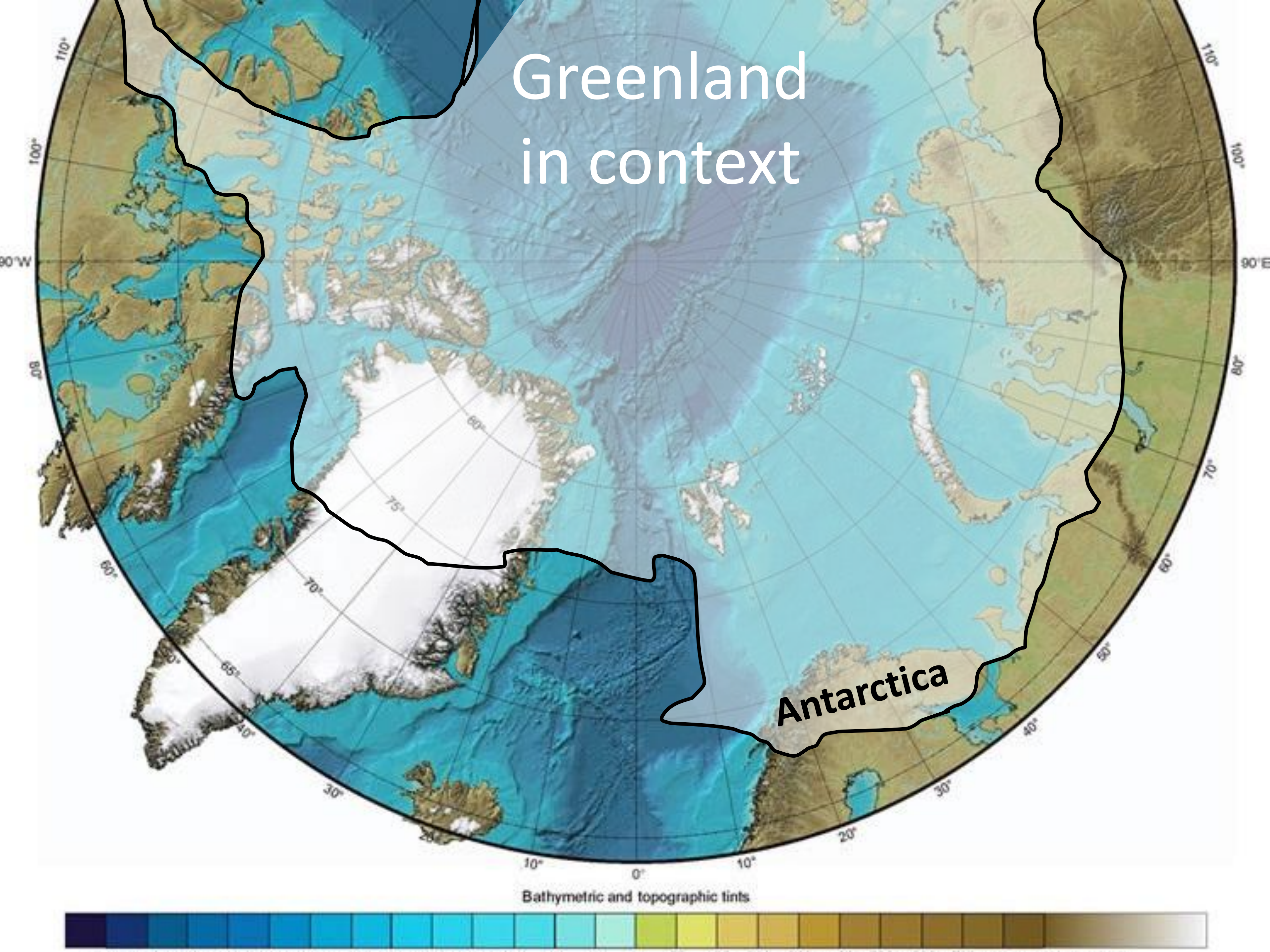
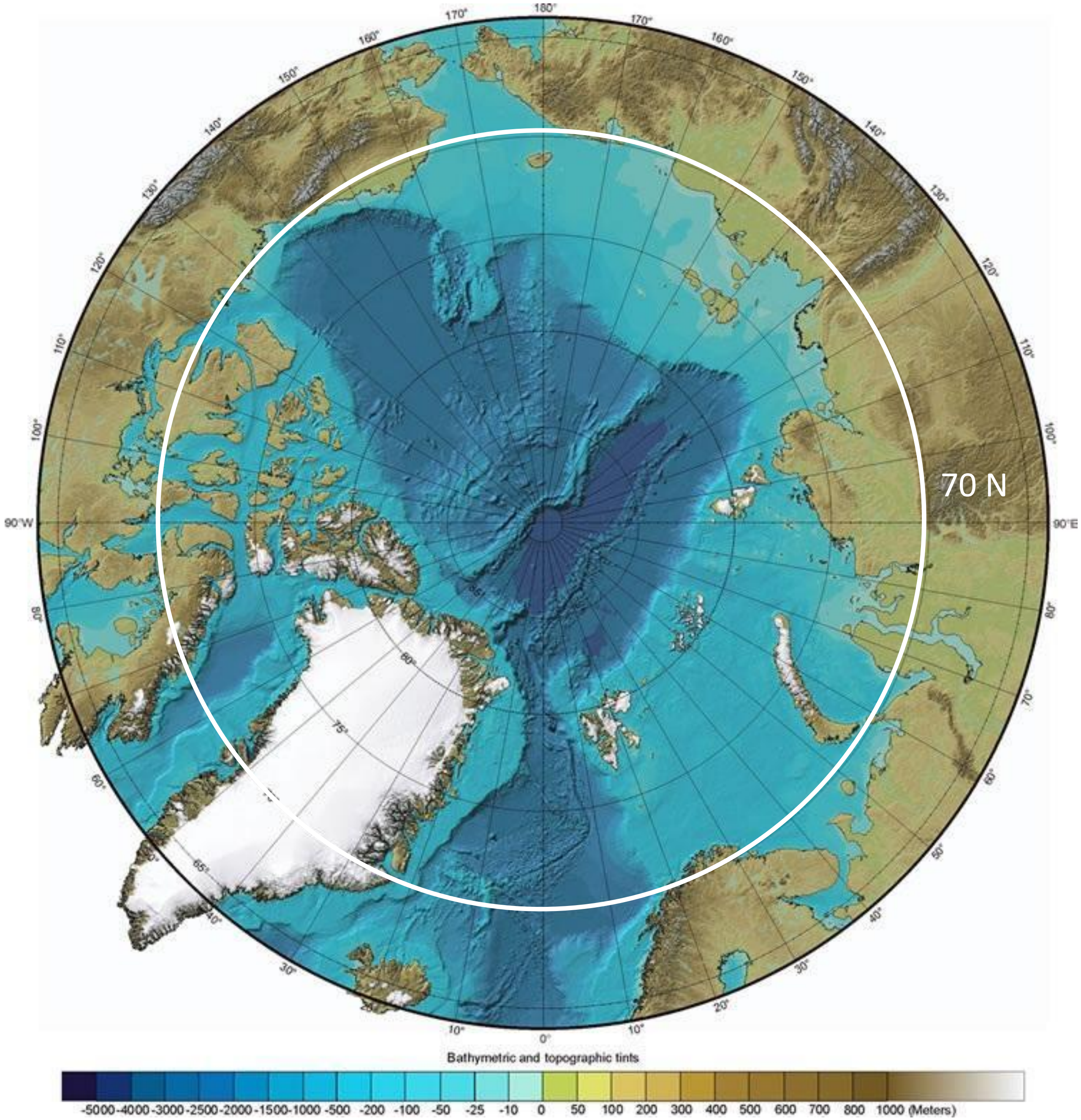
The Greenland Ice Sheet

