2014

The need for Earth Observation of SMB

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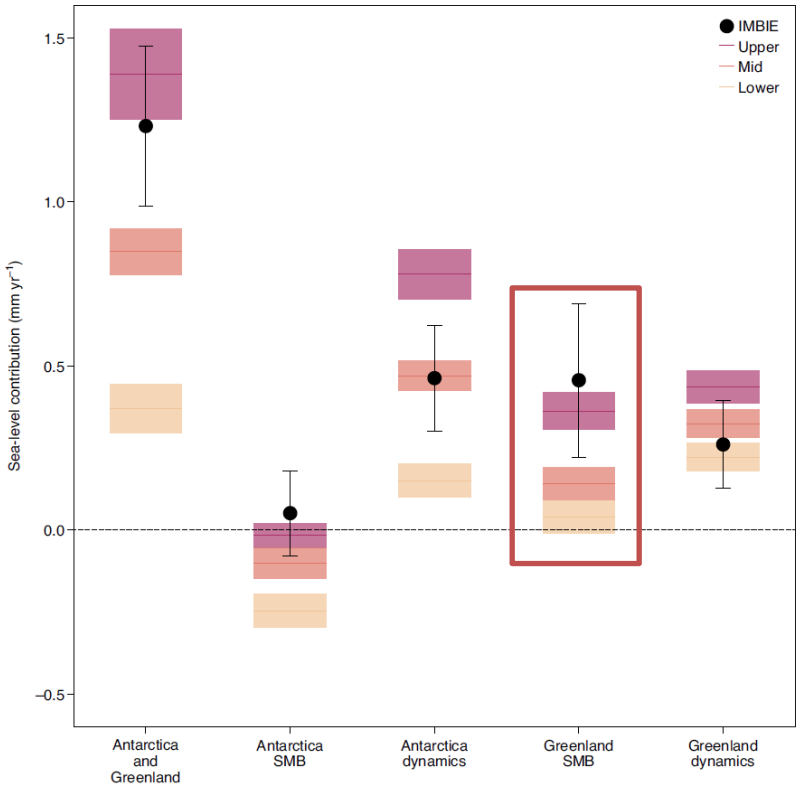
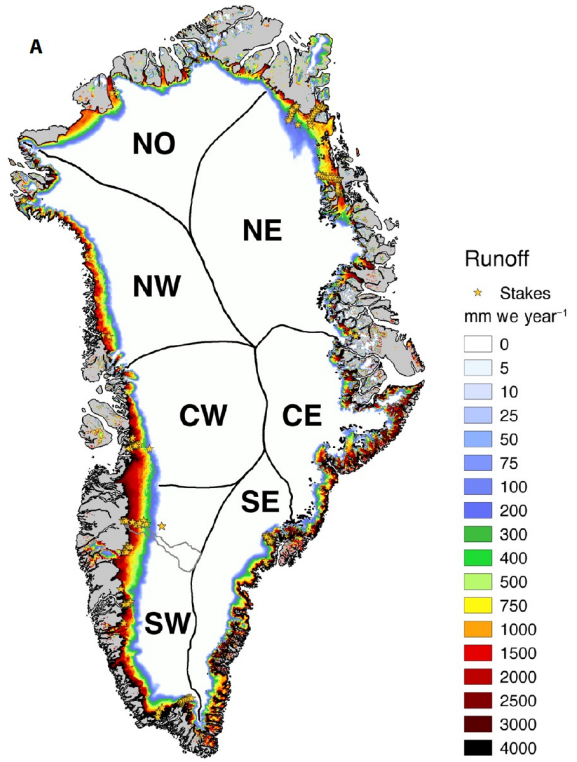


Comparison of IMBIE and AR5 projections, Slater et al., 2020



Average annual runoff (1958-2017) modelled by RACMO. Noël et al., 2019

Global climate models historically used in sea level projections have not captured recent interannual variability in SMB and underestimated Greenland's sea level contribution

Regional climate models have been principal source of ice-sheet wide estimates of SMB parameters; available *in situ* data is sparse

