Interruption of Two Decades of Jakobshavn Isbrae Acceleration and Thinning as Regional Ocean Cools

[1]Ala Khazendar
[1]Ian Fenty
[1]Dustin Carroll
[1]Alex Gardner
[2]Craig Lee
[1]Ichiro Fukumori
[1]Ou Wang
[1]Hong Zhang
[1]Helene Seroussi
[3]Delwyn Moller
[4]Brice Noel
[4]Michiel van den Broeke
[1]Steven Dinardo
[1]Josh Willis

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.
[2]Applied Physics Laboratory, University of Washington, Seattle, WA, USA.
[3]Remote Sensing Solutions, Barnstable, MA, USA.
[4]Institute for Marine and Atmospheric Research Utrecht, Utrecht University, Utrecht, The Netherlands.

Photo: *John Sonntag, Operation IceBridge, NASA*

Work was supported by NASA's Cryospheric Sciences Program and NASA's Oceans Melting Greenland Mission.

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Jet Propulsion Laboratory
California Institute of Technology

UNIVERSITY of WASHINGTON

Universiteit Utrecht

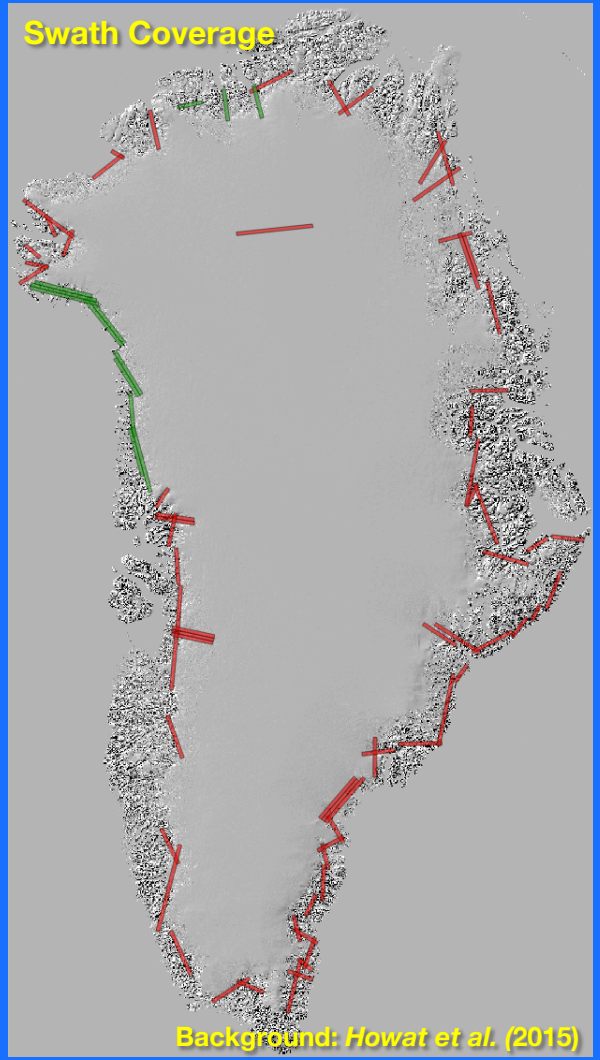
NASA's Oceans Melting Greenland (OMG) Mission

Ice campaigns: GLISTIN-A radar altimeter (Ka-band at 35 GHz; 8.5-mm wavelength) single pass interferometer (25-cm baseline length

Swath width: 10 – 12 km

(*Moller et al.*, 2011; *Hensley et al.*, 2016)

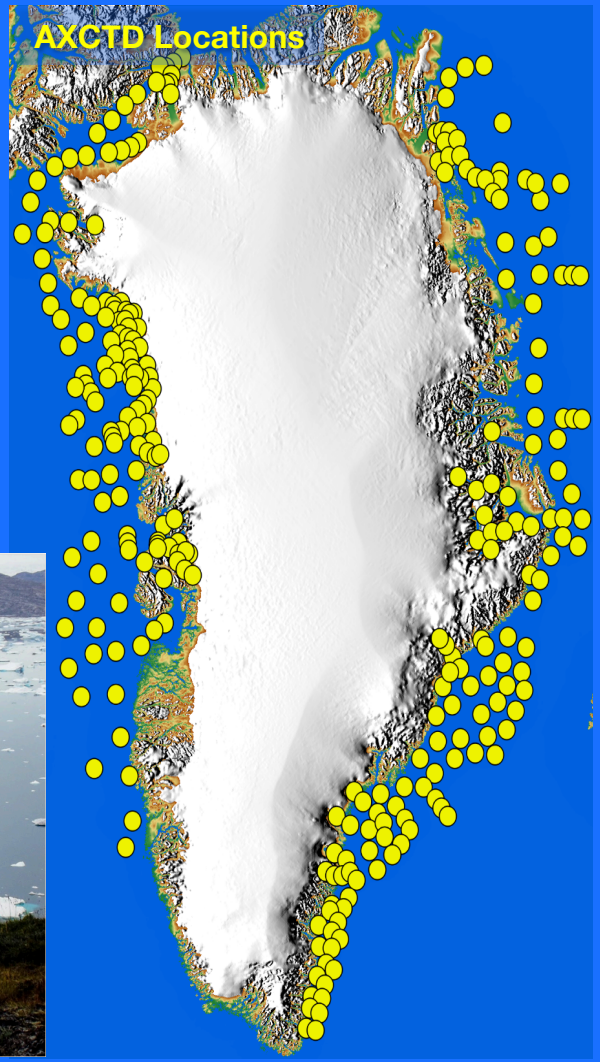
NASA's Gulfstreram-III aircraft, with the GLISTIN-A radar instrument visible below, on the runway at Thule Air Base, Greenland.



NASA's Oceans Melting Greenland (OMG) Mission

Ocean campaigns: Observations made on the continental shelf and in select fjords

The arborne AXCTD campaign is designed to mainly sample the ocean in deep cross-shelf troughs.

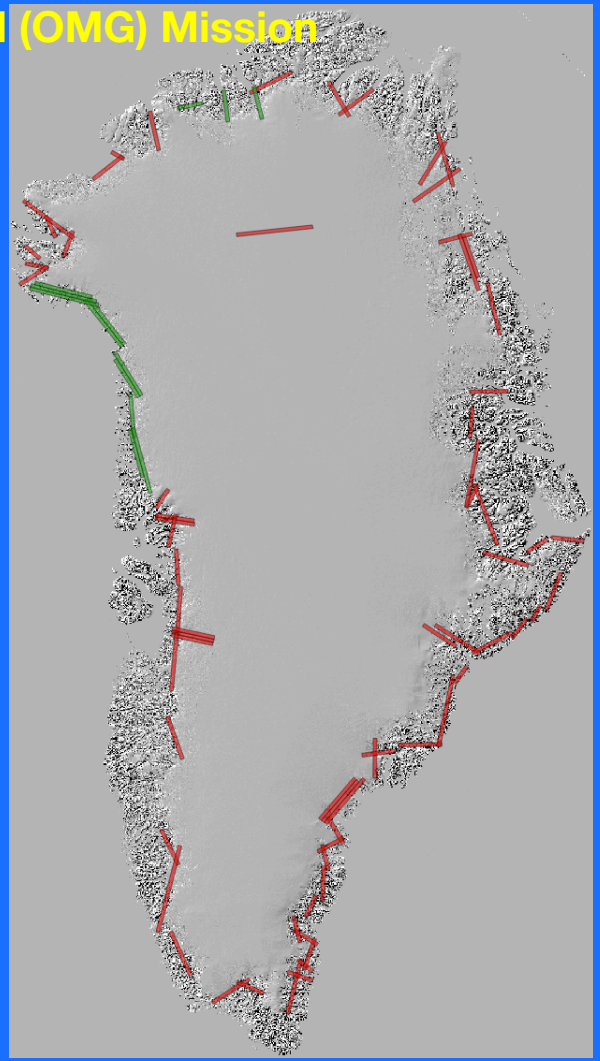


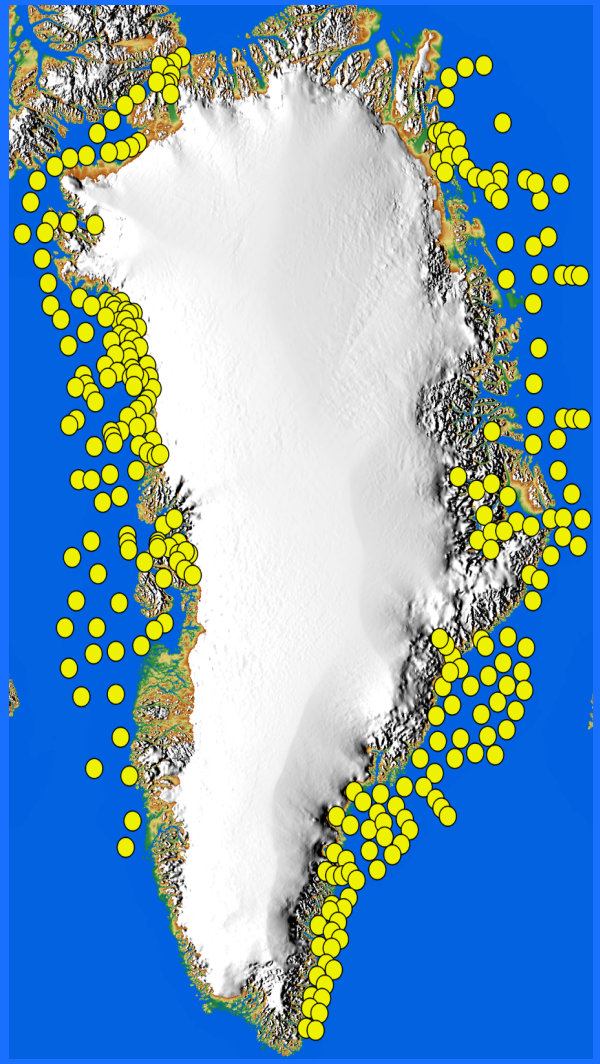
Greenland Institute of Natural Resources

Ocean observations in Disko Bay before 2015

NASA's Oceans Melting Greenland (OMG) Mission

OMG data are publicly available at:
https://omg.jpl.nasa.gov/portal/browse/



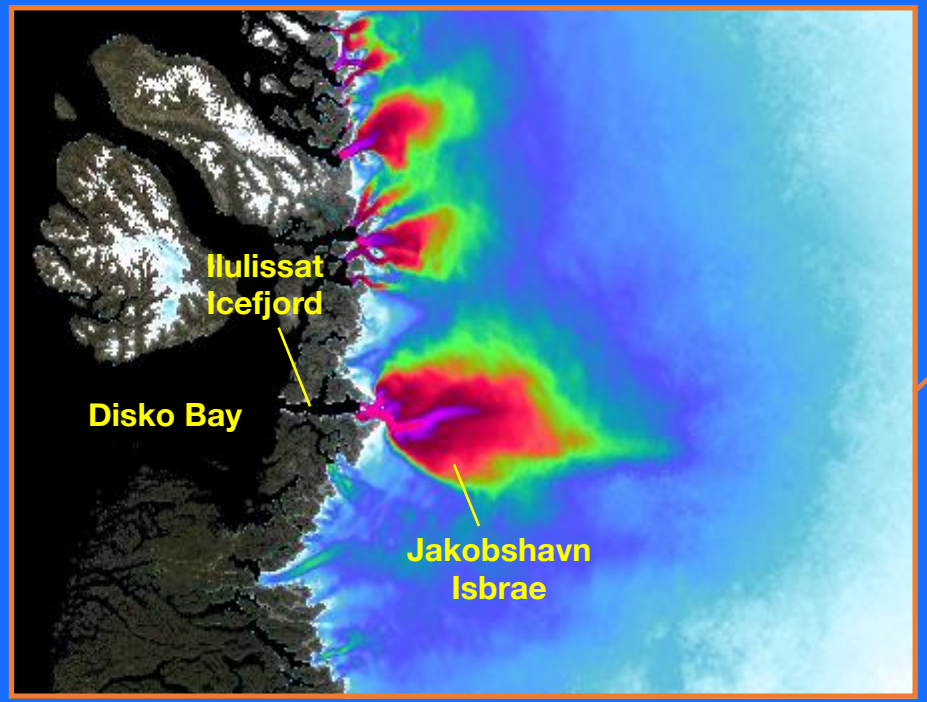


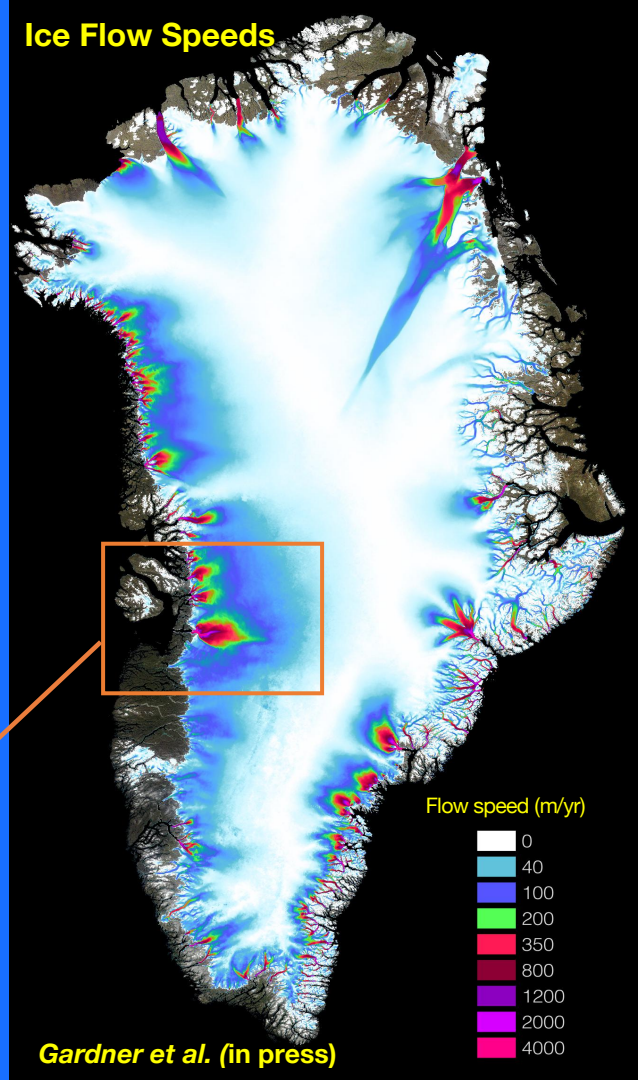
Jakobshavn Isbrae (Sermeq Kujalleq)

Greenland's fastest flowing glacier, with the largest ice discharge.
(*Joughin et al.*, 2014; *Bindschadler*, 1989)

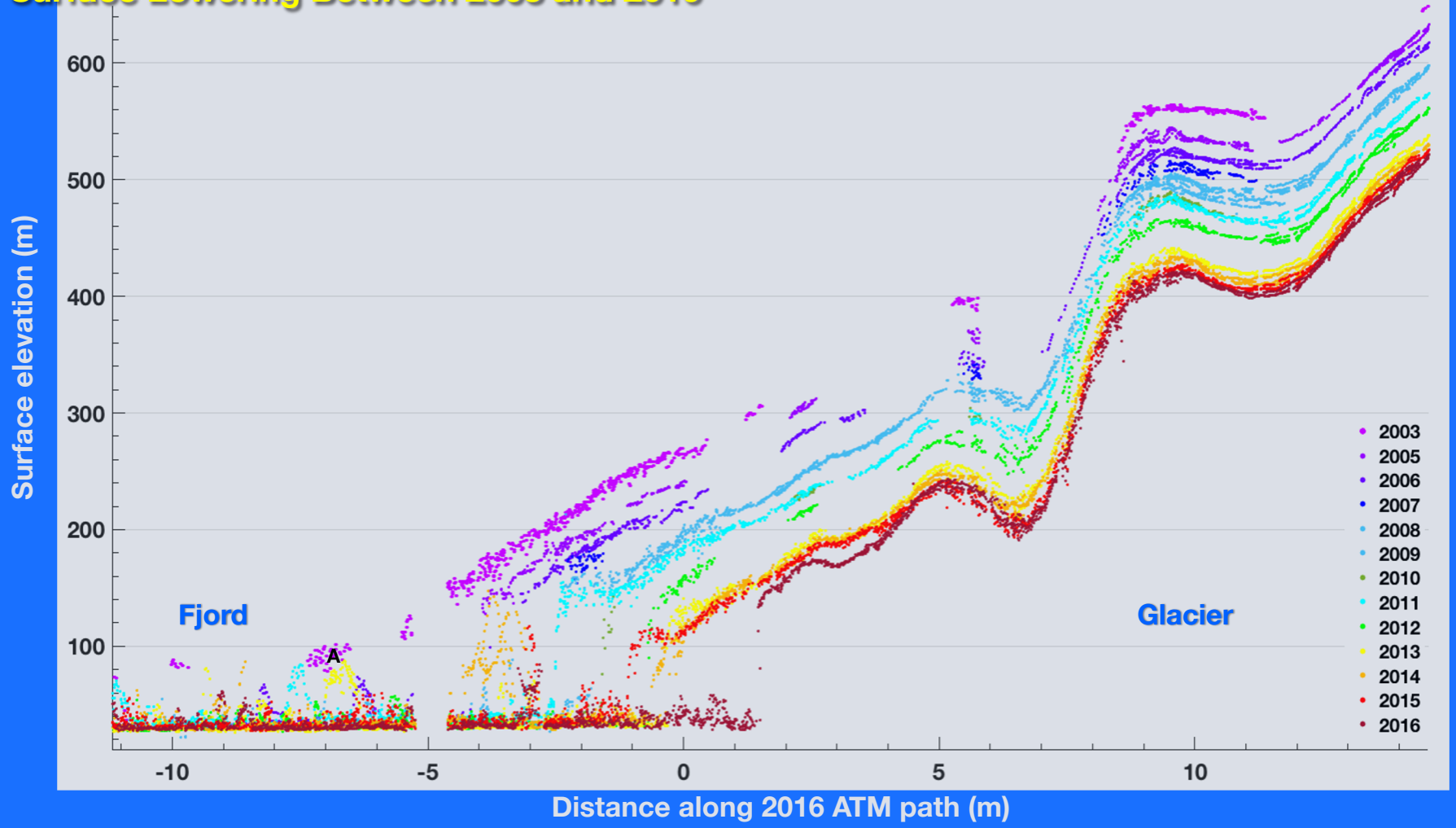
The glacier has been undergoing rapid retreat since the late 1990s.
(e.g., *Thomas et al.*, 2003; *Holland et al.*, 2008; *Motyka et al.*, 2011)

Developed Greenland largest ice discharge anomaly.
(*Enderlin et al.*, 2014; *Howat et al.*, 2014)