Overview

- Greenland in context
- History of glaciation
- Ice flow characteristics
- Variations in ice flow
- Extent and consequences of melting

Greenland in context

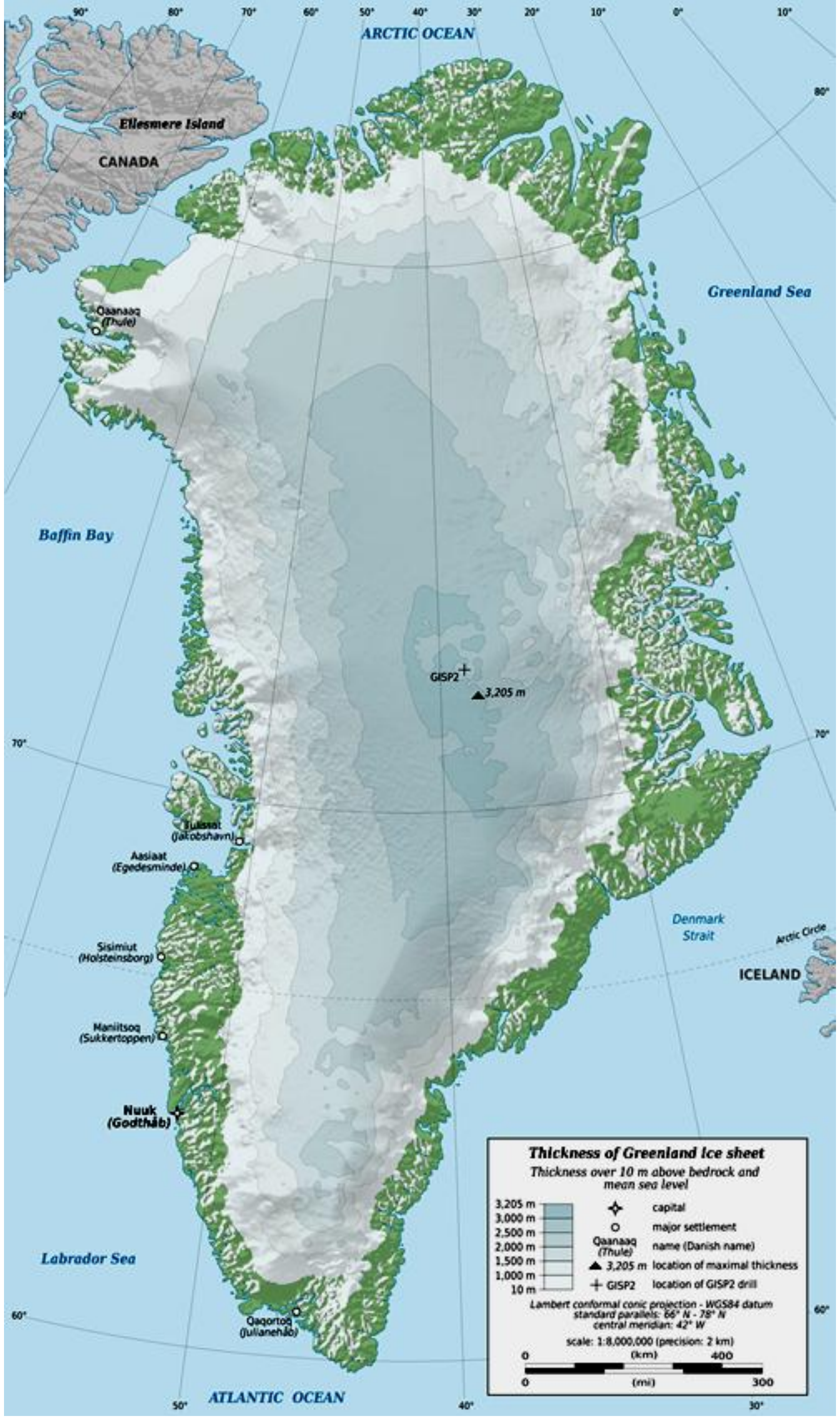




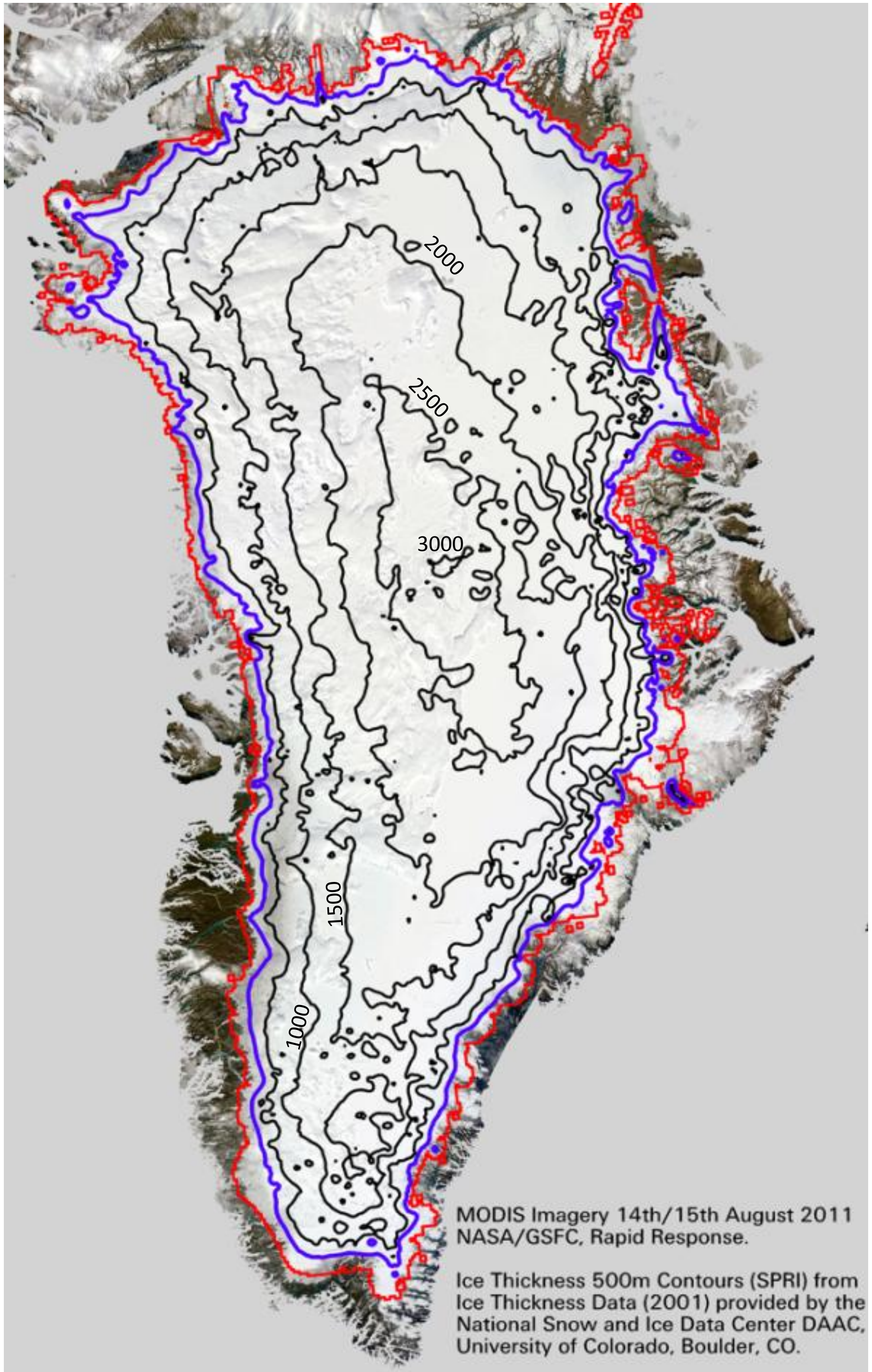
Why is there so much more ice on Greenland than on other land masses at the same latitude?

(e.g. Ellesmere Is. Baffin Is., Iceland, Svalbard, northernmost Russia)

LGM


ARCTIC OCEAN
Ellesmere Island
CANADA
Greenland Sea
Qaanaaq
(Thule)
Baffin Bay
GISP2
3,205 m
Ilulissat
(Jakobshavn)
Aasiaat
(Egedesminde)
Sisimiut
(Holsteinsborg)
Maniitsoq
(Sukkertoppen)
Nuuk
(Godthåb)
Denmark
Strait
Arctic Circle
ICELAND
Labrador Sea
Qaqortoq
(Julianehåb)
ATLANTIC OCEAN
Thickness of Greenland Ice sheet
Thickness over 10 m above bedrock and mean sea level
3,205 m
3,000 m
2,500 m
2,000 m
1,500 m
1,000 m
10 m
capital
major settlement
Qaanaaq (Thule) name (Danish name)
3,205 m location of maximal thickness
GISP2 location of GISP2 drill
Lambert conformal conic projection - WGS84 datum
standard parallels: 66° N - 78° N
central meridian: 42° W
scale: 1:8,000,000 (precision: 2 km)
0 (km) 400
0 (mi) 300