Partitioning CryoSat-2 elevation changes

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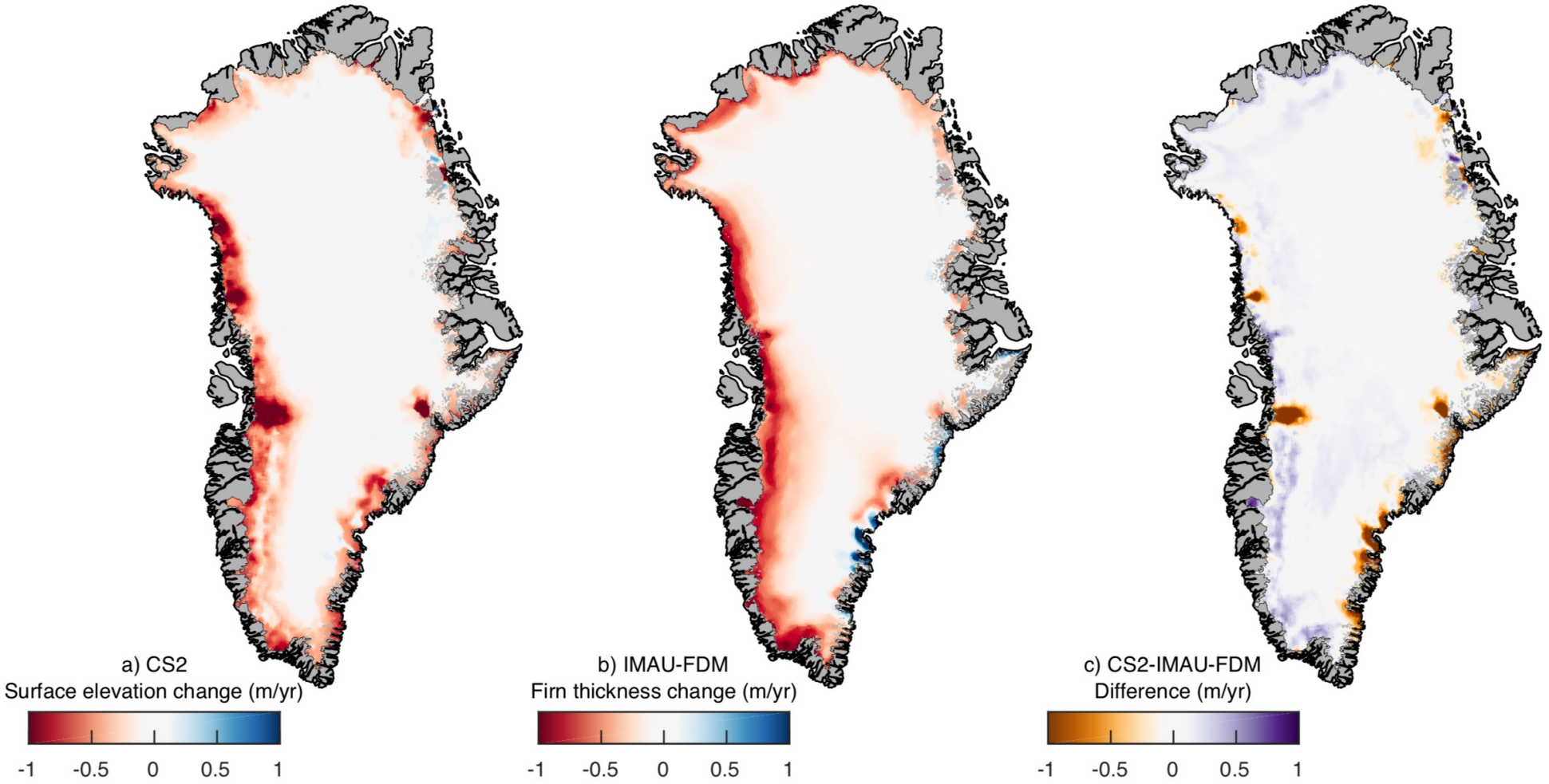

Seasonal cycle of melting and snowfall

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Video Credit: Planetary Visions