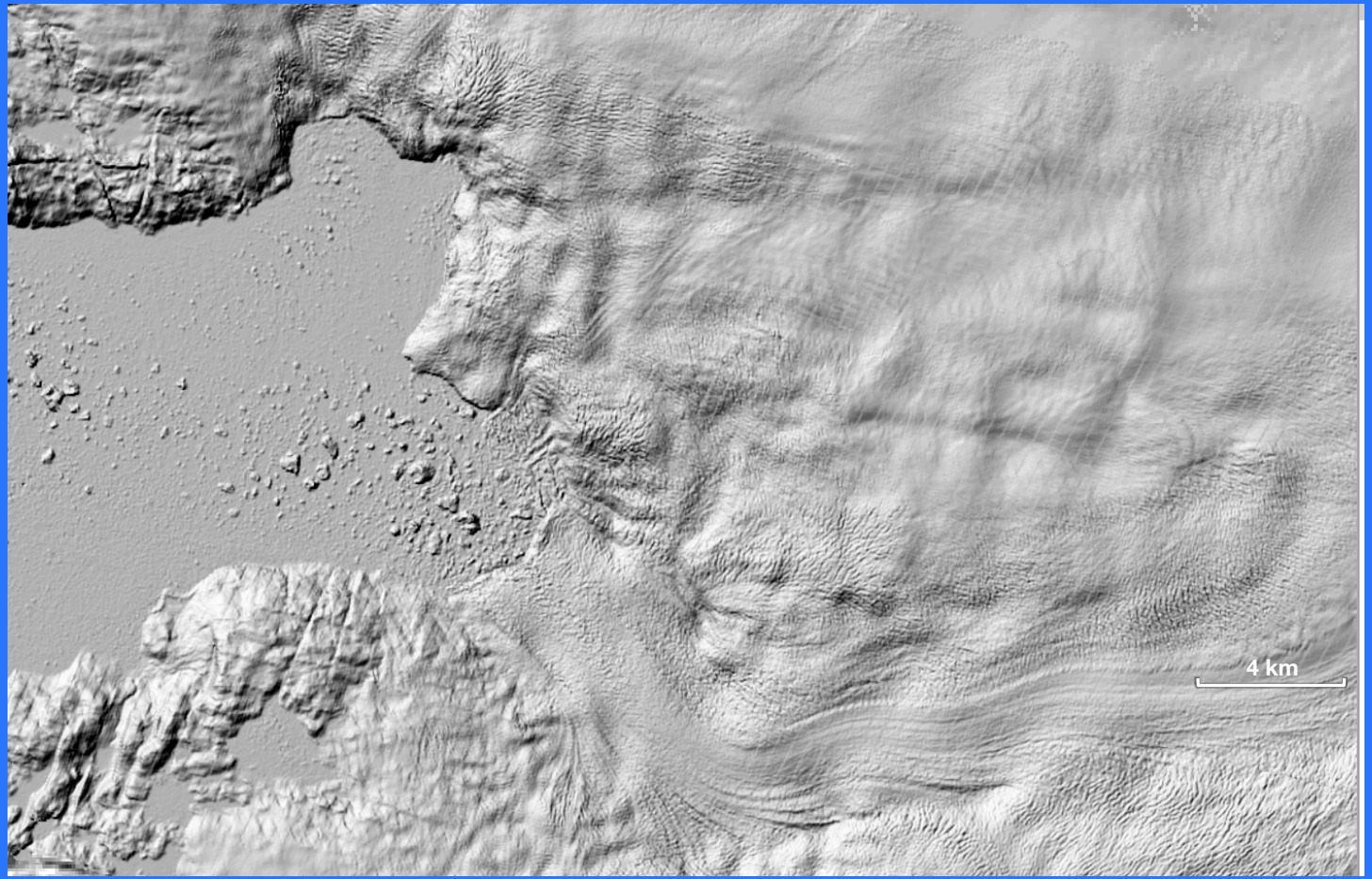




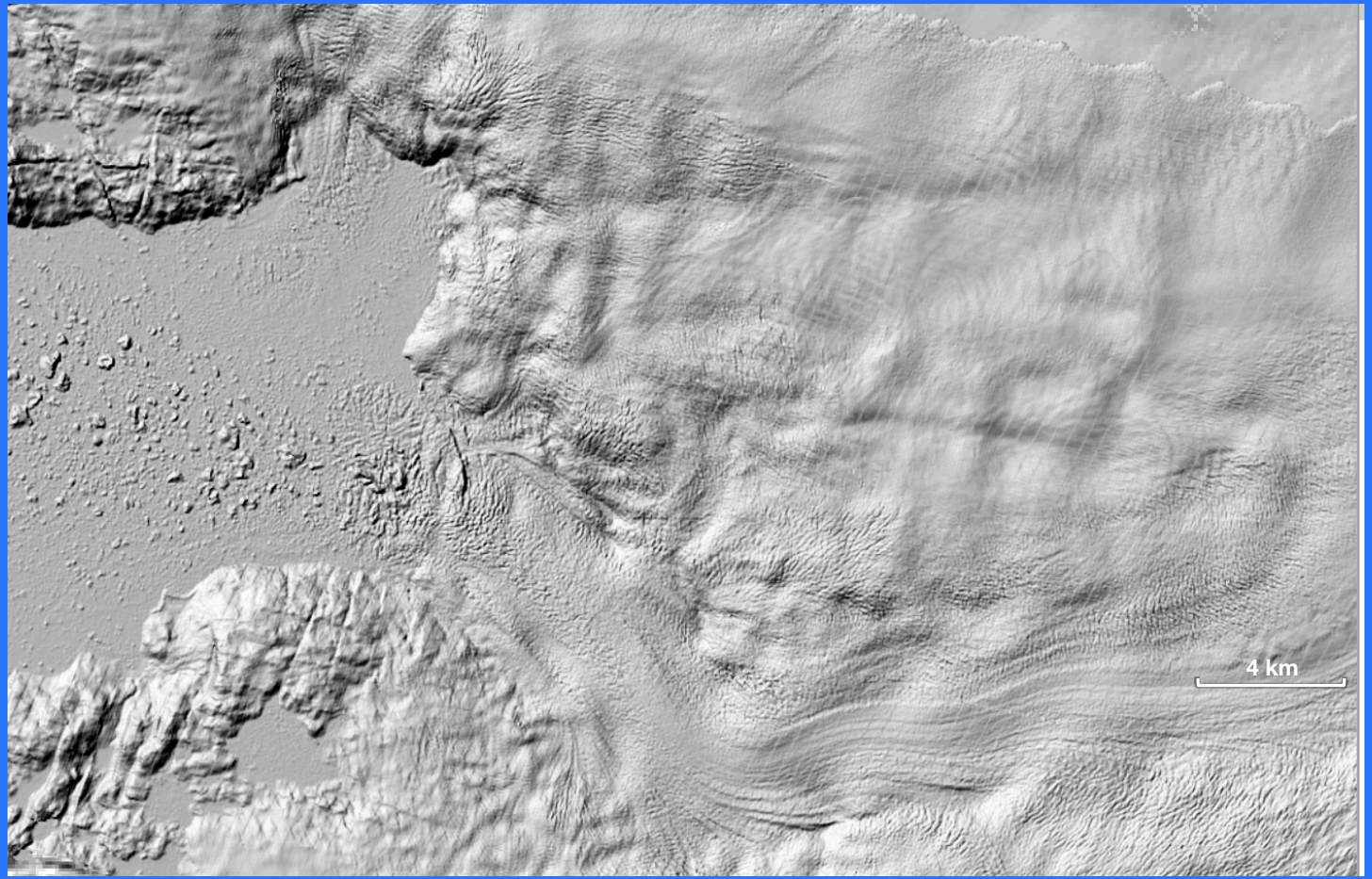
Surface Lowering Between 2003 and 2016



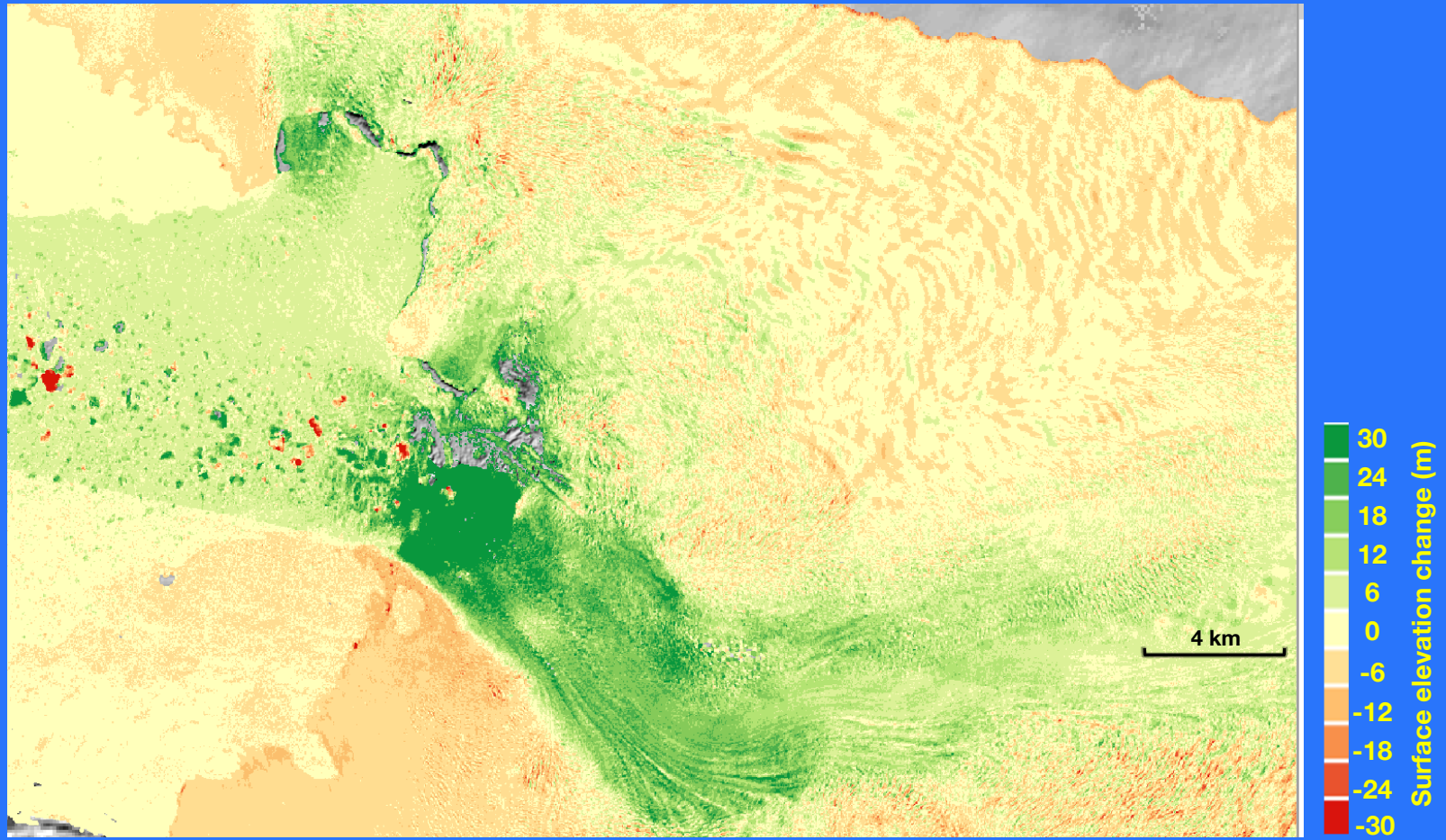
Jakobshavn 2016



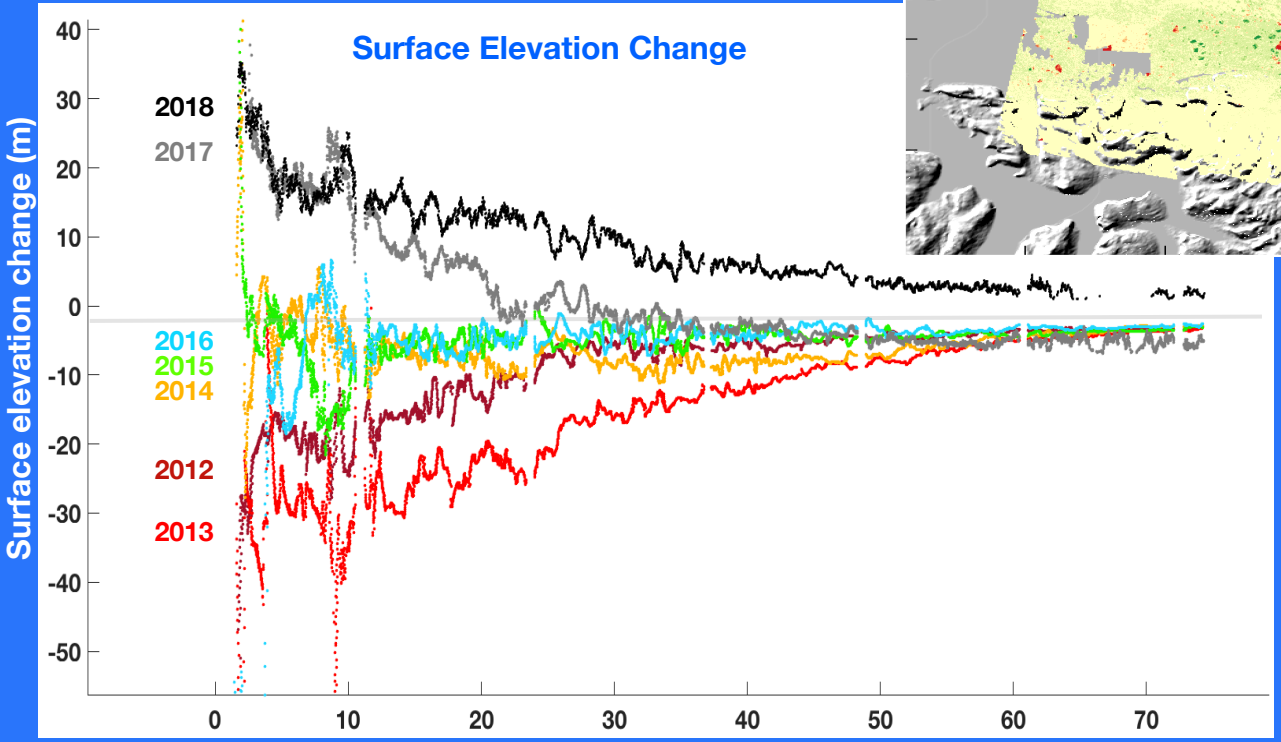
Jakobshavn 2017

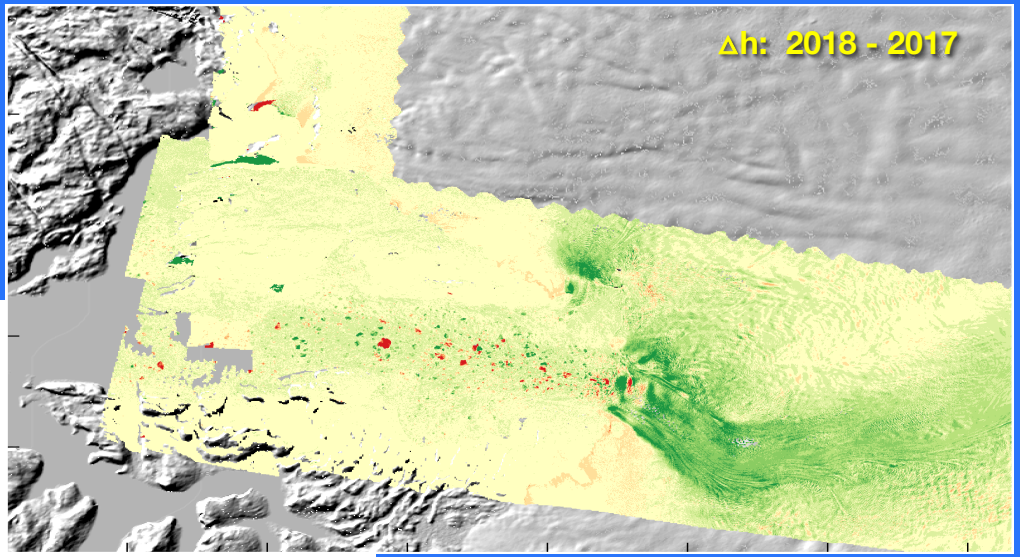


Jakobshavn Δh: 2017 - 2016

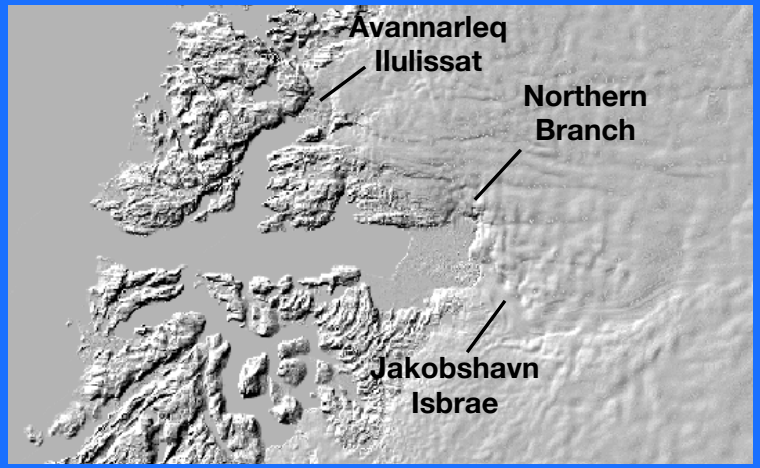


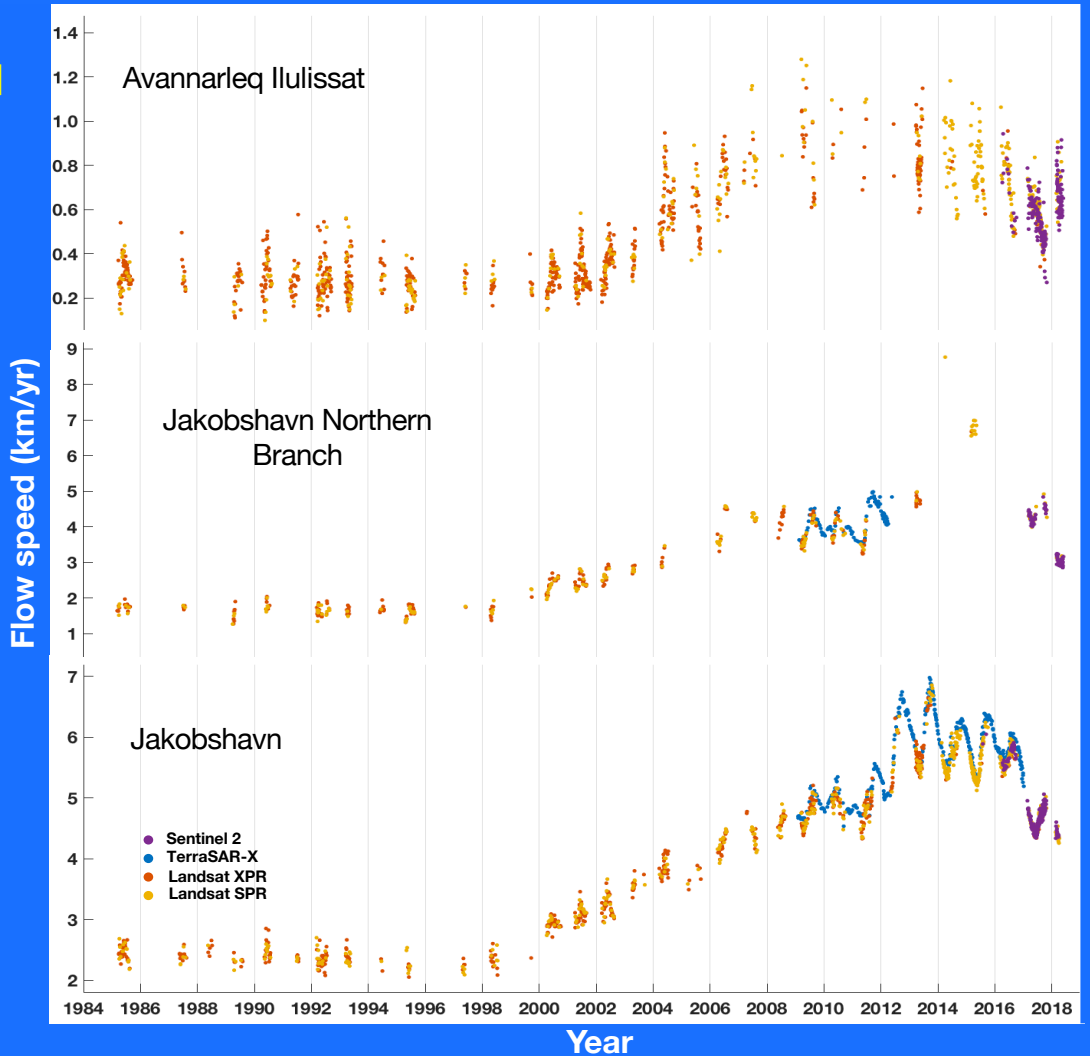
Thickening continued in 2018





Similar flow speed changes for three glaciers terminating in Ilulissat Icefjord

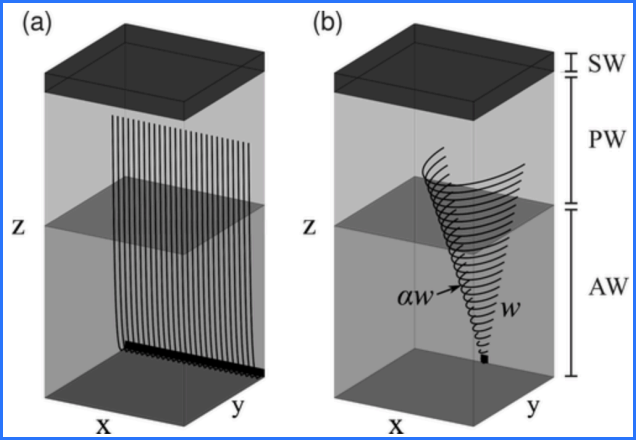