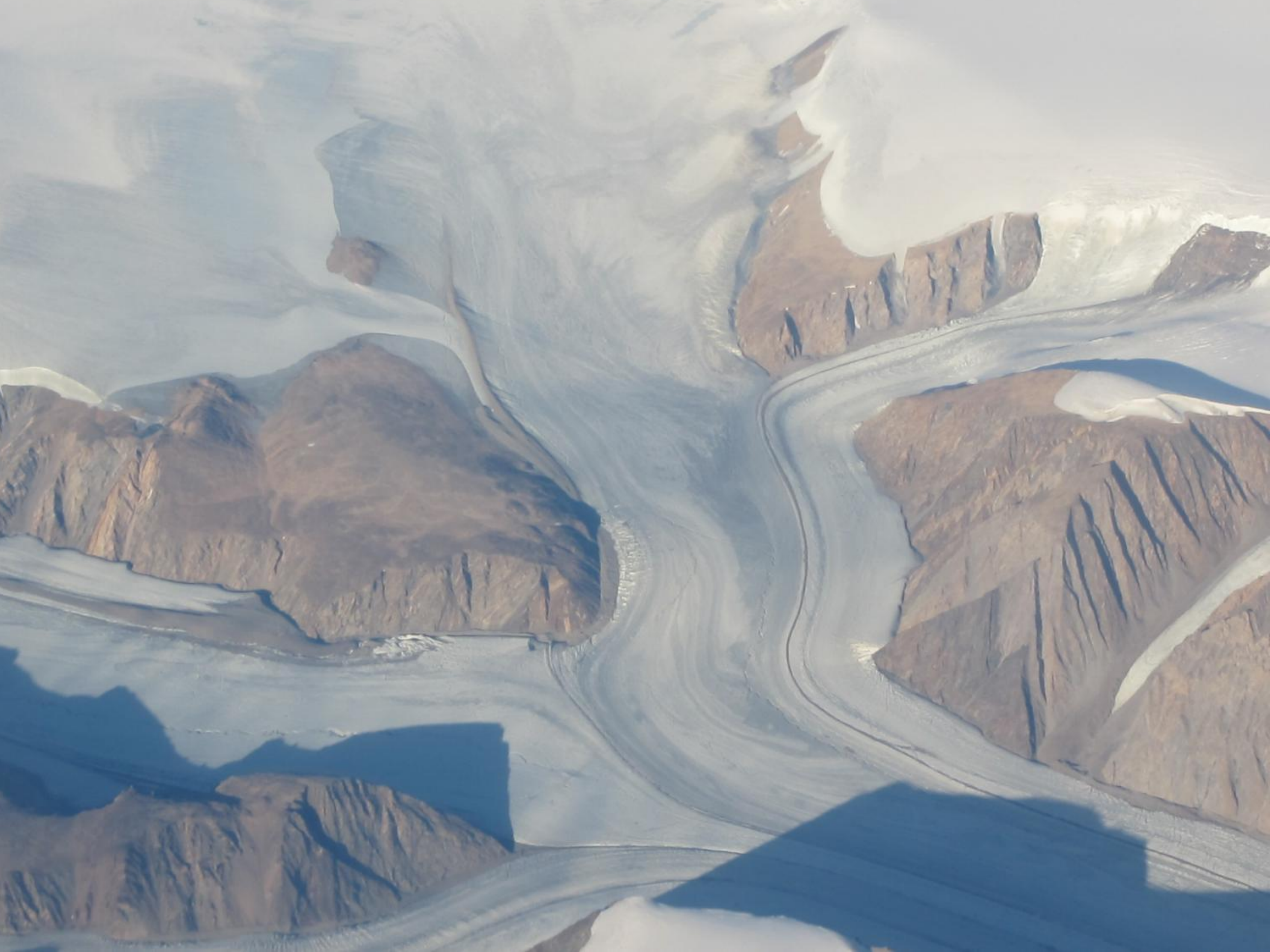
Ice thickness

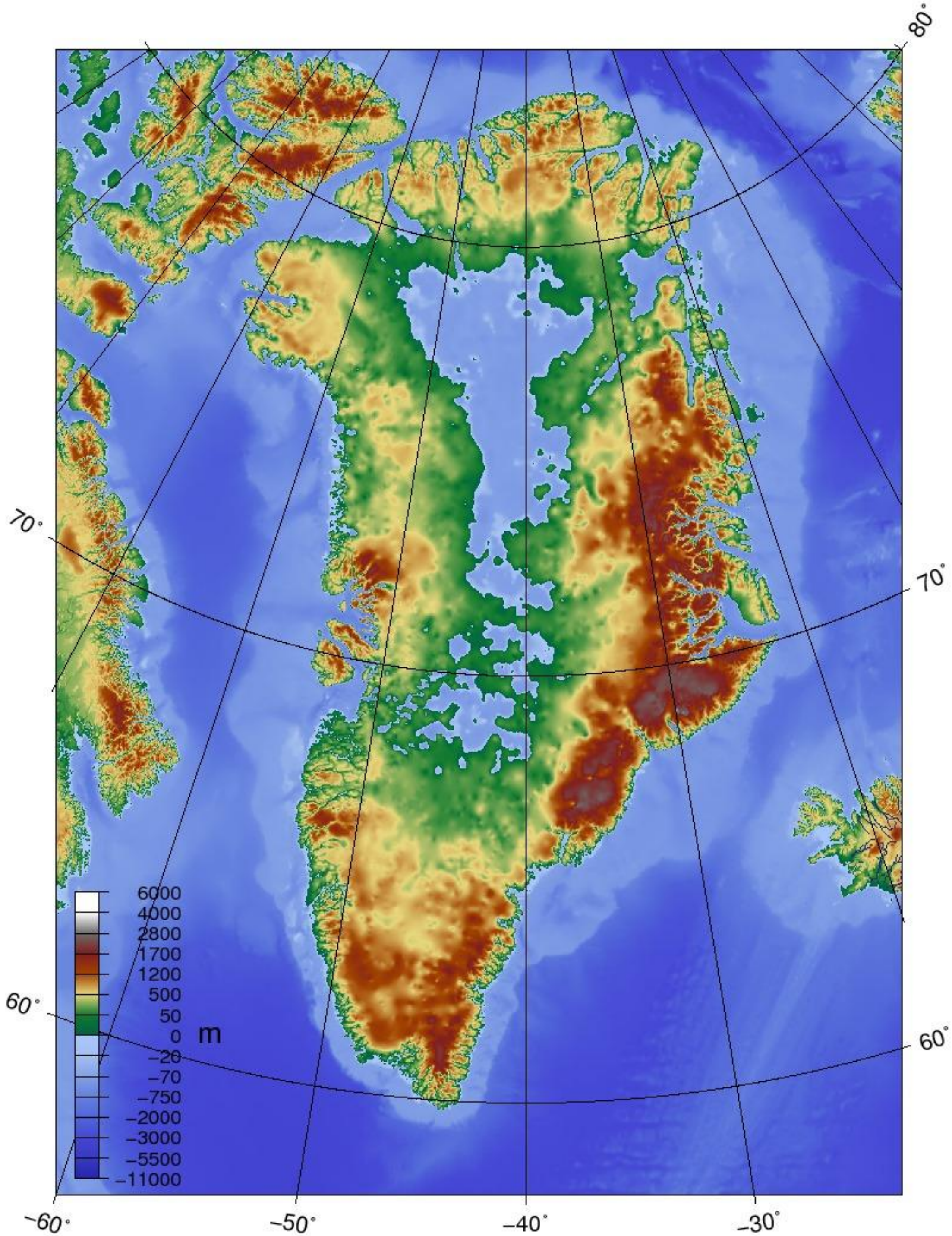


MODIS Imagery 14th/15th August 2011
NASA/GSFC, Rapid Response.