Seasonal cycle of melting and snowfall

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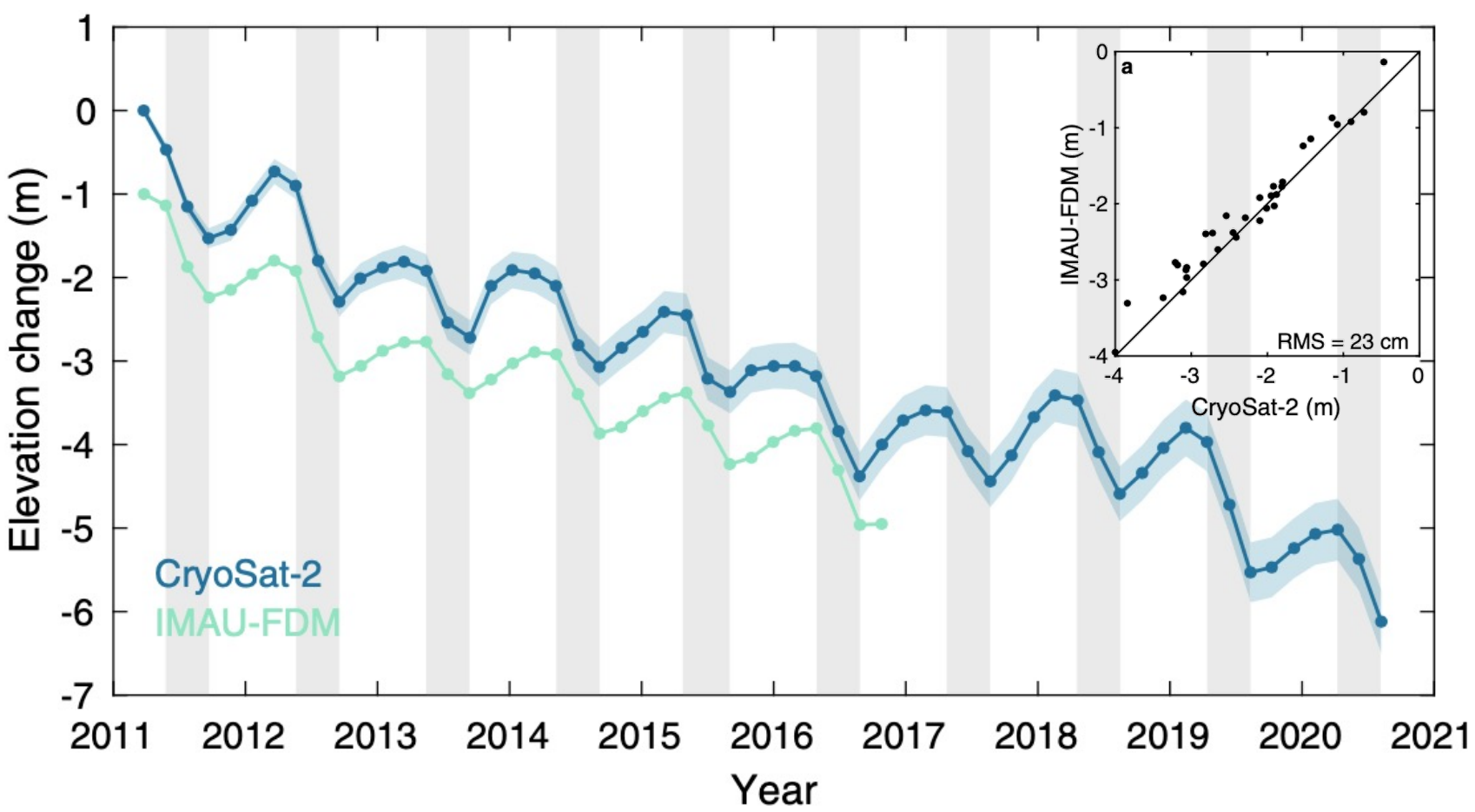
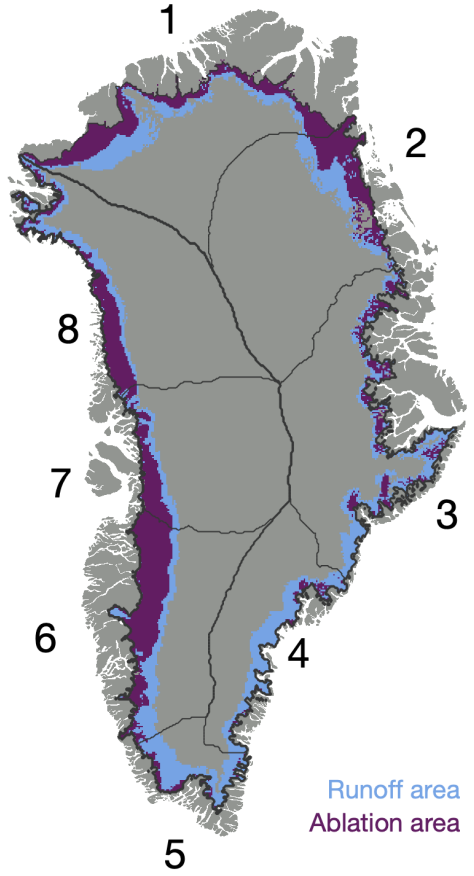
Ablation zone time series