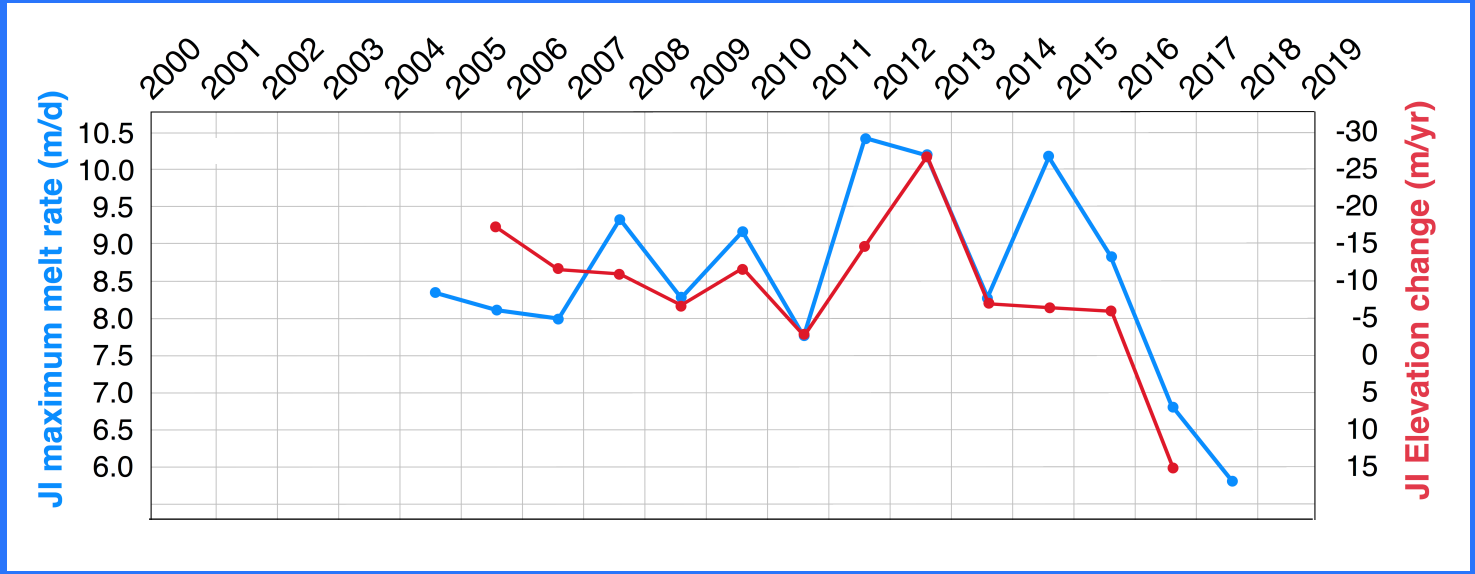
Submarine melting at the front of the glacier

Submarine melting at the front is calculated with a plume model.
(*Carroll et al*., 2016; *Jenkins*, 2011)

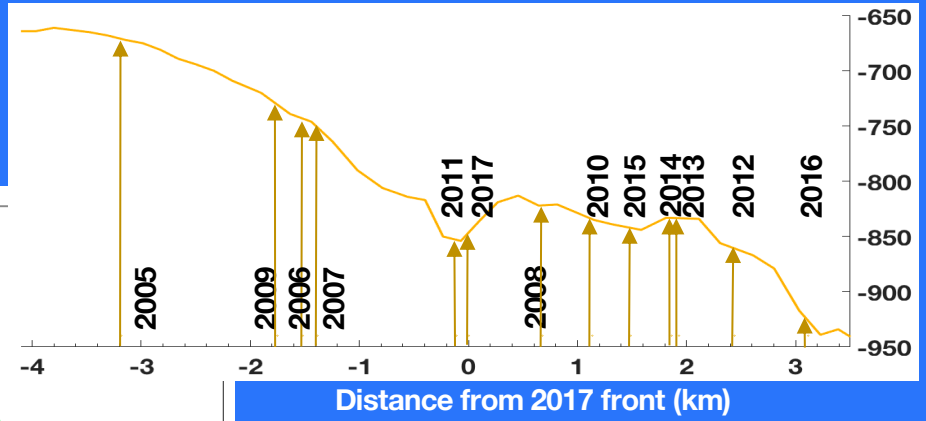
Strong correlation is found between rates of submarine melting and glacier elevation change.



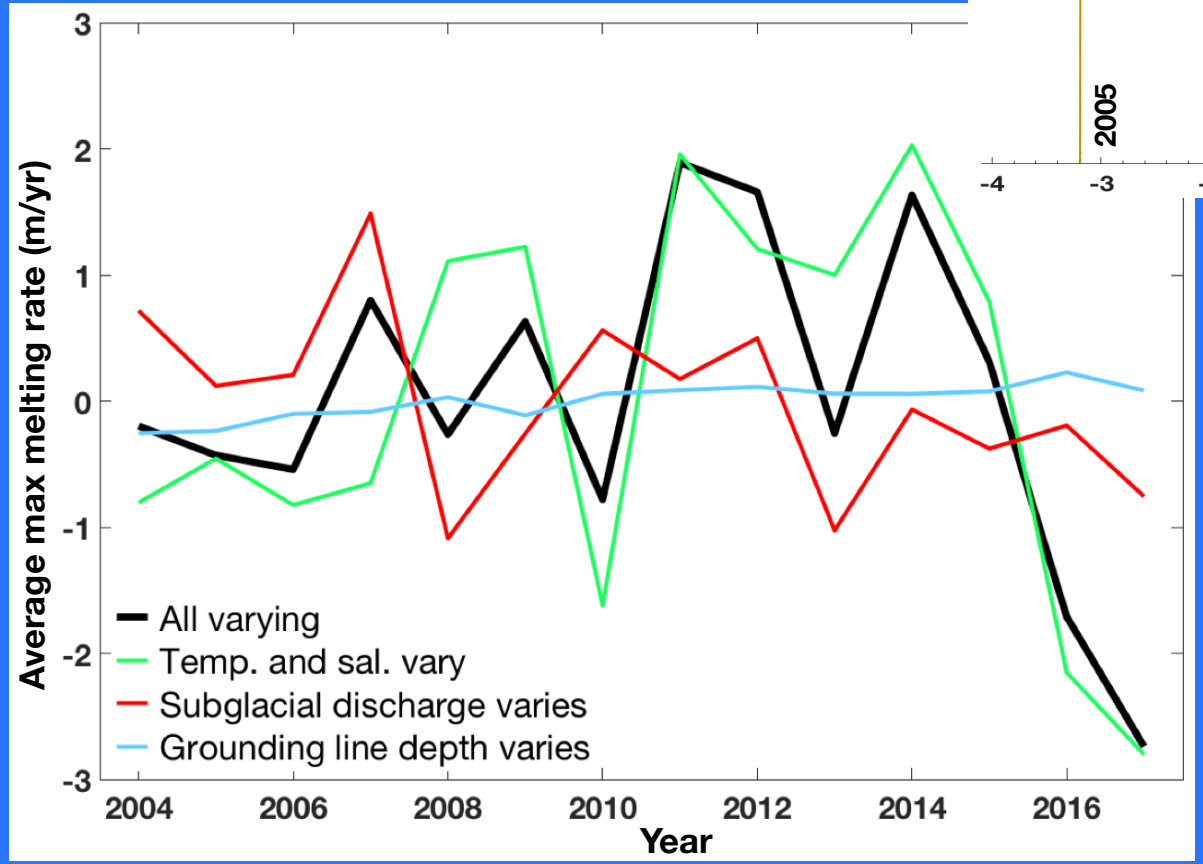
Carroll and Sutherland (2015)



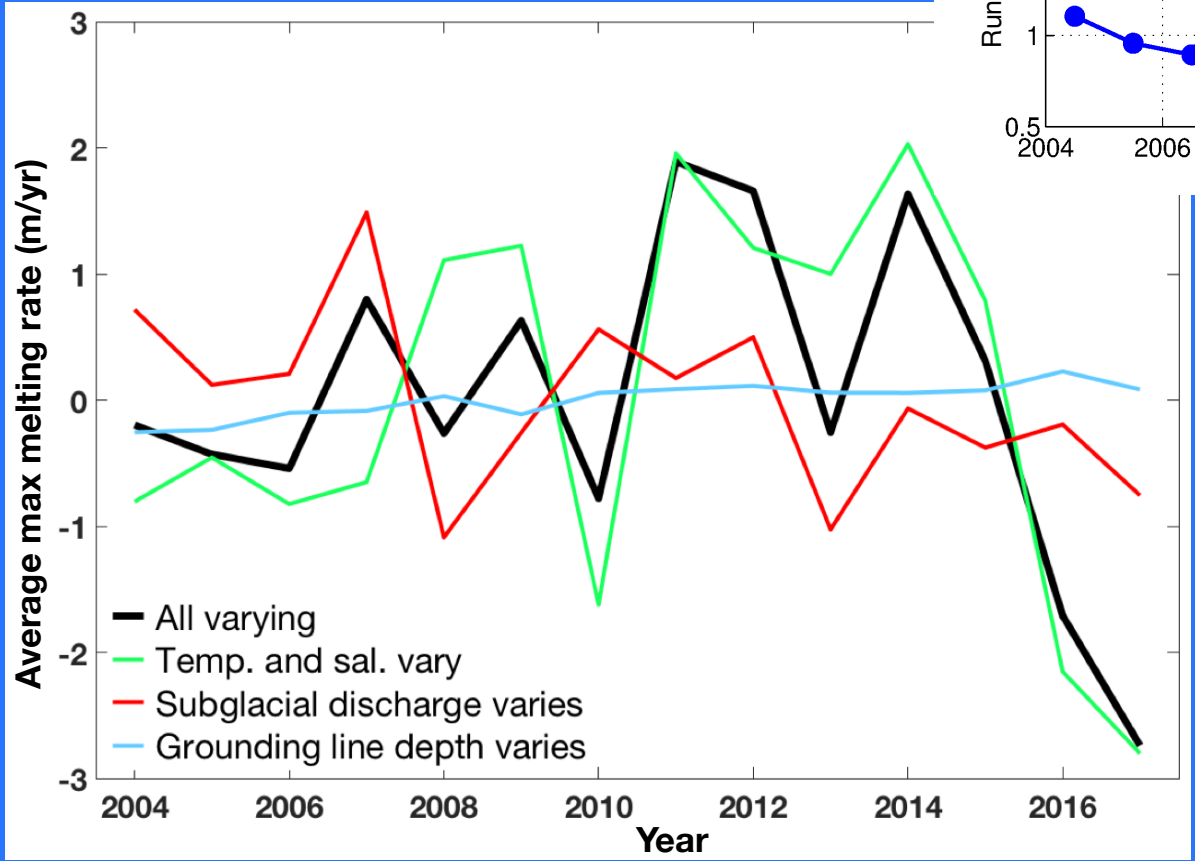
Sensitivity of calculated melting rates to plume model inputs

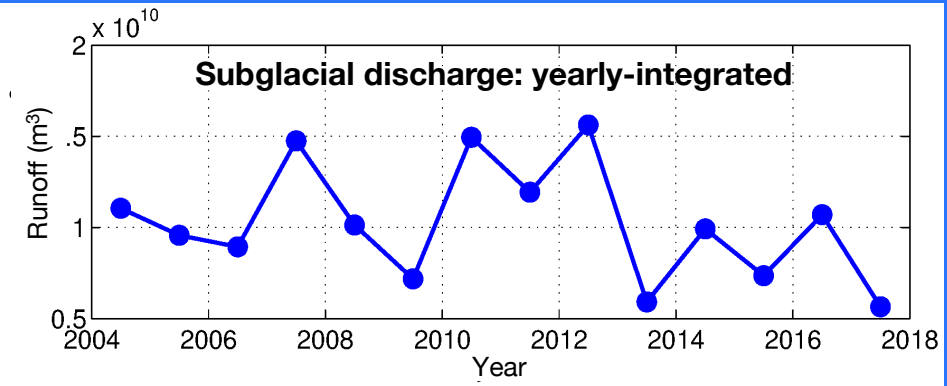


Bed: *Morlighem et al.* (2017)