Ice Thickness 500m Contours (SPRI) from Ice Thickness Data (2001) provided by the National Snow and Ice Data Center DAAC, University of Colorado, Boulder, CO.

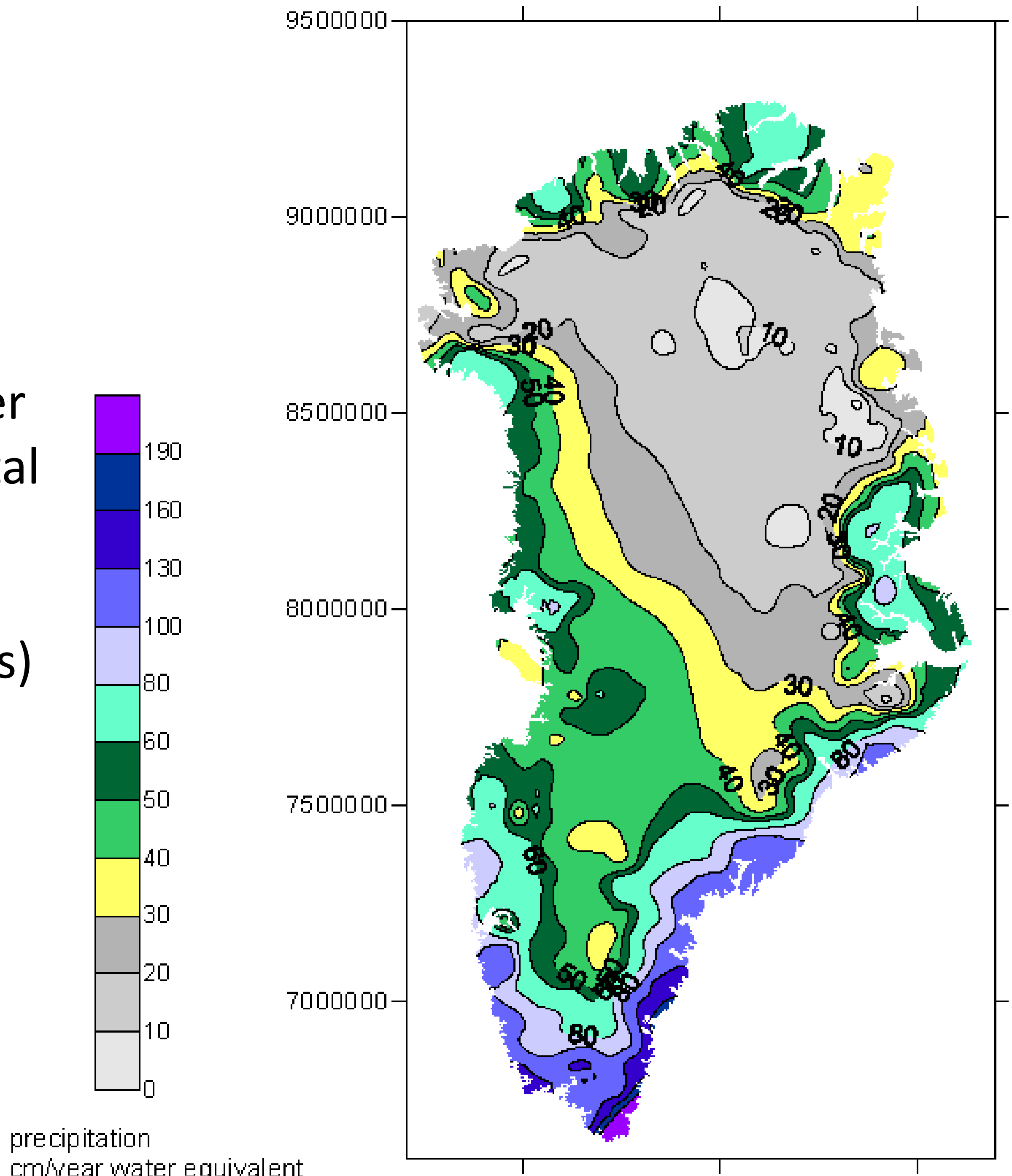
Ginny’s photos from last month

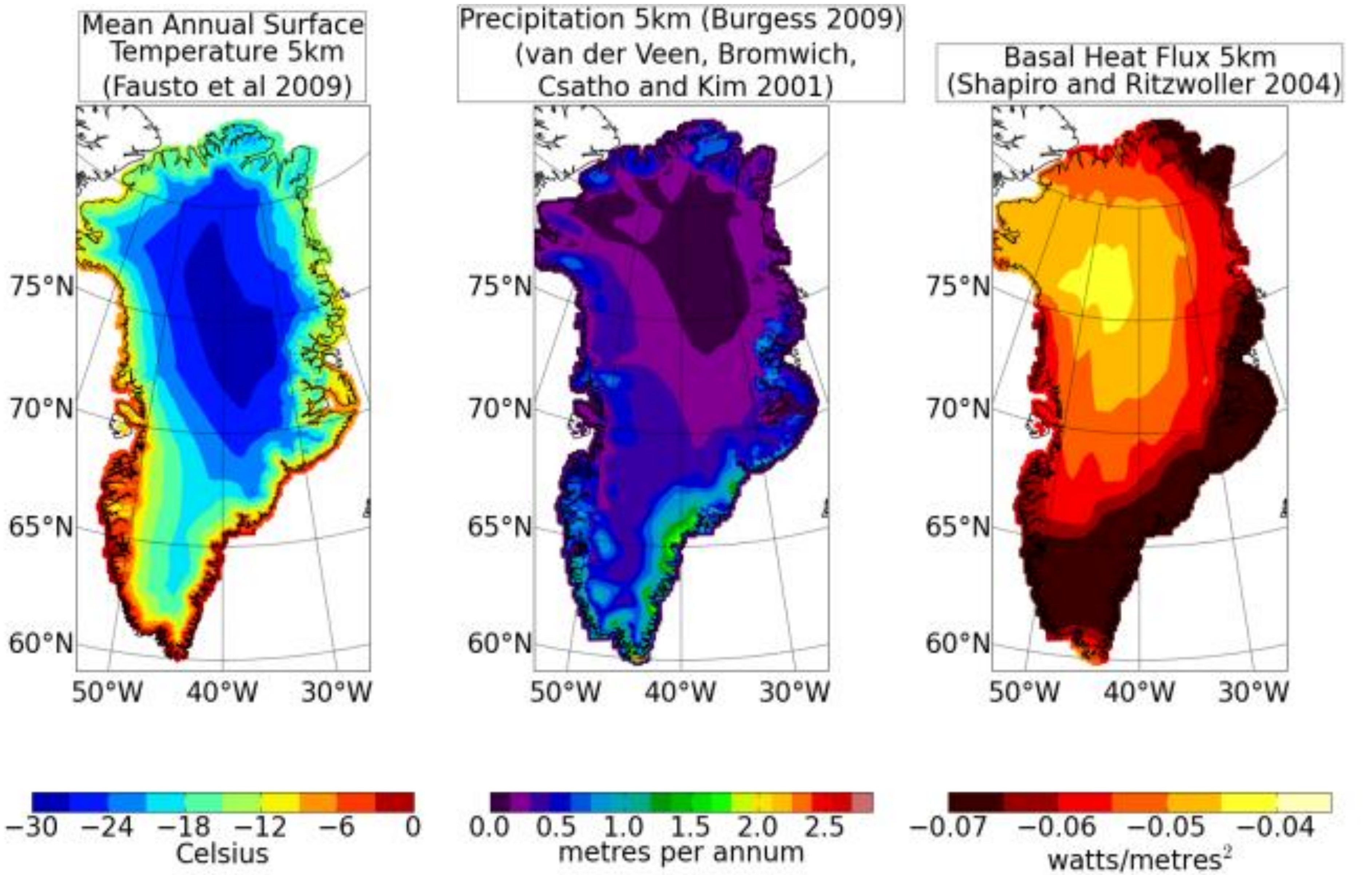