Seasonal cycle of melting and snowfall

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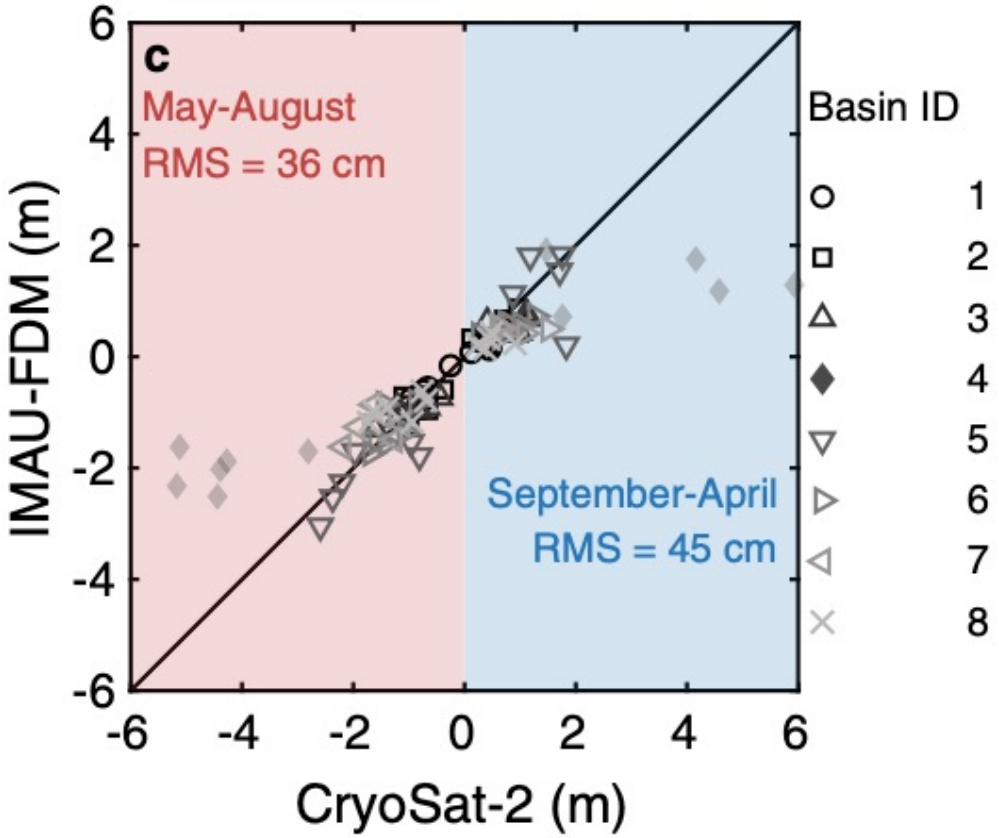
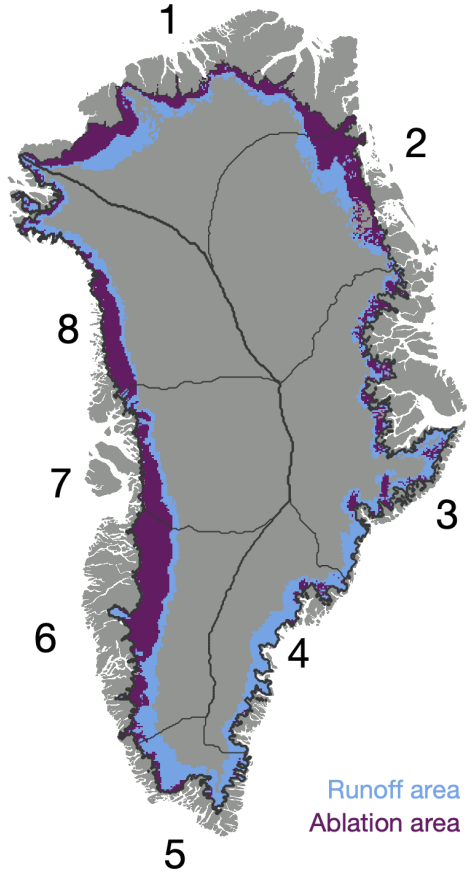
Seasonal changes between CryoSat-2 and firn modelling also agree well in ablation zone – indicates that SMB processes are the primary driver