Sensitivity of calculated melting rates to plume model inputs

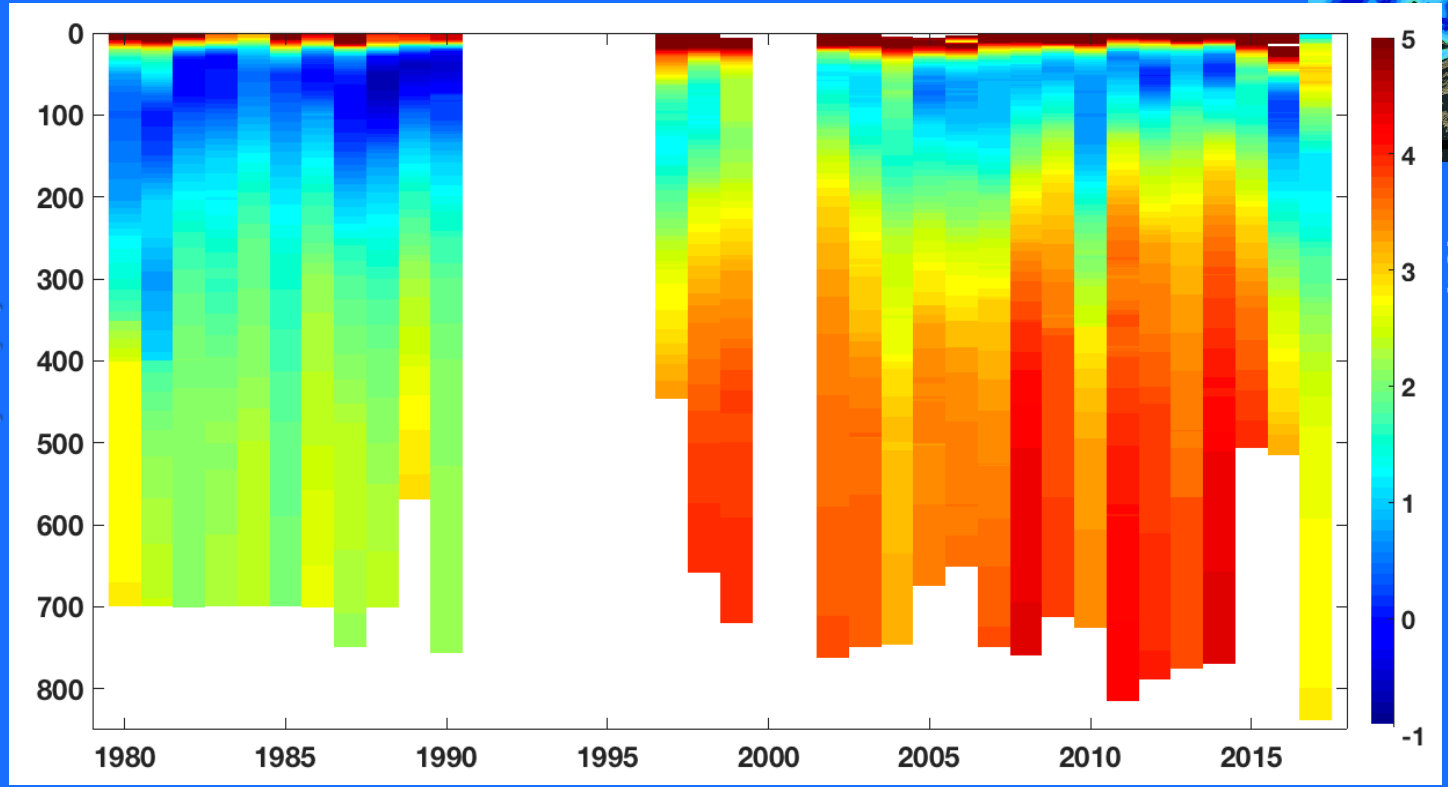


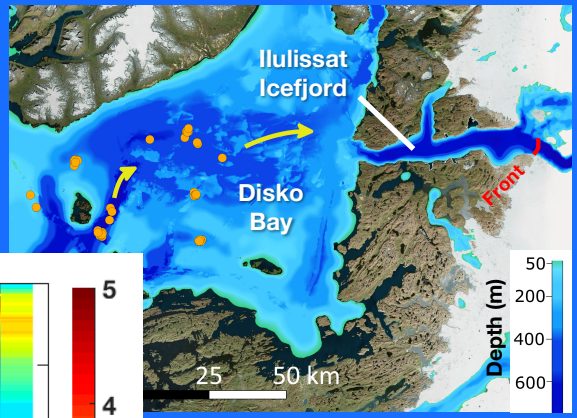


Subglacial discharge from RACMO2.3p2

Ocean temperatures in Disko Bay

Temperatures in Disko Bay have cooled to lowest level since mid 1980s

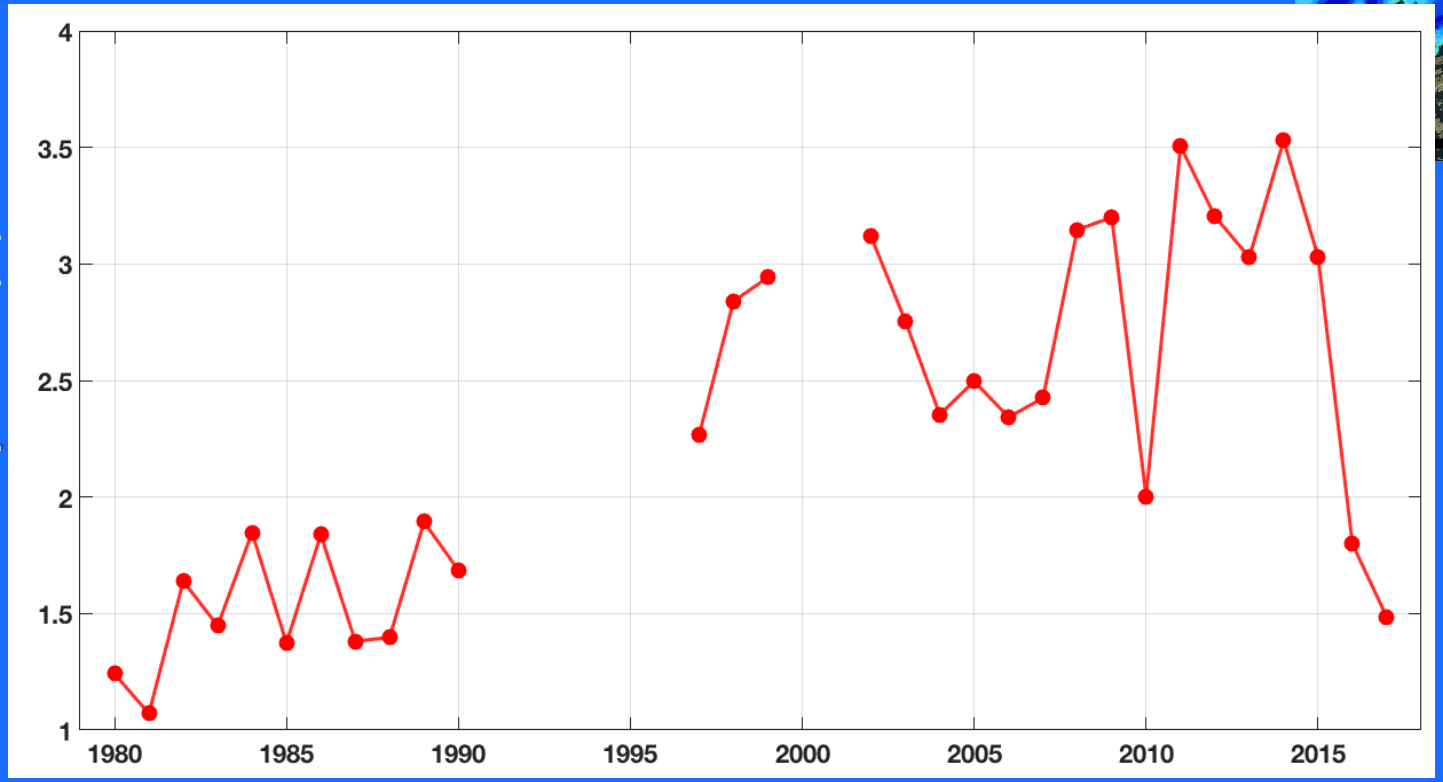


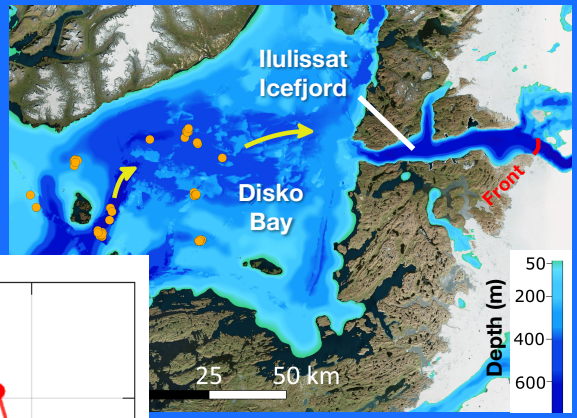


Locations of CTD profiles

Ocean temperatures in Disko Bay at 250-m depth

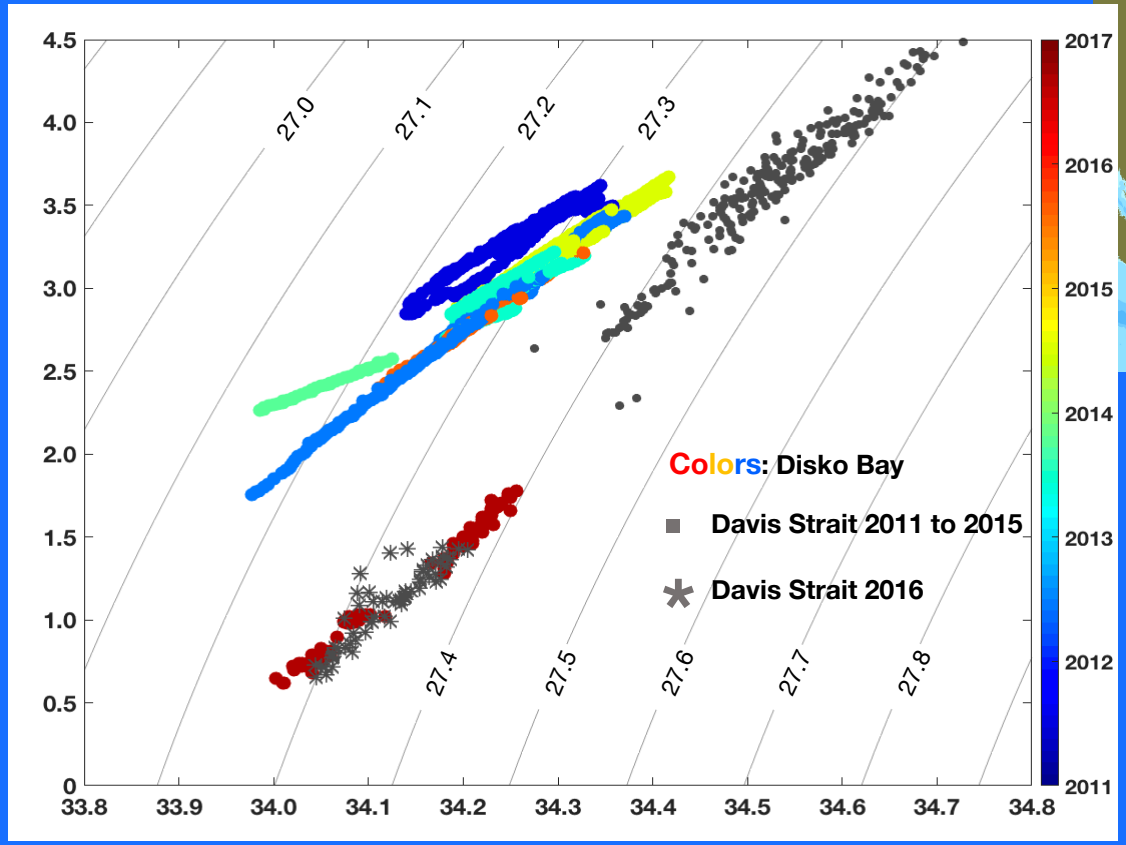
Sill at entrance of the fjord is ~250 m deep.

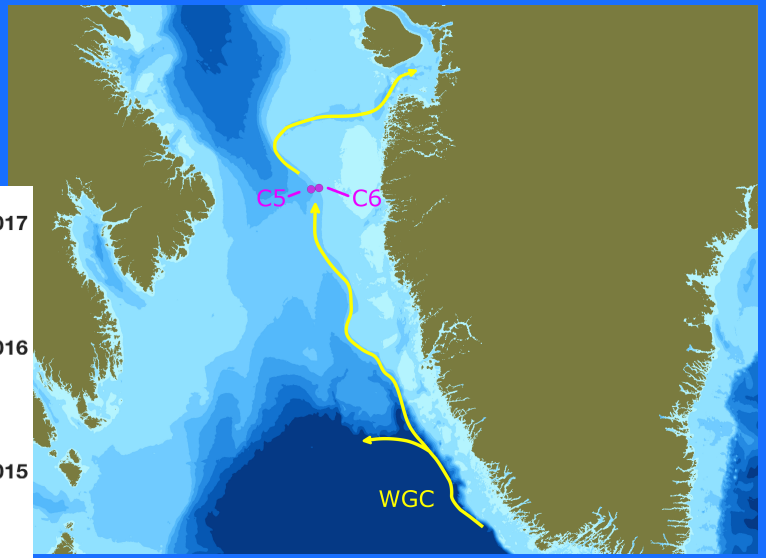




Locations of CTD profiles

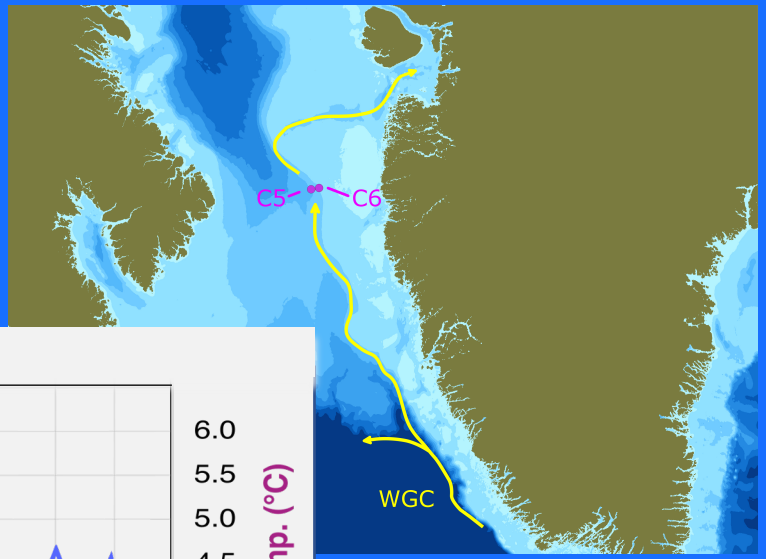
Temperature and Salinity in Disko Bay and Davis Strait (200 – 250 m)



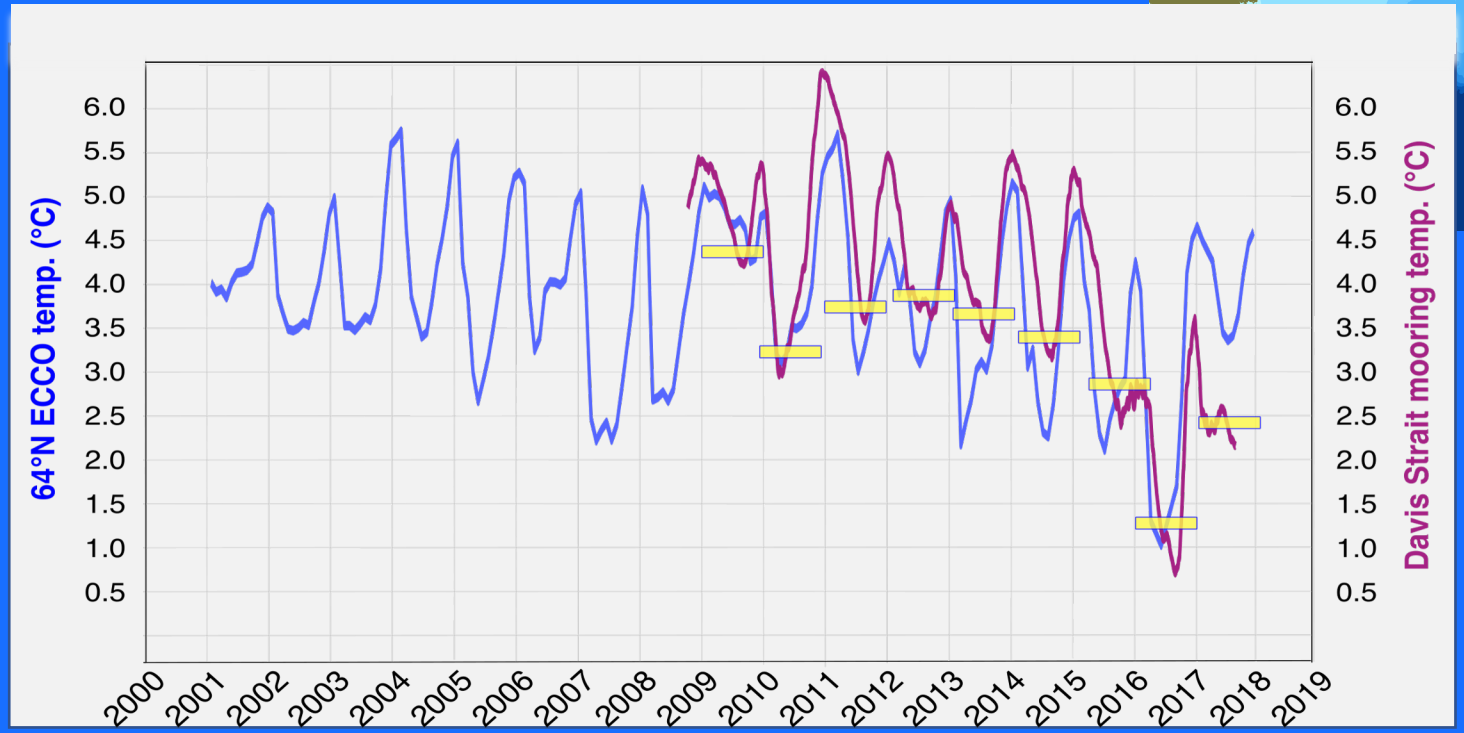


Cooling signal is originating from farther south

Temperature Evolution in Davis Strait (200 – 250 m)



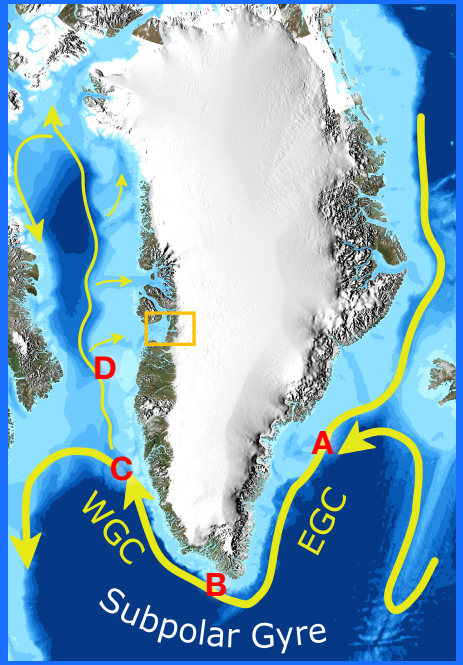
Good agreement between observation and ECCO state estimate

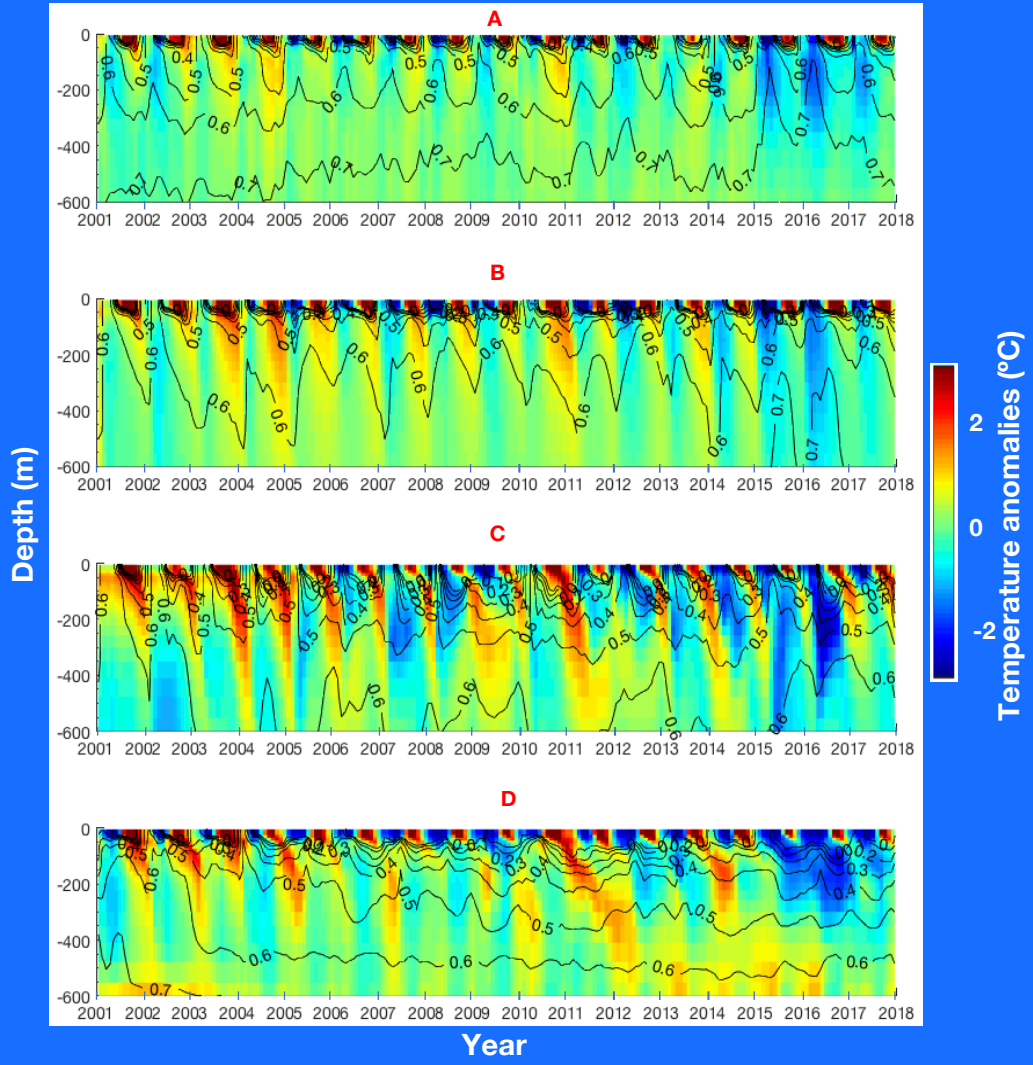


Depth-time evolution of temperature anomalies

We use the ECCO ocean state estimate to investigate the origins of the cooling.