80°
70°
70°
60°
60°
−60°
−50°
−40°
−30°
6000
4000
2800
1700
1200
500
50
0
m
−20
−70
−750
−2000
−3000
−5500
−11000

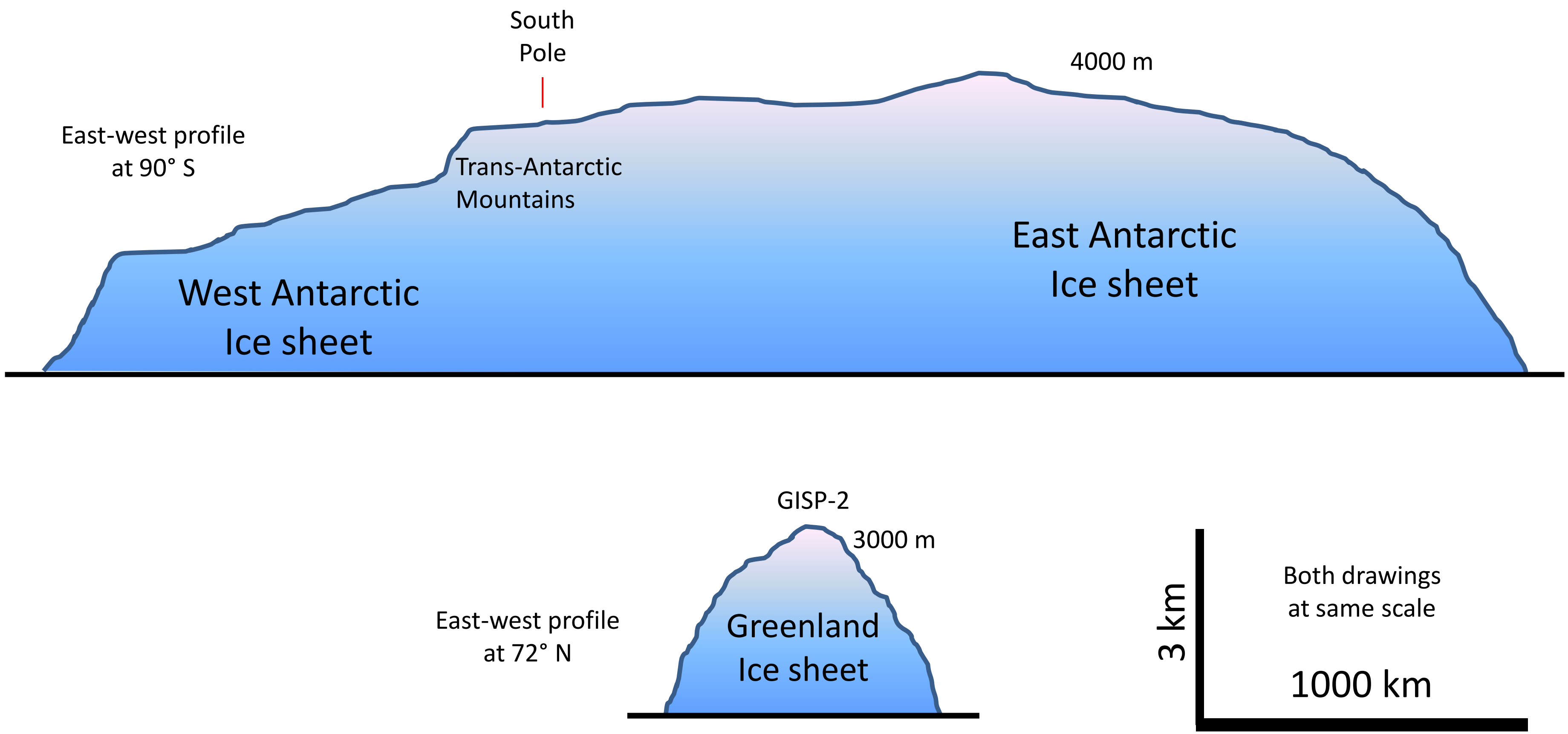
Precipitation from observations: (ice-cores, manned weather stations in coastal areas and automatic weather stations)