Interannual variations in e.g. ice-sheet wide summer elevation changes reflect variations in atmospheric forcing – summer thinning ~40% lower on average 2013-2015 (1.2 ± 0.4 m) than 2012 and 2019 (1.9 ± 0.5 m)

Seasonal elevation changes in ablation zone in summer (red) and winter (blue)





A CryoSat-2 record of Greenland runoff

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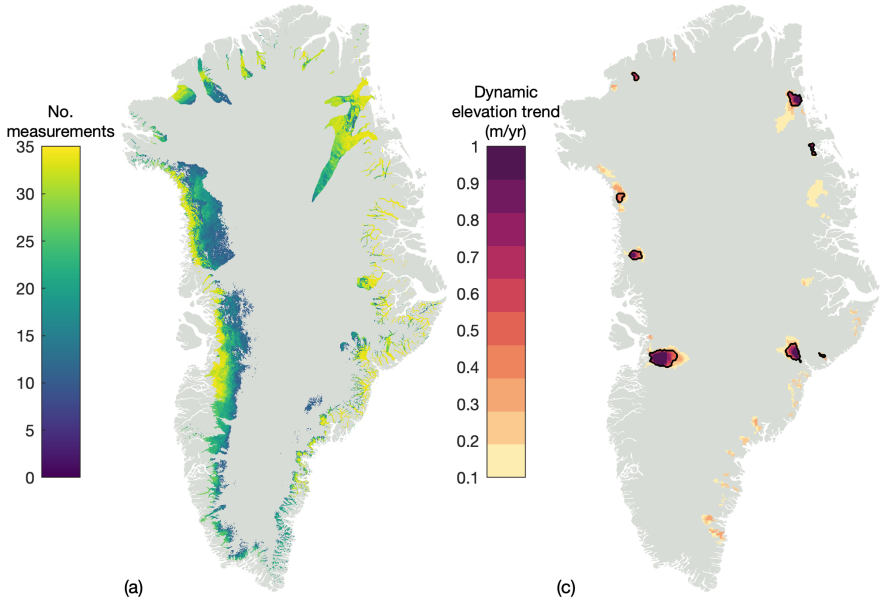
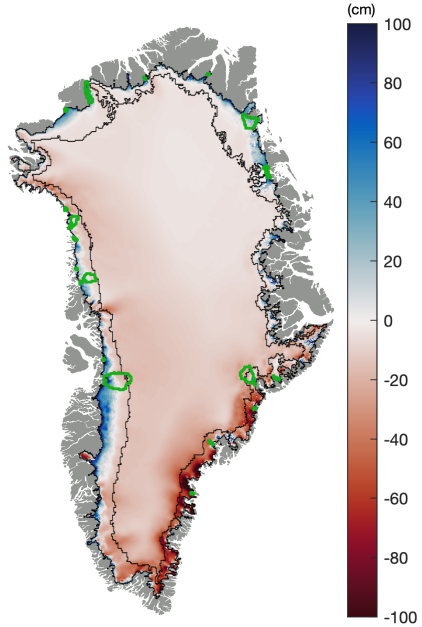
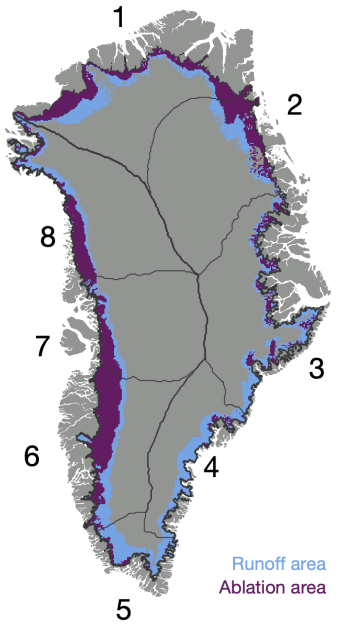
Because observed seasonal changes are driven by SMB, and dominant process in summer is melting, we use CryoSat-2 elevation measurements to estimate ice-sheet runoff