Greater than normal cooling in the first half of 2015 and exceptionally weak warming in the latter half.

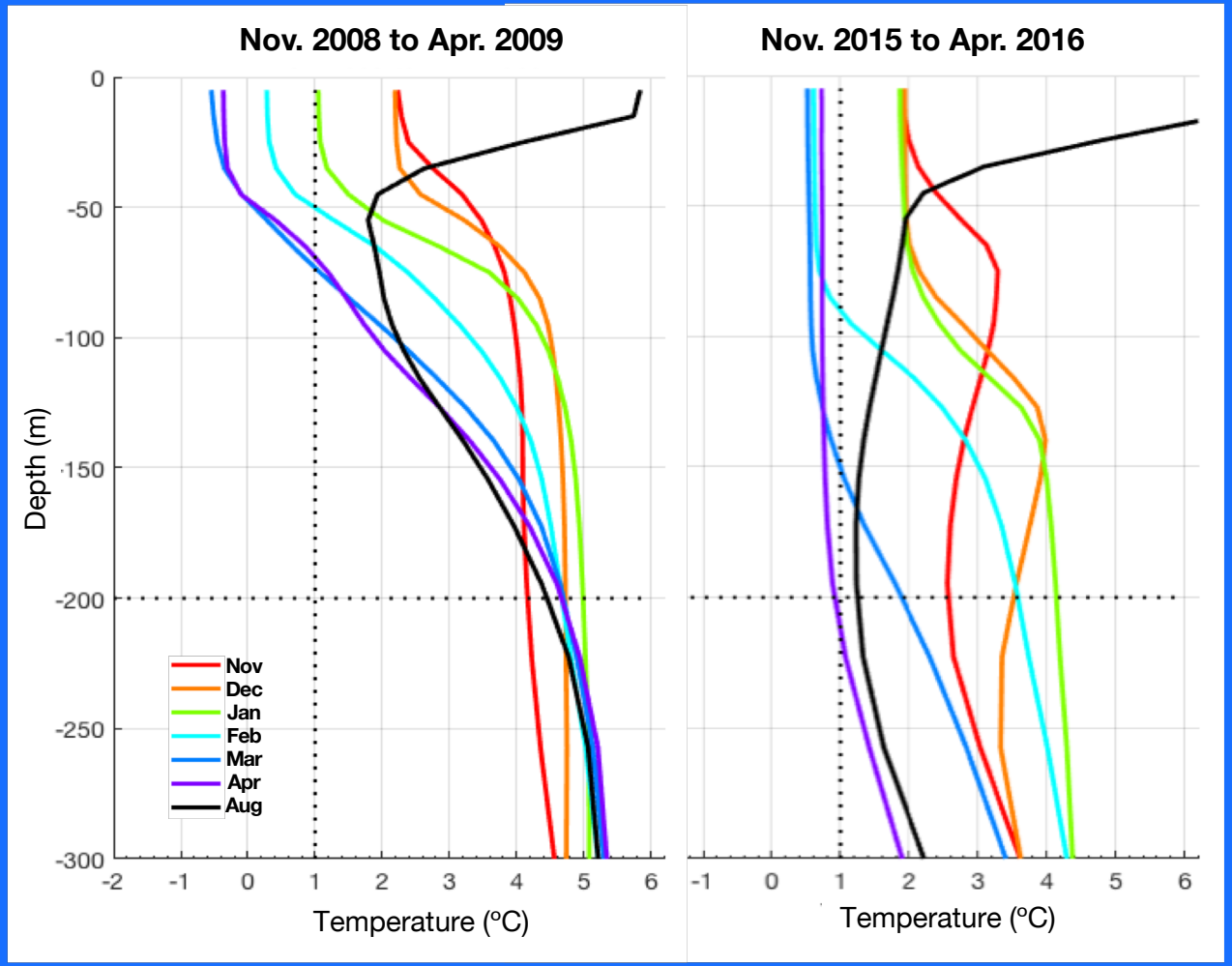




Evolution of temperature in the West Greenland Current (Location C)

Wintertime heat loss in 2015-2016 leads to mixed layer deepening and cooling relative to other years.

Of the 2 °C Cooling, 1.25 °C is explained by boundary current change. The remainder is due to Subpolar Gyre cooling.

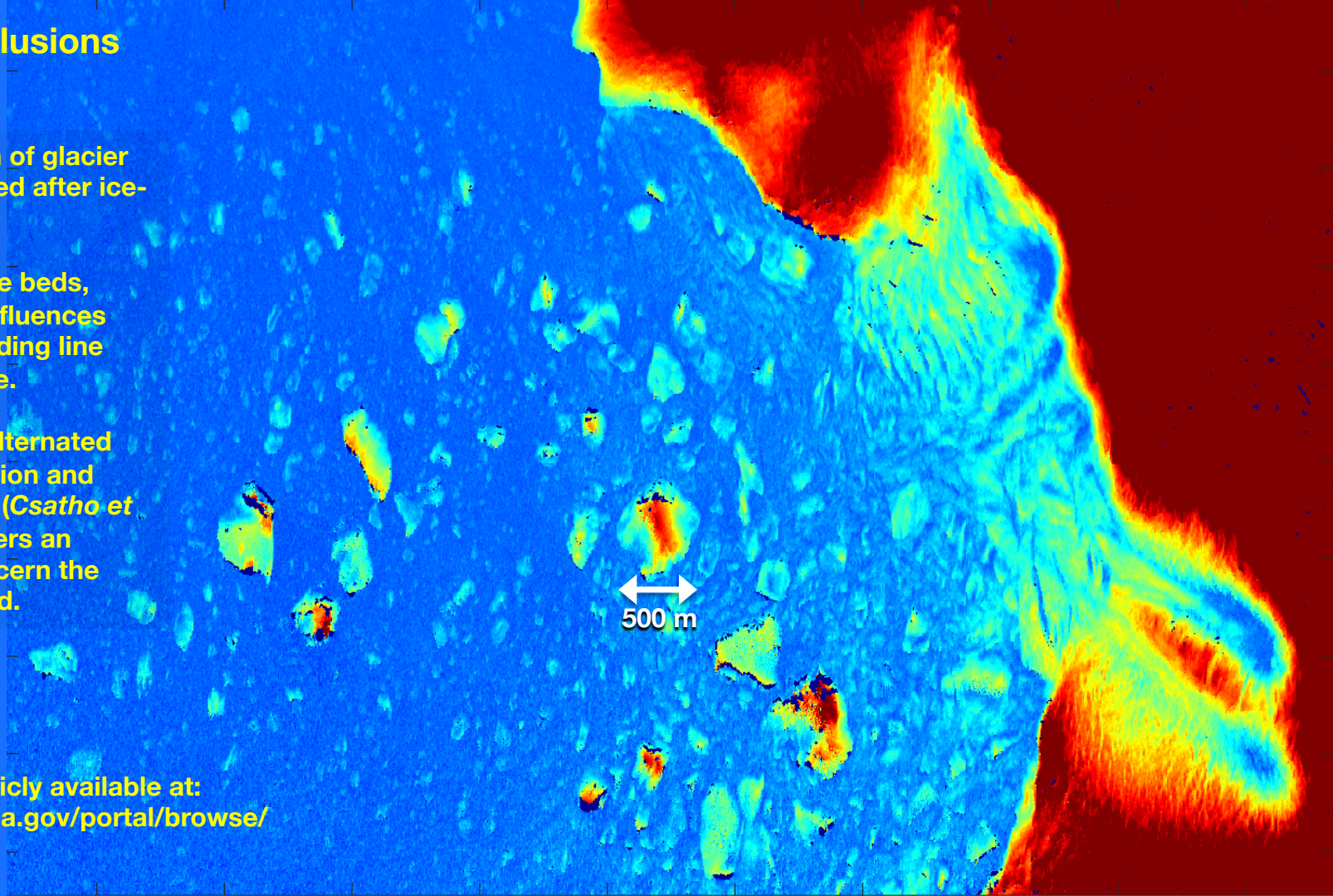


General Conclusions

Ocean modulation of glacier dynamics continued after ice-shelf removal.

Even on retrograde beds, external forcing influences the rates of grounding line retreat, or advance.

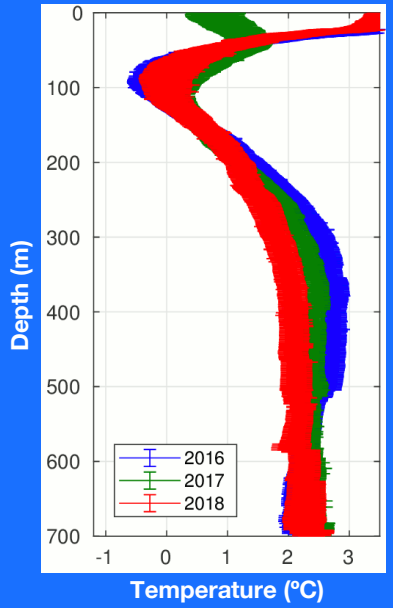
Jakobshavn has alternated between stabilization and retreat in the past (*Csatho et al.*, 2008). That offers an opportunity to discern the processes involved.

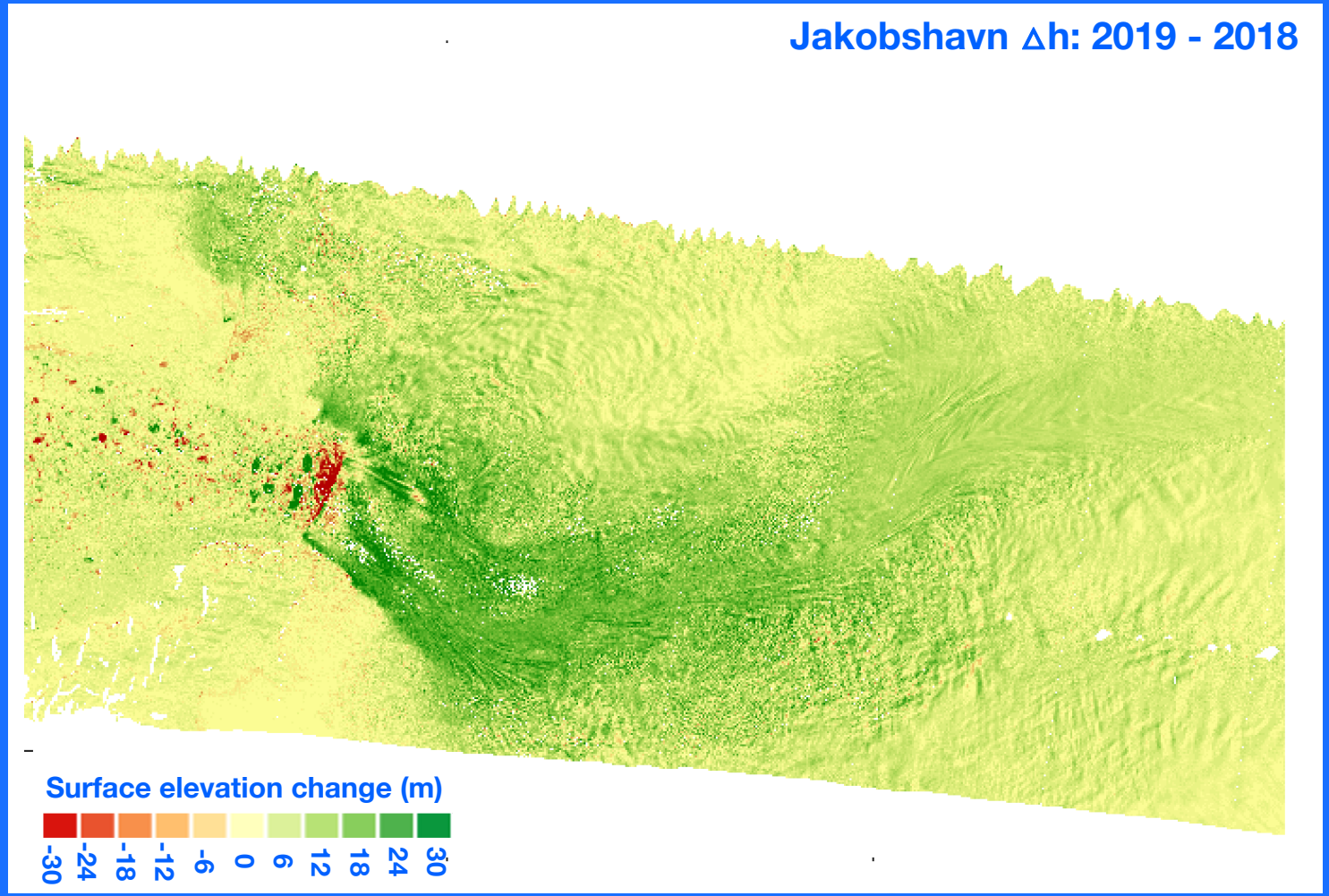


OMG data are publicly available at:
https://omg.jpl.nasa.gov/portal/browse/

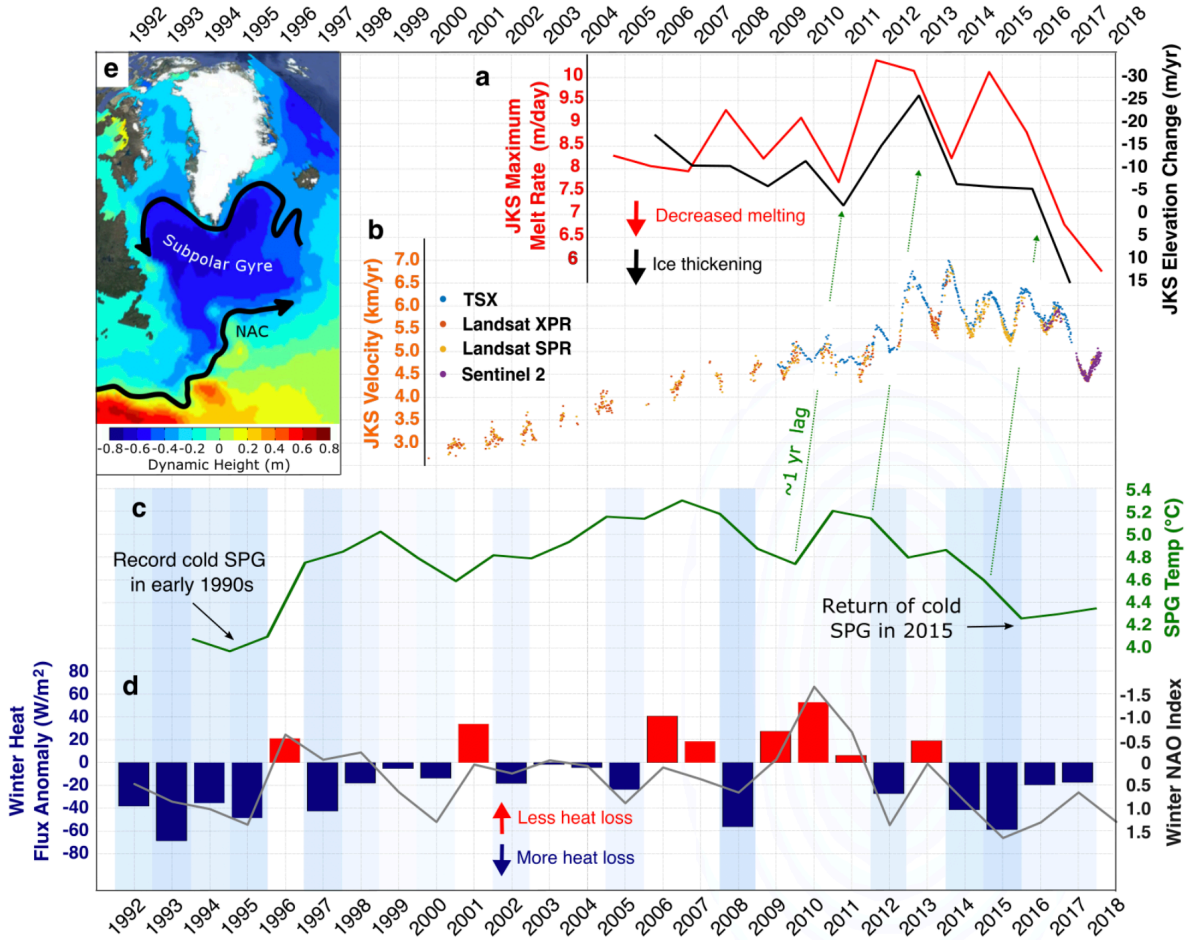
Epilogue

Disko Bay temps.