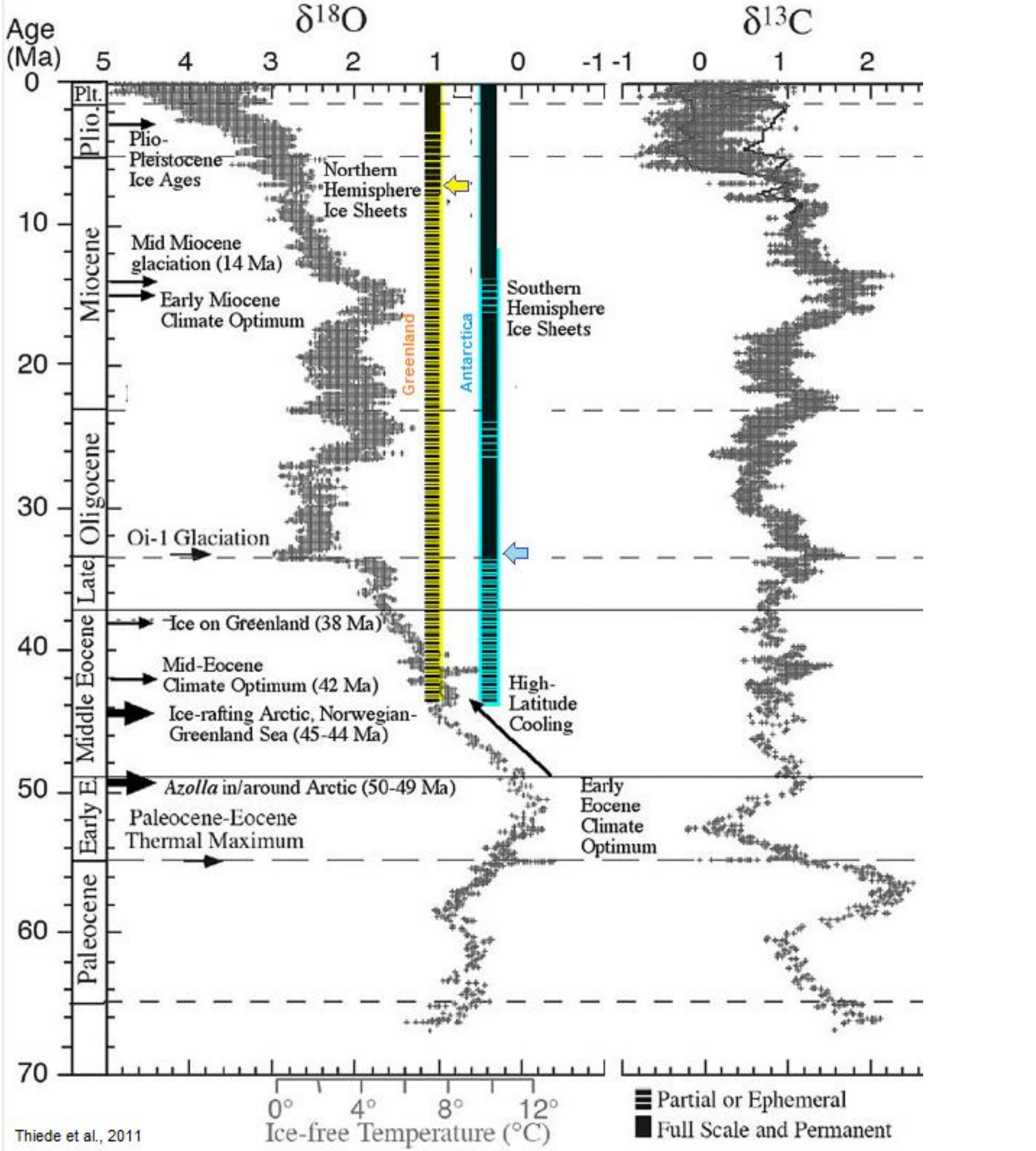
Mean Annual Surface Temperature 5km (Fausto et al 2009)
Precipitation 5km (Burgess 2009) (van der Veen, Bromwich, Csatho and Kim 2001)
Basal Heat Flux 5km (Shapiro and Ritzwoller 2004)
75°N
70°N
65°N
60°N
50°W
40°W
30°W
−30 −24 −18 −12 −6 0
Celsius
0.0 0.5 1.0 1.5 2.0 2.5
metres per annum
−0.07 −0.06 −0.05 −0.04
watts/metres²