Identify and remove areas of dynamic imbalance using velocity data and dynamic elevation trends from CryoSat-2



Account for elevation signal associated with steady-state divergence of ice to isolate contribution due to SMB anomalies



Convert elevation changes to mass assuming constant densities

A CryoSat-2 record of Greenland runoff

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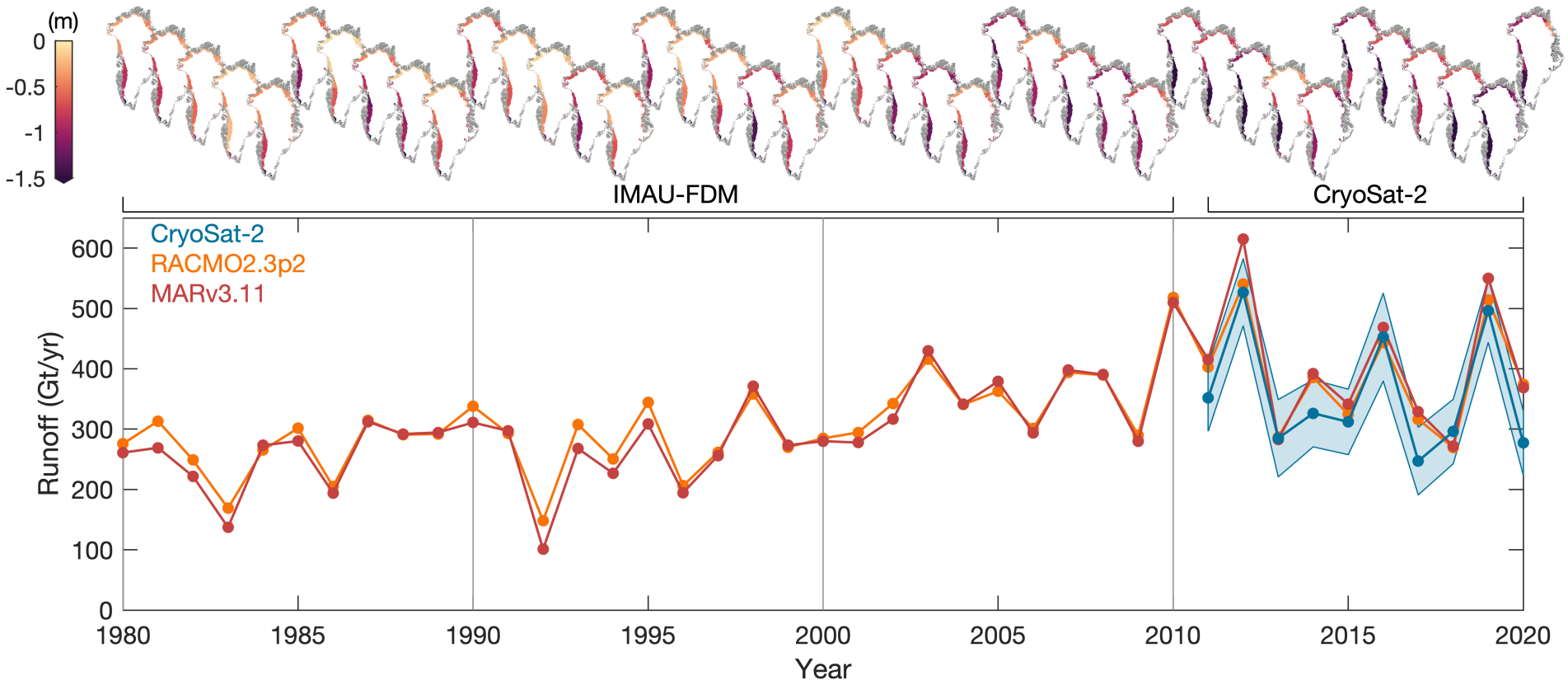

Average runoff from CryoSat-2 (2011-2020): 357 ± 58 Gt/yr

Good agreement with runoff estimates derived from RACMO2.3p2 (rmsd 47 Gt/yr) and MARv3.11 (rmsd 60 Gt/yr)