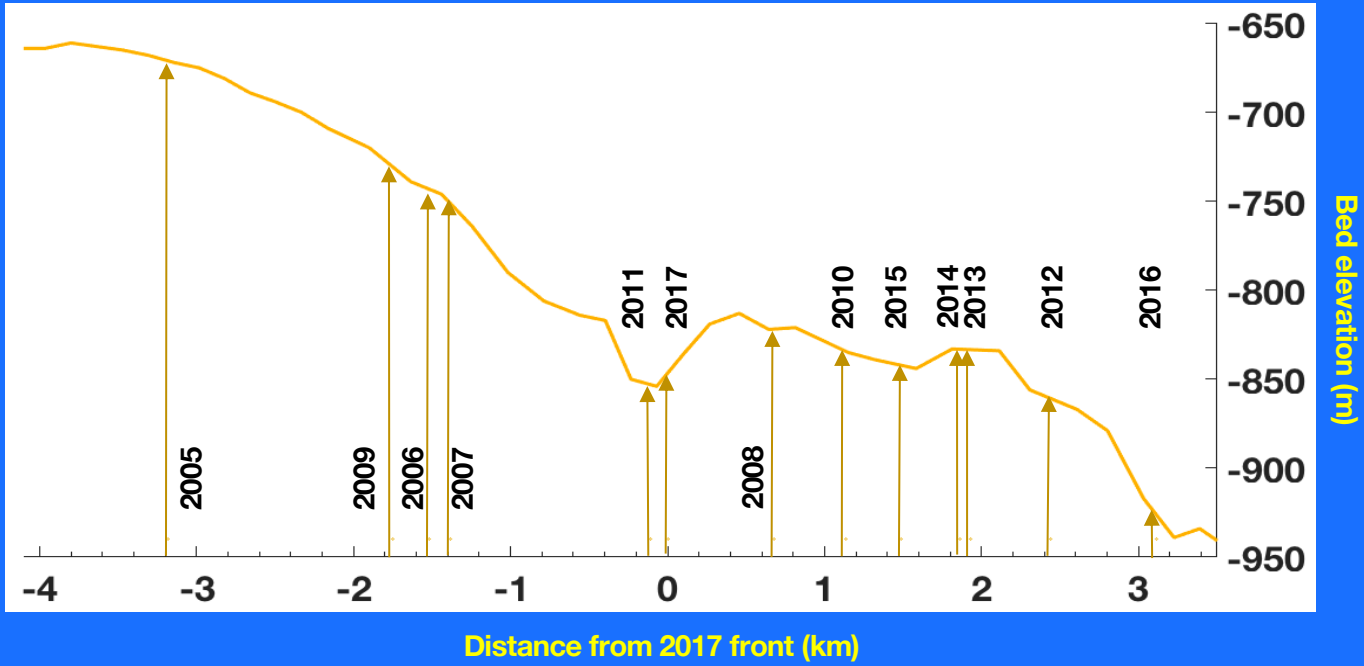


Backup Material


e
Subpolar Gyre
NAC
-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
Dynamic Height (m)
a
JKS Maximum Melt Rate (m/day)
JKS Elevation Change (m/yr)
Decreased melting
Ice thickening
b
JKS Velocity (km/yr)
TSX
Landsat XPR
Landsat SPR
Sentinel 2
~1 yr lag
c
Record cold SPG in early 1990s
Return of cold SPG in 2015
SPG Temp (°C)
d
Winter Heat Flux Anomaly (W/m²)
Winter NAO Index
Less heat loss
More heat loss

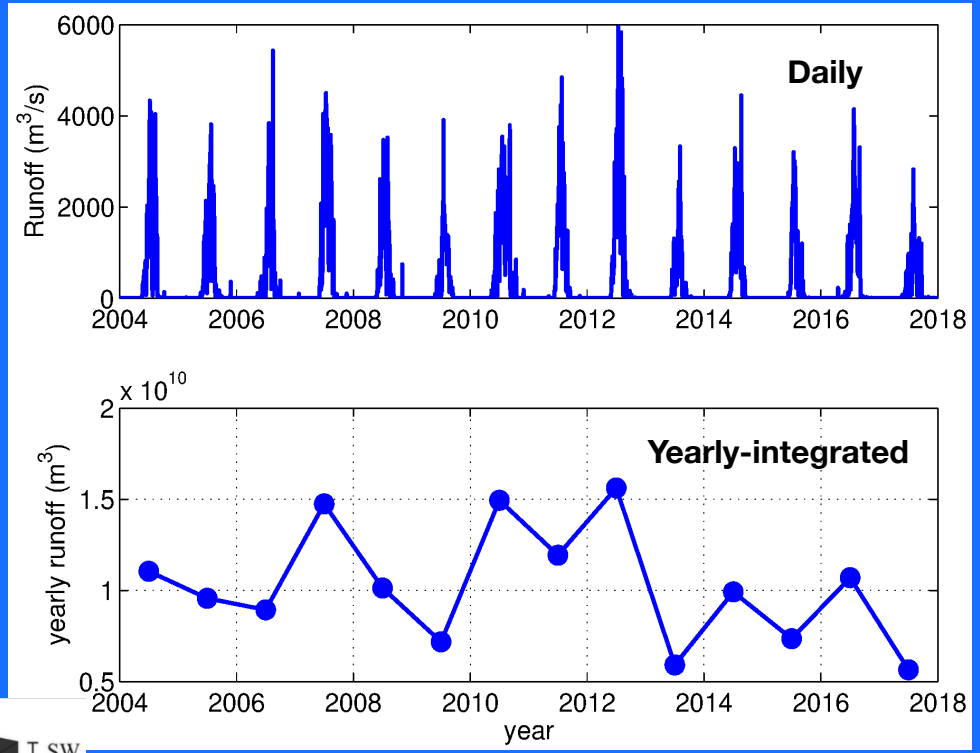
Jakobshavn expected to continue retreating

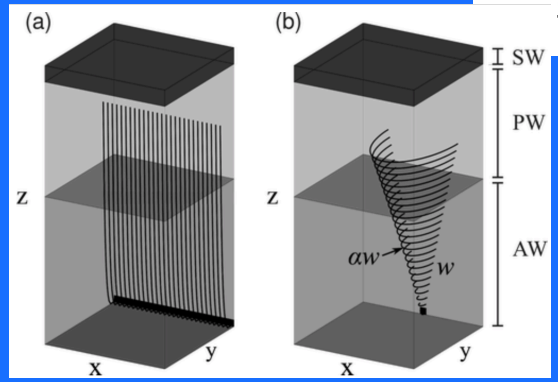
Retrograde bed and the decadal persistence of the retreat suggested similar behavior over the coming decades.



Submarine melting

Subglacial discharge from RACMO2.3p2



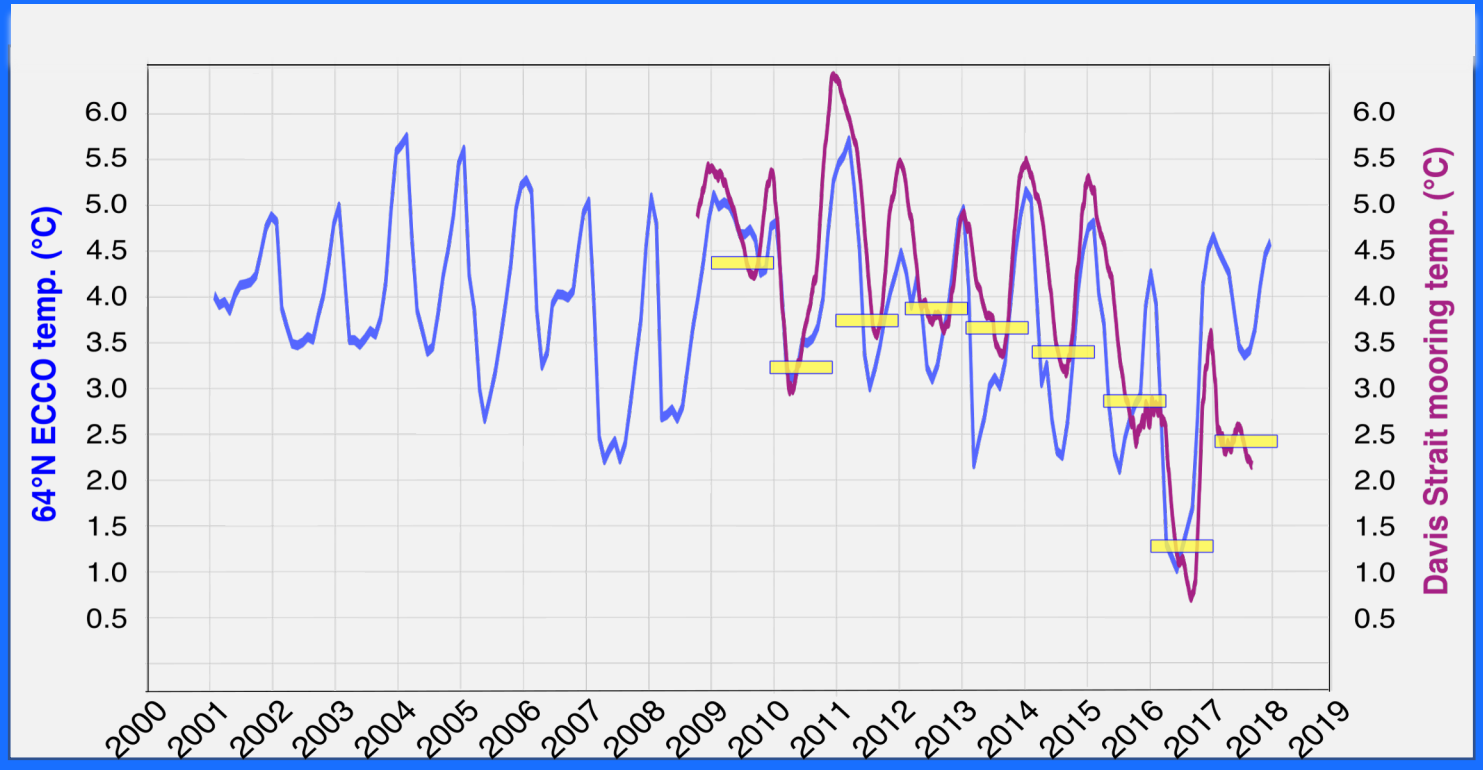


Submarine melting at the front calculated with a plume model

Carroll and Sutherland (2015)

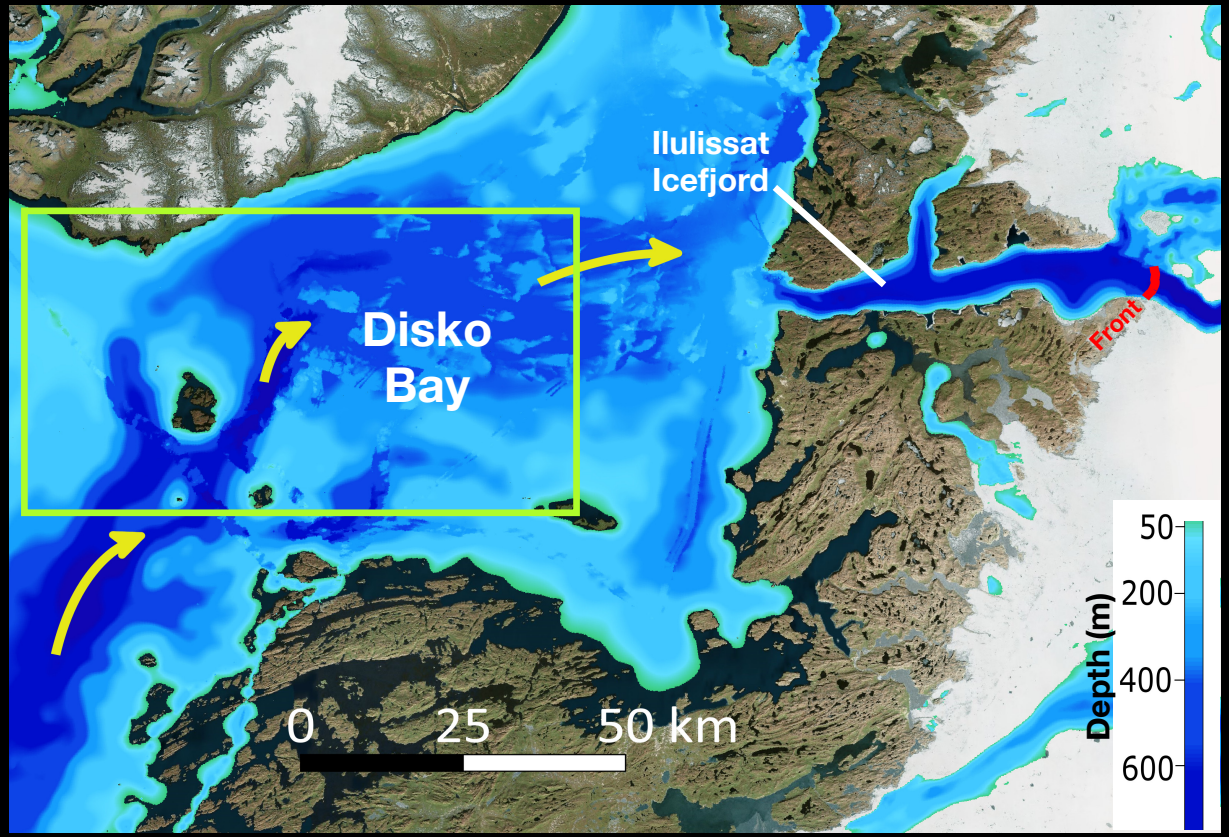
ECCO2 ocean state estimate produces a similar timing and magnitude of the 2015-2016 cooling event, supporting the conclusion that most cooling is coming through DS, and enhancing confidence in ECCO as a diagnostic tool.

Temperature and Salinity in Davis Strait (200 – 250 m)



Greater than normal cooling in the first half of 2015 and exceptionally weak warming in the latter half.

Jakobshavn

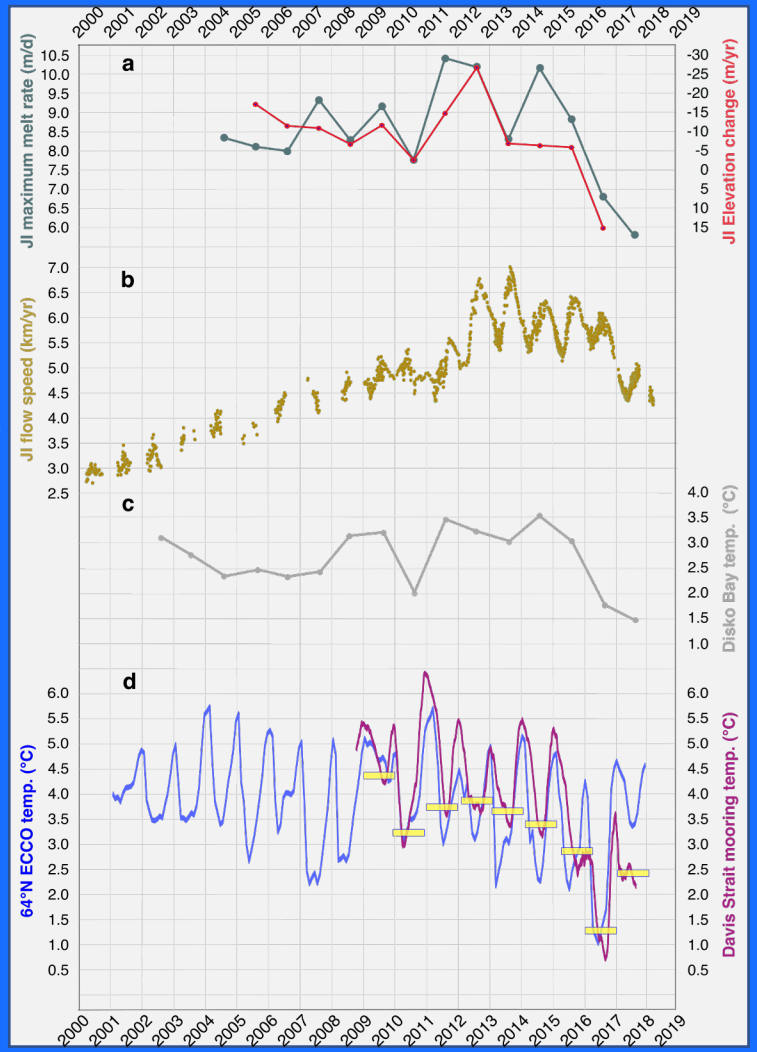


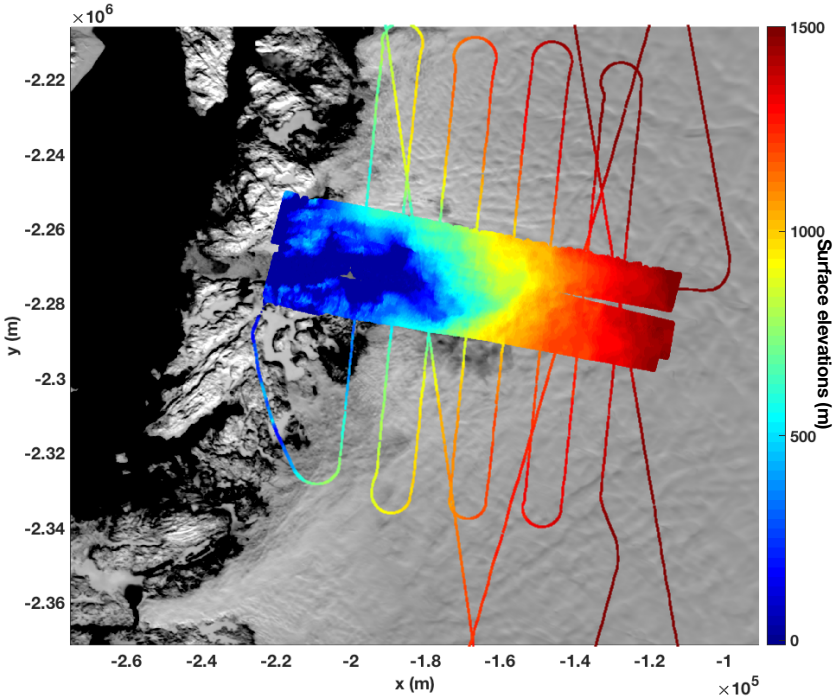
Cooling of 1.5 to 2°C in Atlantic water between 2015 and 2017.

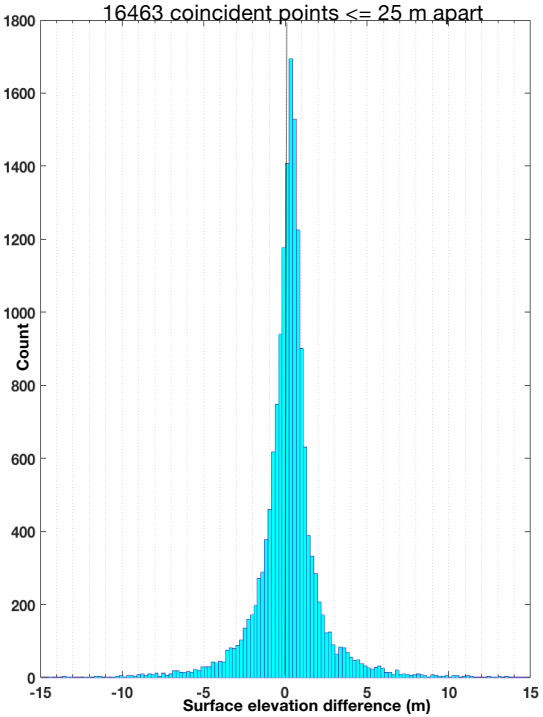
Submarine melting

Correlation is strong between submarine melting and surface elevation change.

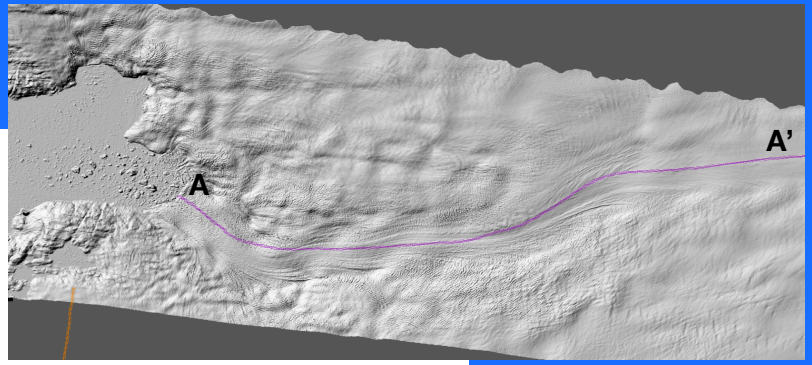
Ocean cooling is the main factor in lowering submarine melting rates between 2015 and 2017.