Increased variability in Greenland runoff

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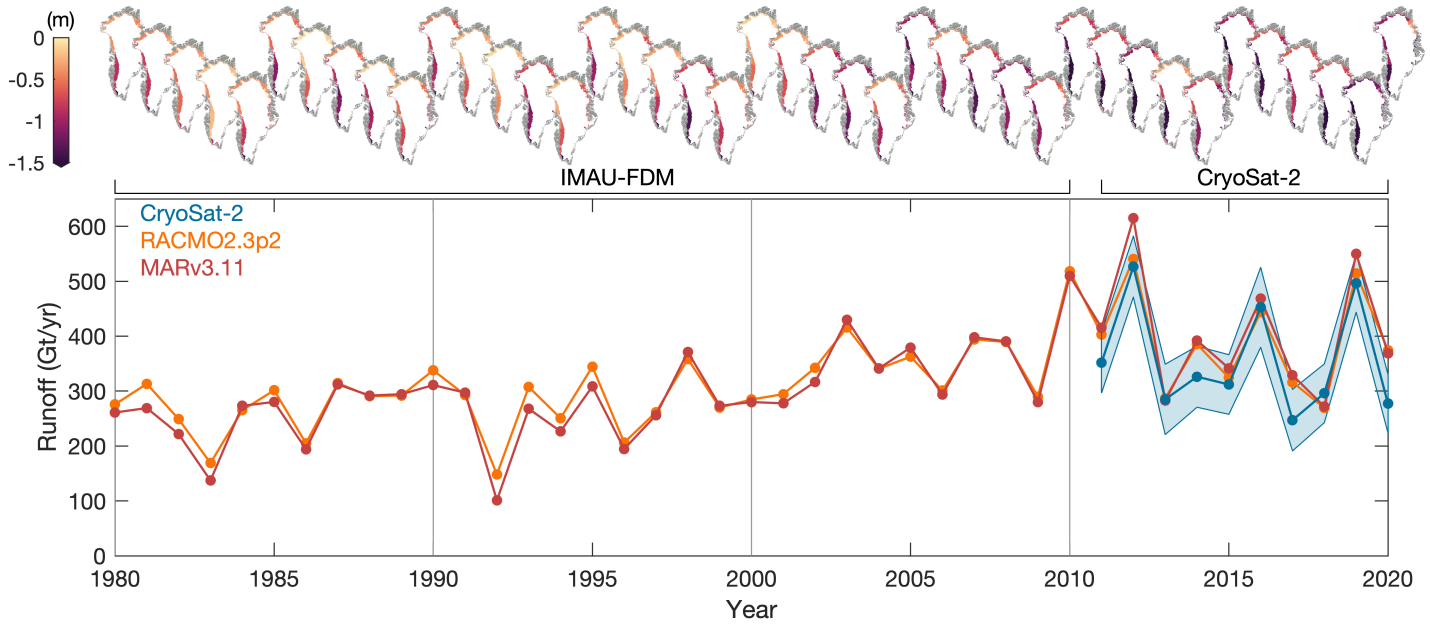
Decadal runoff variability (Gt/yr)

	1980s	1990s	2000s	2010s*
CryoSat-2	-	-	-	99
MARv3.11	54	74	57	111
RACMO 2.3p2	48	66	48	101

* This decade not entirely covered by CryoSat-2 (2011-2020)



CryoSat-2 records high year-to-year variability in runoff between 2011-2020: maximum spread 280 Gt/yr and standard deviation 99 Gt/yr

Record runoff in 2012 (527 ± 56 Gt/yr) closely followed by 2019 (496 ± 53 Gt/yr)

Interannual variability in 2010s twice as high as 2000s, 60% higher than during previous three decades

Response to recent large-scale fluctuations in atmospheric circulation

Key Points

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- CryoSat-2 can detect Greenland ice-sheet and regional scale seasonal elevation changes.
- Close agreement with firn modelling suggests these changes are driven by SMB…
- … CryoSat-2 can provide observational and satellite-based estimate of ice sheet runoff at scale.
- Runoff estimated by CryoSat-2 between 2011-2020 21% higher and 60% more variable than previous three decades.
- Observational approach allows runoff to be measured in near real-time, and support improvements in model capability.
- Work ongoing to extend methods to other ice sheet SMB processes e.g. snowfall variability and improve spatial resolution.