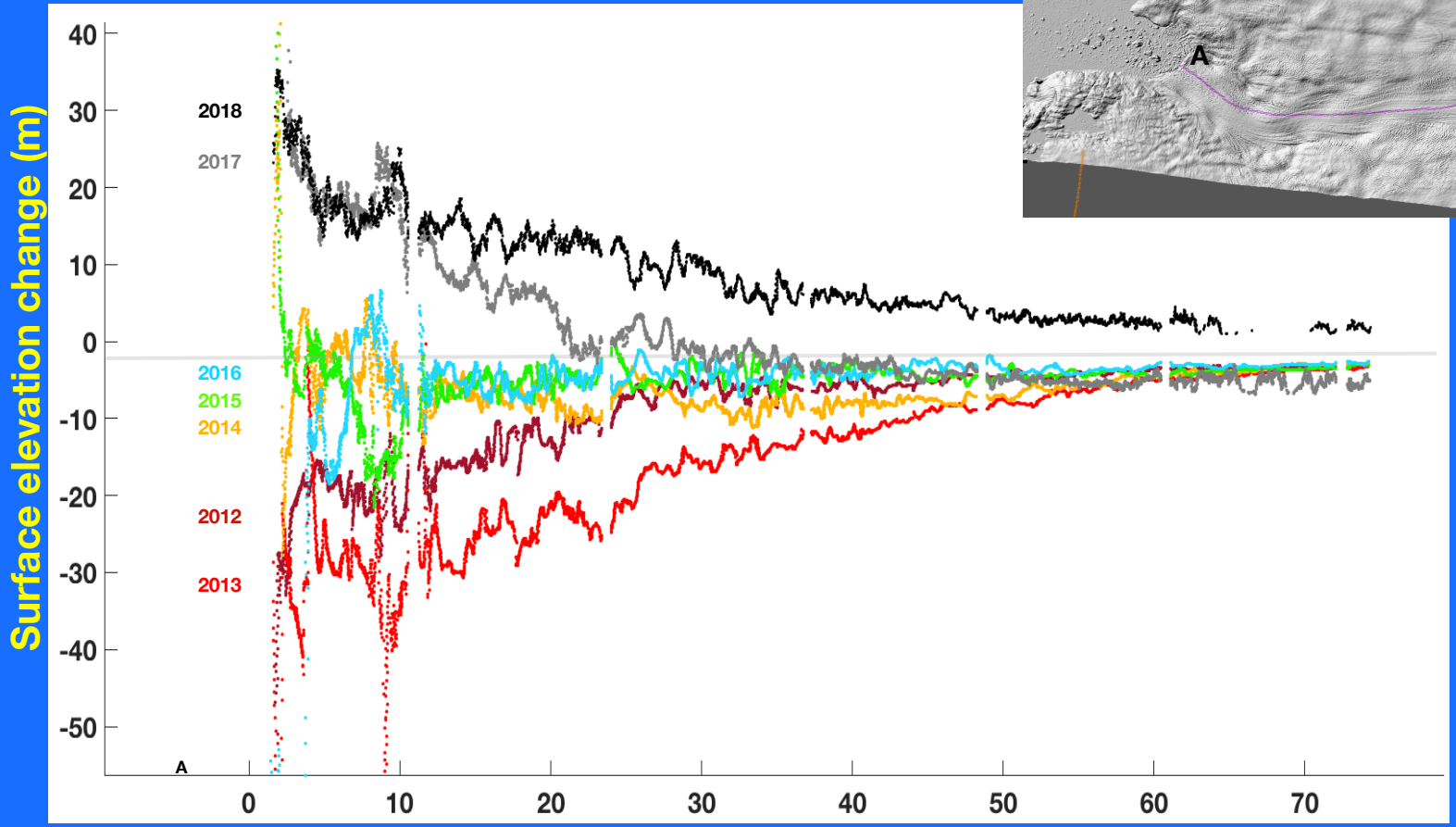


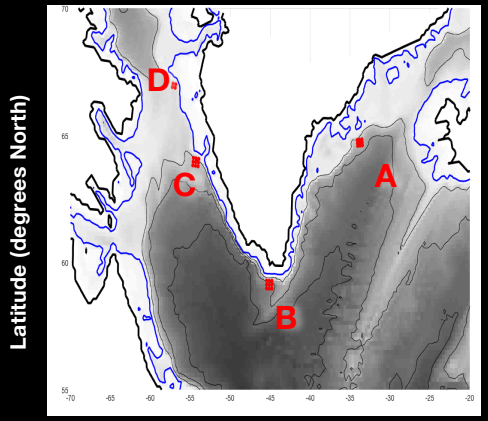

×10^6
-2.22
-2.24
-2.26
-2.28
-2.3
-2.32
-2.34
-2.36
y (m)
-2.6
-2.4
-2.2
-2
-1.8
-1.6
-1.4
-1.2
-1
x (m)
×10^5
1500
1000
500
0
Surface elevations (m)

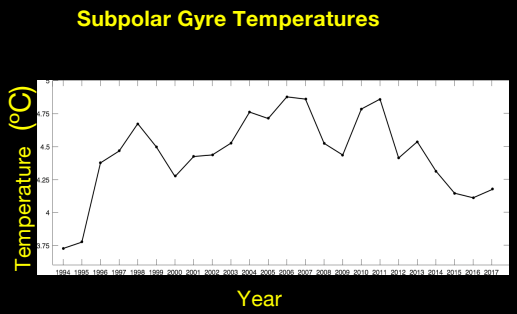

16463 coincident points <= 25 m apart
1800
1600
1400
1200
1000
800
600
400
200
0
Count
-15
-10
-5
0
5
10
15
Surface elevation difference (m)

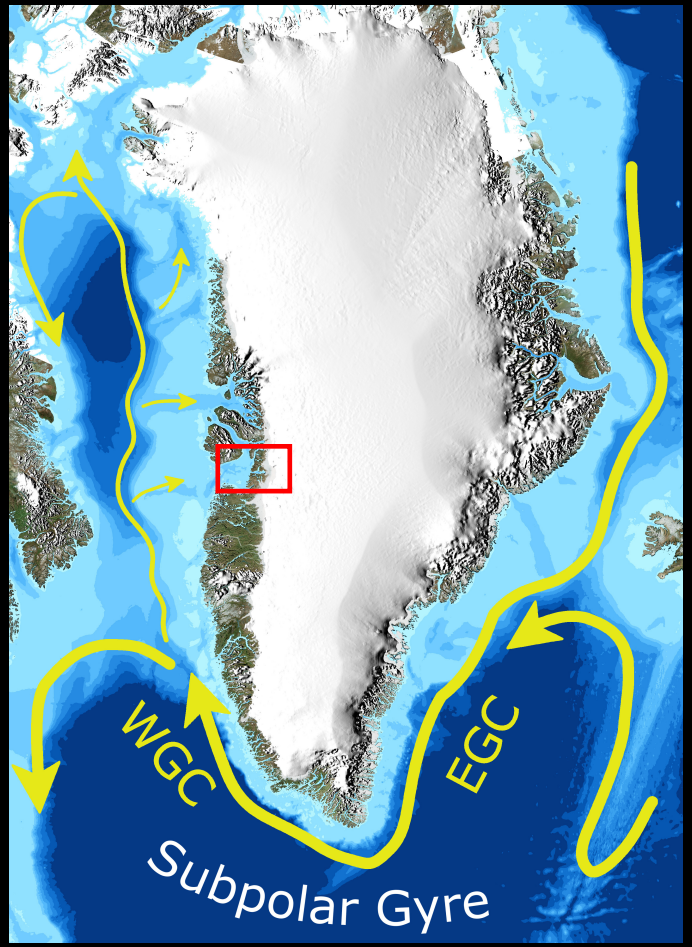
Surface elevation changes from ATM



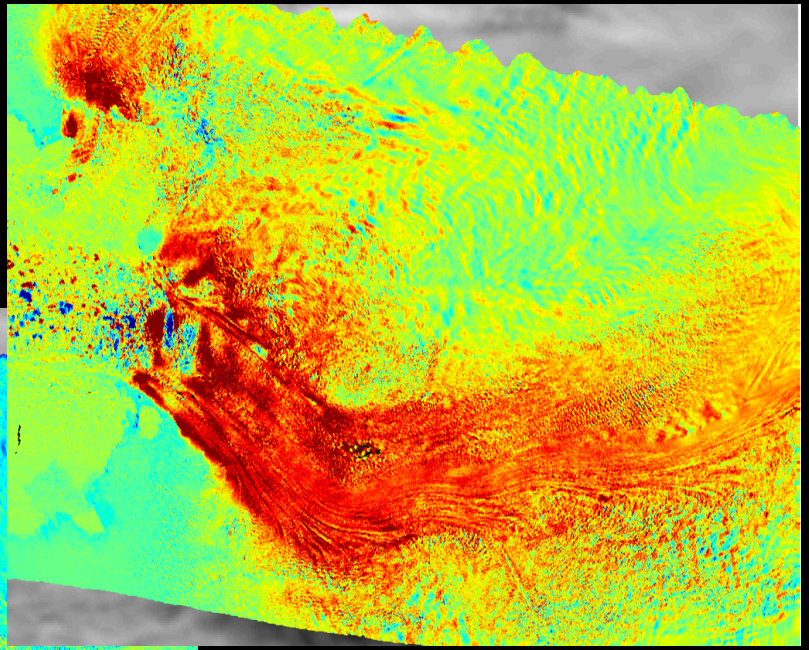


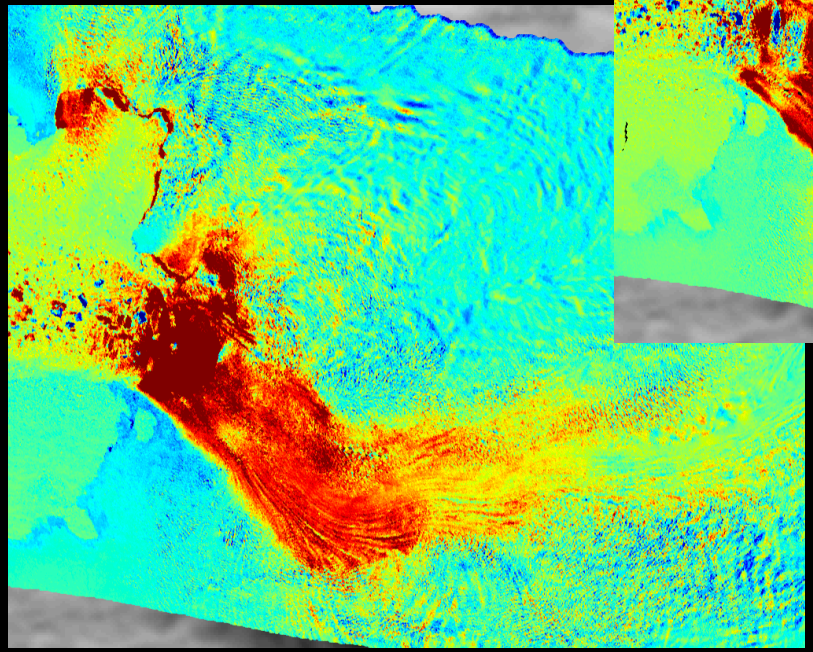

D
C
A
B
Latitude (degrees North)
Longitude (degrees East)

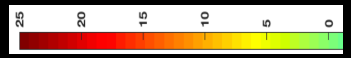

Subpolar Gyre Temperatures
Temperature (°C)
Year


WGC
EGC
Subpolar Gyre

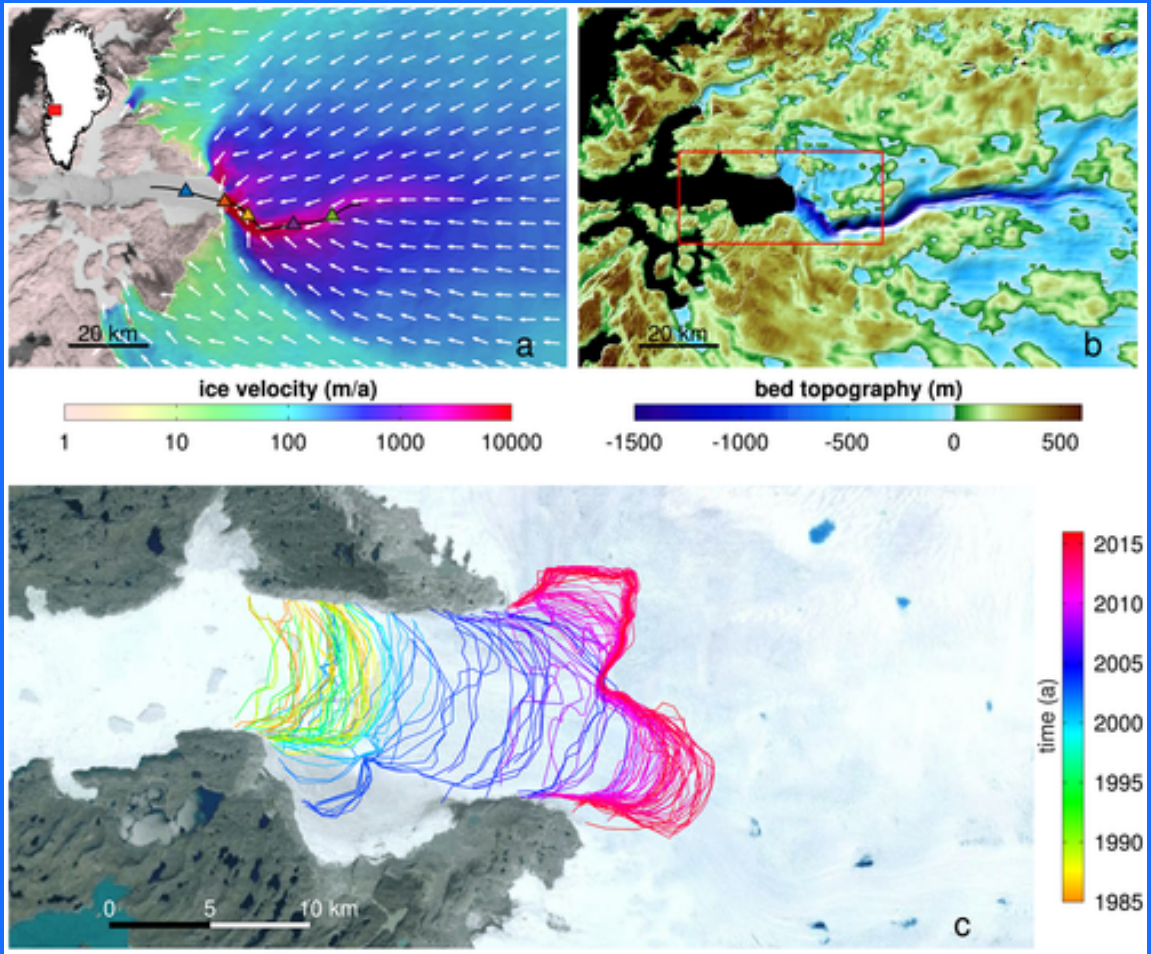
Thickening continued in 2018







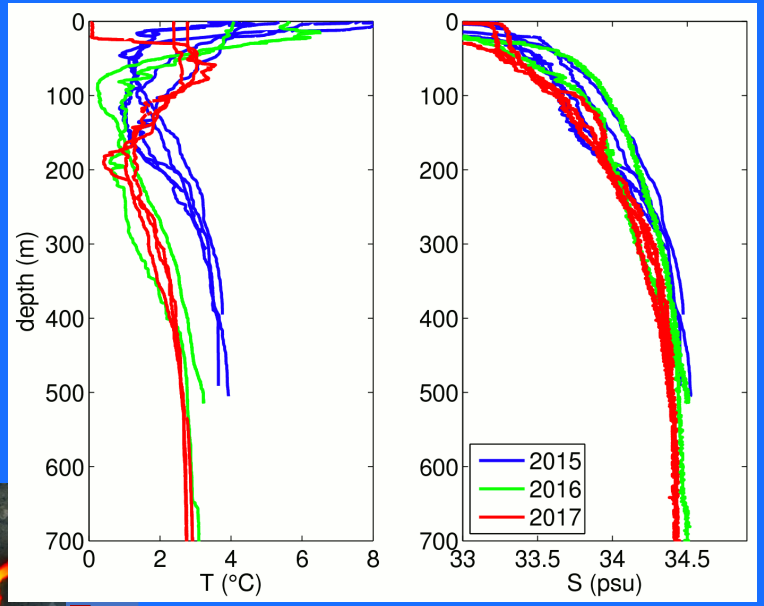
Front retreat



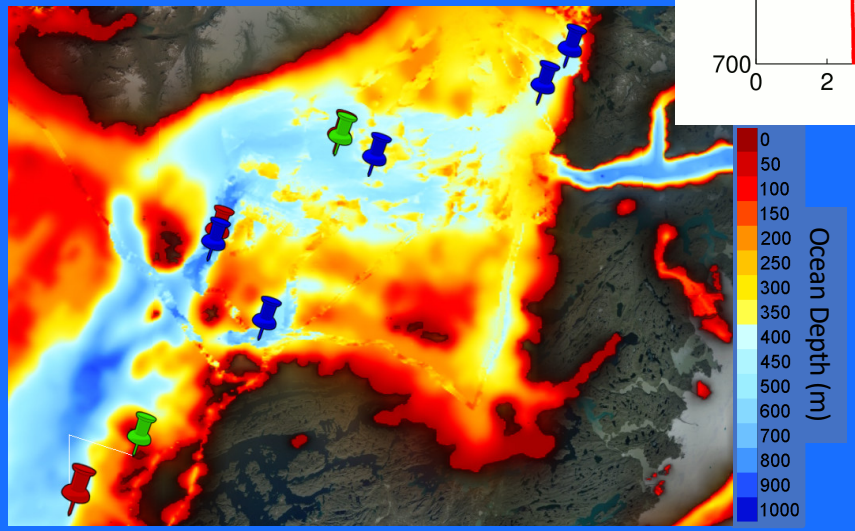
Bondzio et al. (2017)

Disko Bay: cooling of Atlantic Water

CTD data: 2015, 2016 and 2017



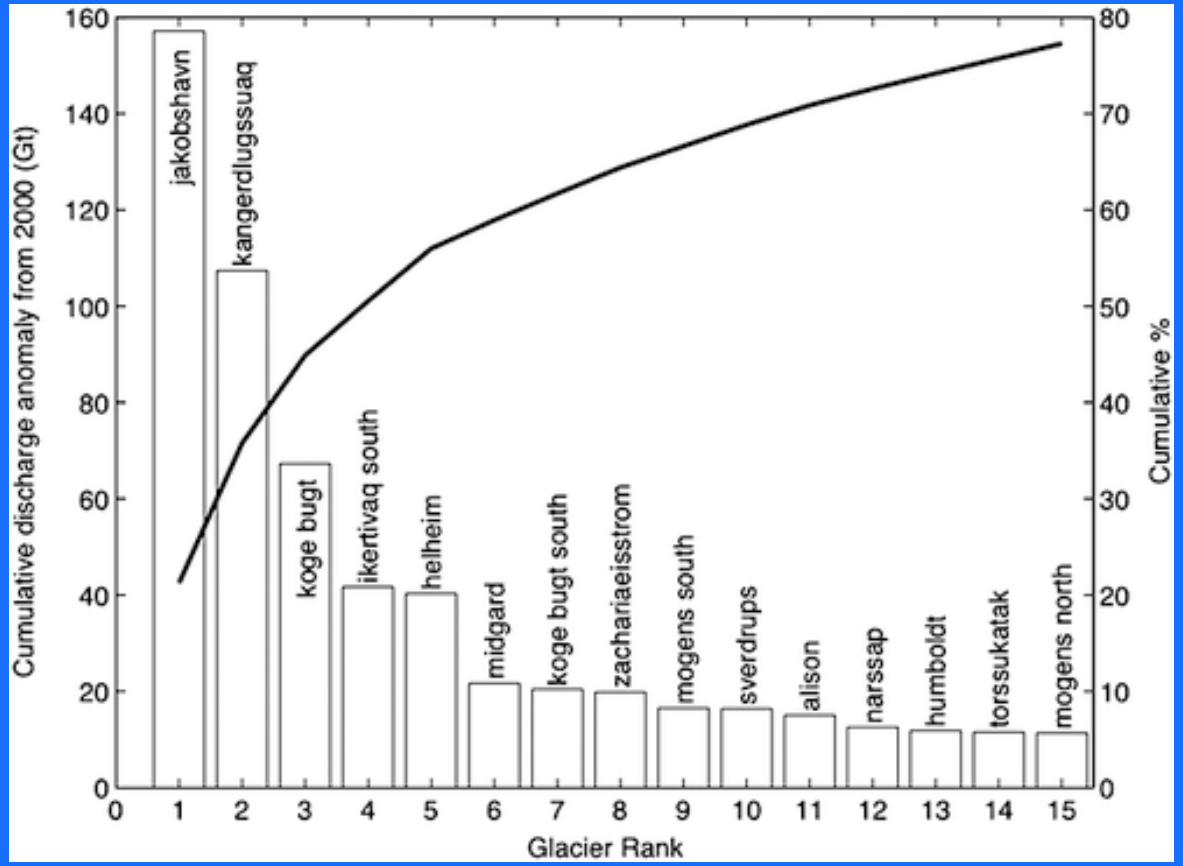
Cooling of 1.5 to 2°C in Atlantic Water between 2015 and 2017.



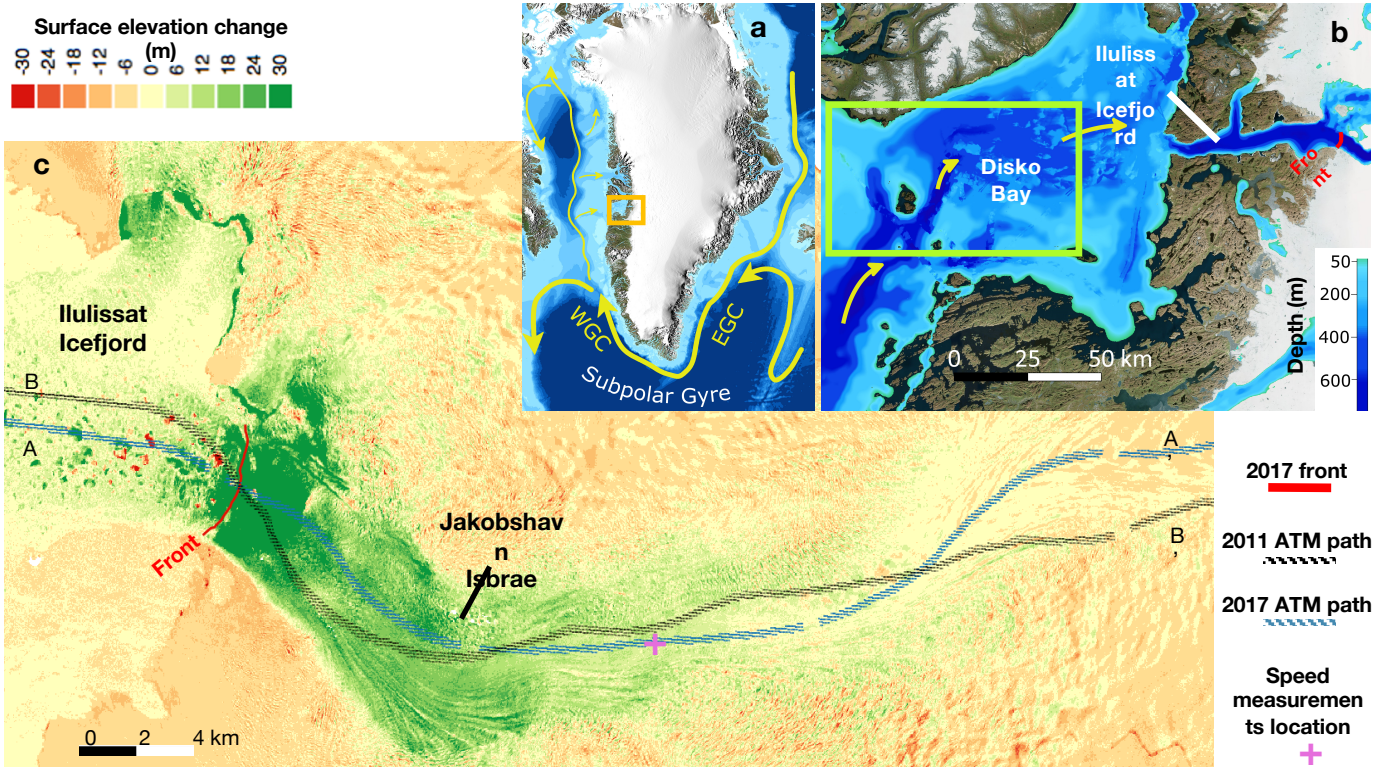
10 profiles with data from below 300 m in Disko bay during summers of 2015, 2016 and 2017.

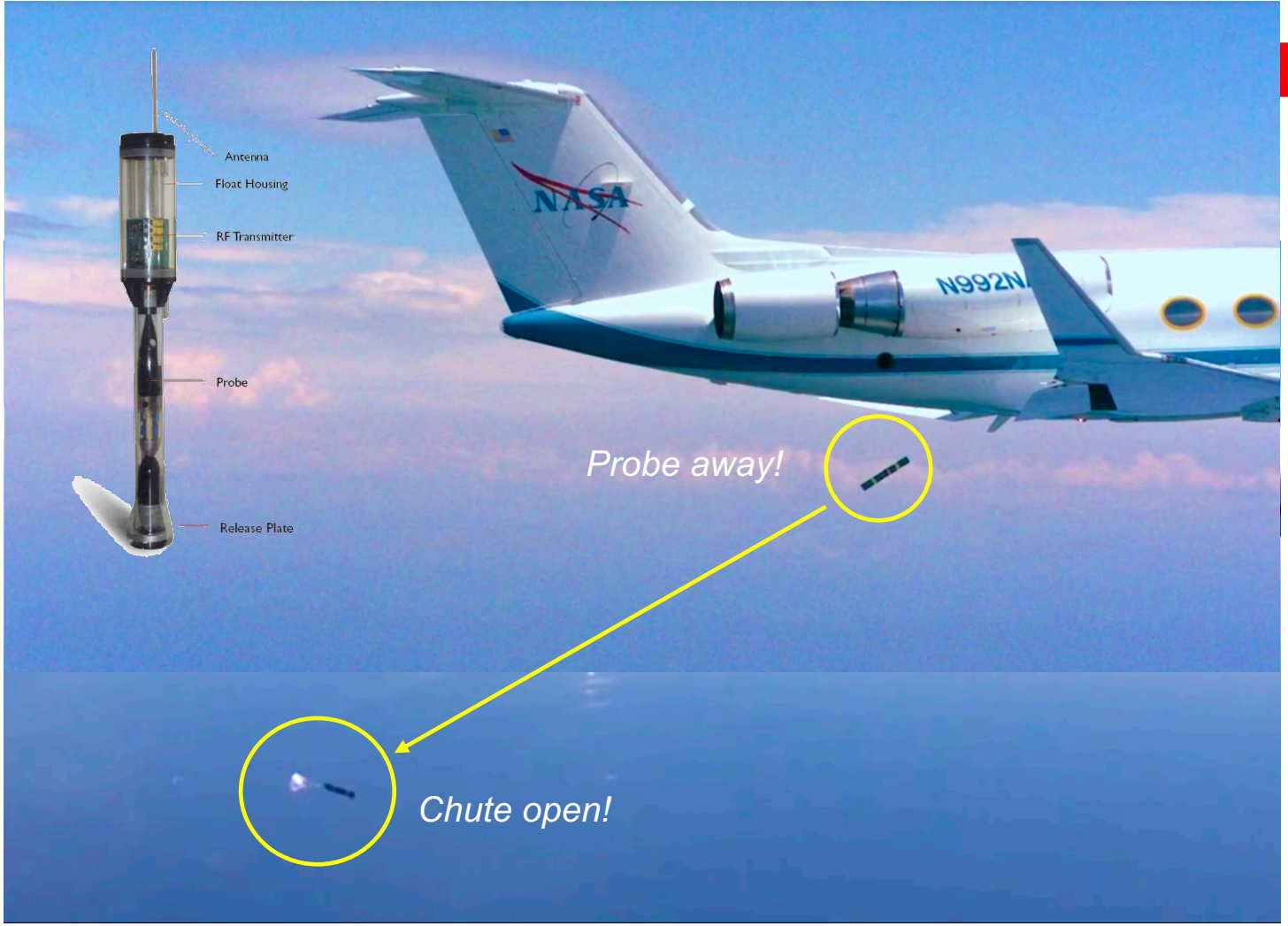
Largest mass loss to the ocean

Contributed the equivalent of ~0.9 mm to global mean sea-level rise between 2000 and 2010 (*Howat et al.*, 2011).



Enderlin et al. (2014)


Surface elevation change (m)
-30 -24 -18 -12 -6 0 6 12 18 24 30
a
WGC
EGC
Subpolar Gyre
b
Ilulissat Icefjord
Disko Bay
Front
0 25 50 km
Depth (m)
50 200 400 600
c
Ilulissat Icefjord
B
A
Front
Jakobshavn Isbræ
A'
B'
0 2 4 km
2017 front
2011 ATM path
2017 ATM path
Speed measurements location


Antenna
Float Housing
RF Transmitter
Probe
Release Plate
NASA
N992N
Probe away!
Chute open!

Summary and Conclusions

1. Jakobshavn : 15 to 20 m

2. Kangerlussuaq : -5 to -10 m

3. Koge Bugt : 20 to 30 m

5. Helheim : -10 m

6. Midgard : -20 to -25 m
   (Eastern branch : -10 m)

7. Koge Bugt South: No clear change

9. Mogens South : -10 m

15. Mogens North : -20 to -30 m

>> Mogens Central : -15 to -20 m

>> Maelkevejen : -35 to -40 m

Summary and Conclusions

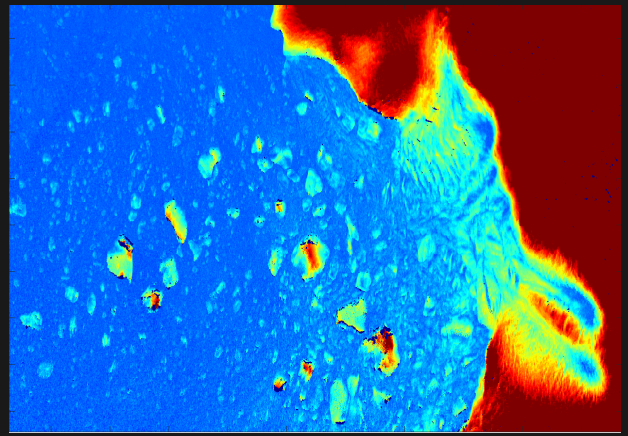
Jakobshavn might be entering a new regime of slower flow, increased volume, advancing front and cooler ocean conditions.

In the southeast, changes in glacier and ocean conditions are diverse.

Wide-swath, high-resolution observations help interpretation and can constrain numerical models.

Simultaneous observations of ice and ocean conditions are providing valuable insights into observed changes.

Data are publically available at:
https://omg.jpl.nasa.gov/portal/browse/

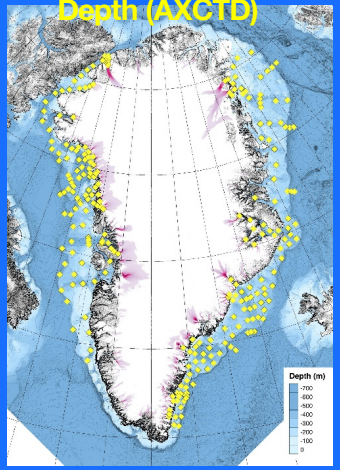


OMG: Mission Components

Ocean campaigns

CTD

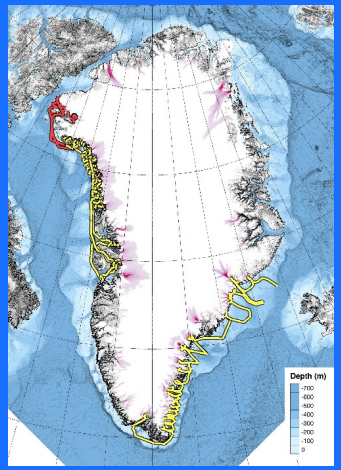
Airborne eXpendable Conductivity, Temperature and Depth (AXCTD)



in situ temperature and salinity from ~250 CTD probes deployed mainly on the Greenland shelf.

Bathymetry

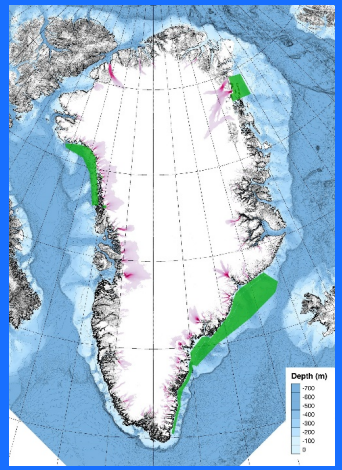
Multibeam + singlebeam echo sounders



Bathymetry from sonar.

Horizontal res.: 25 m, vertical precision < 1 m.

Airborne gravimetery

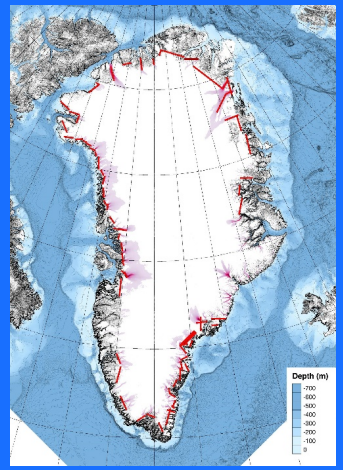


Bathymetry from gravity anomalies.

Horizontal res.: 1.5 km, vertical precision of ~100 m.

Glacier campaign

GLacier and Ice Surface Topography INterferometer (GLISTIN-A)



Glacier elevation in a 10 km swath from radar.

Horizontal res.: 3 m, vertical precision < 0.5 m.

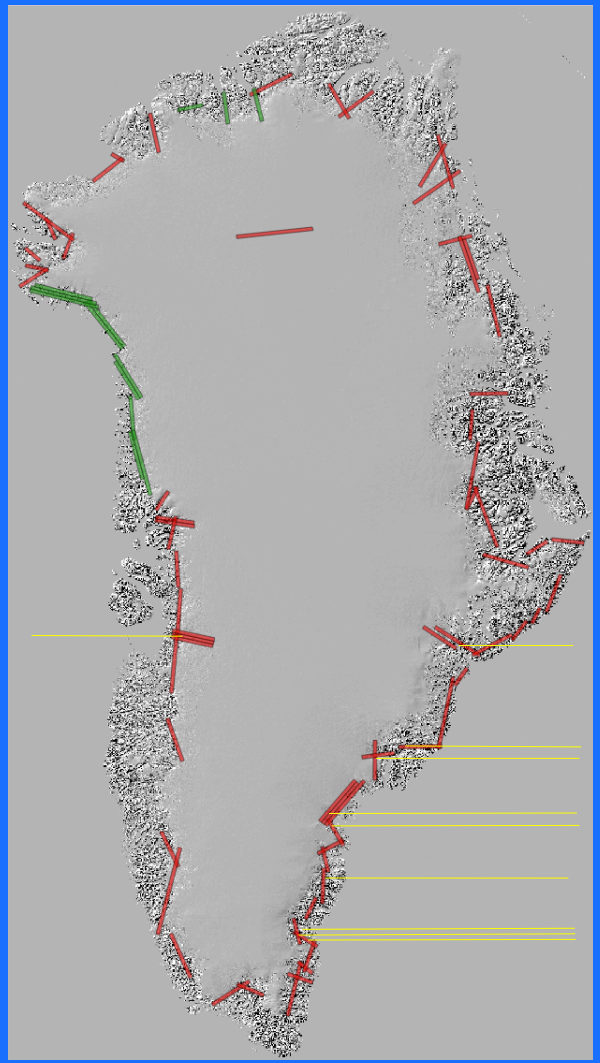
Talk Plan

Data Validation
(Jakobshavn)

Changes in the Southeast

Jakobshavn

Summary and Conclusions



Background DEM:
Howat et al. (2015)

Glacier fronts:
Joughin and Moon (2015)

Glacier mass-loss ranking:
Enderlin et al. (2014)

References:

GIMP:

Howat, I., A. Negrete, and B. Smith. 2015. *MEaSURES Greenland Ice Mapping Project (GIMP) Digital Elevation Model, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: http://dx.doi.org/10.5067/NV34YUIXLP9W. [Date Accessed].

GLISTIN:

D. Moller et al., “The glacier and land ice surface topography interferom- eter: An airborne proof-of-concept demonstration of high-precision Ka- band single-pass elevation mapping,” IEEE Trans. Geosci. Remote Sens., vol. 49, no. 2, pp. 827–842, Feb. 2011, doi: 10.1109/TGRS.2010.2057254.

HENSLEY et al.: KA-BAND MAPPING AND MEASUREMENTS OF INTERFEROMETRIC PENETRATION OF THE GREENLAND ICE SHEETS, IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 9, NO. 6, JUNE 2016

Fronts:

Joughin, I. and T. Moon. 2015. MEaSUREs annual Greenland outlet glacier terminus positions from SAR Mosaics. Boulder, CO: Natiional Snow and Ice Data Center. Digital media. doi:10.5067/DC0MLBOCL3EL.