Profiles of the Antarctic and Greenland Ice Sheets



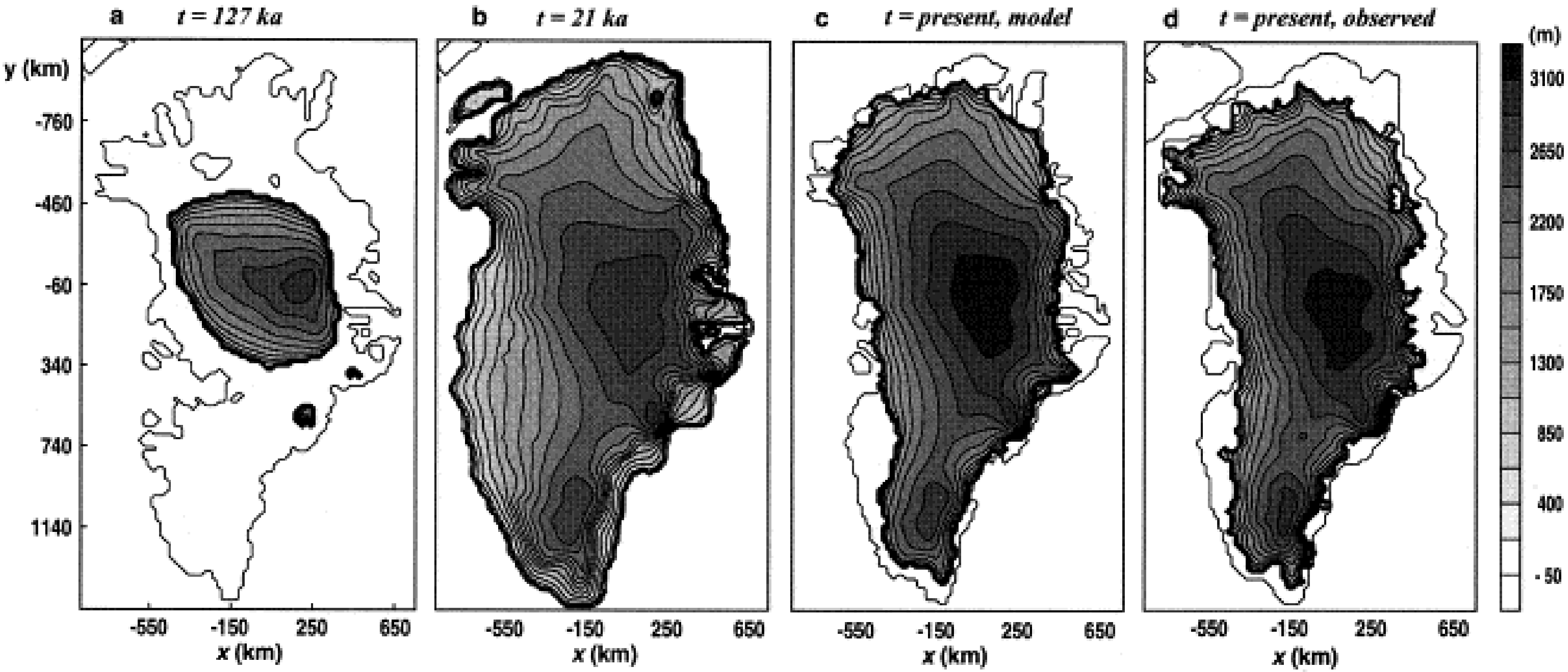
SE-2012

History of Greenland and Antarctic glaciation



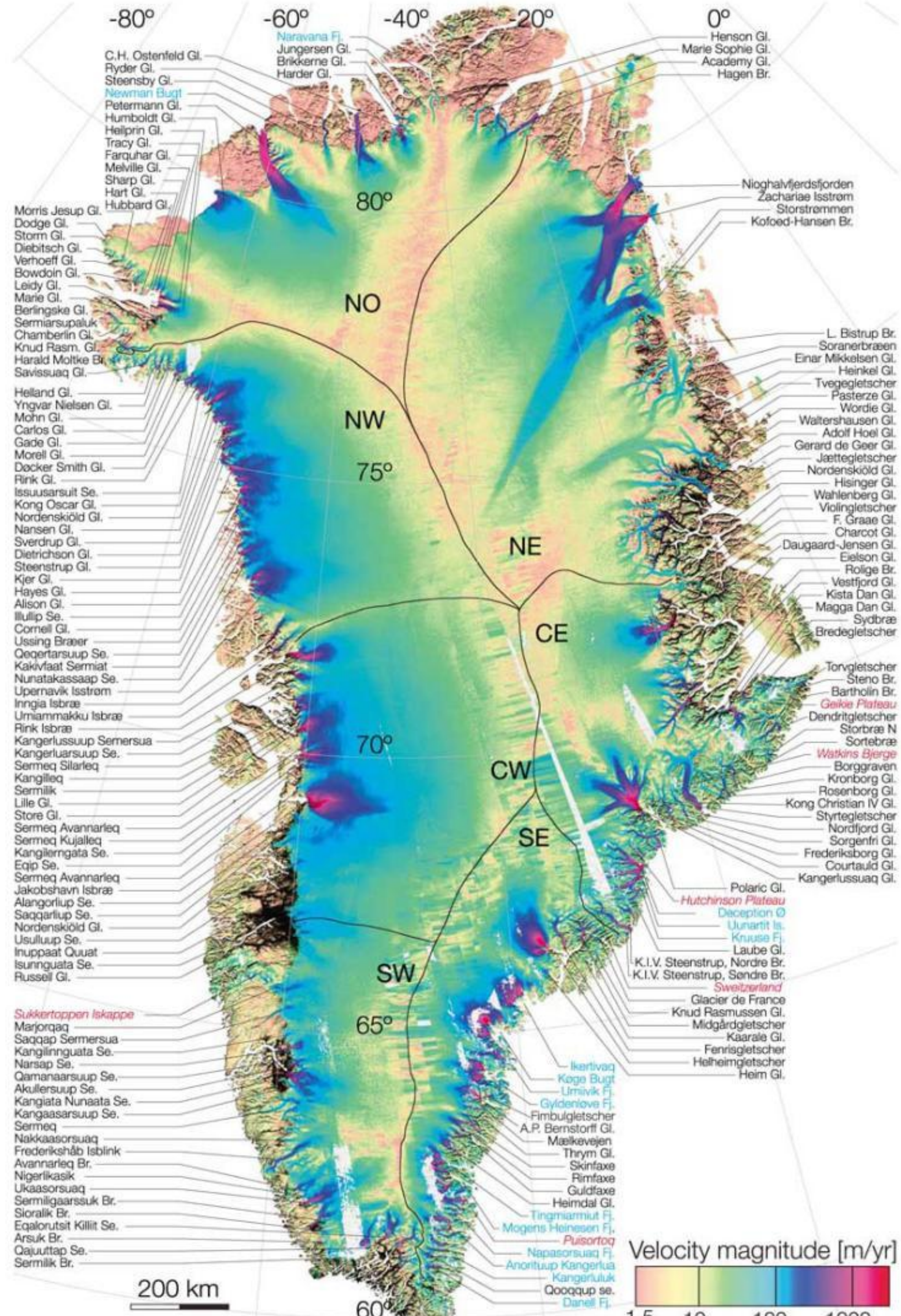
Modelled extent of Greenland ice during last interglacial and last glacial maximum

Last interglacial | Last glacial maximum | Present



Marshall and Cuffey, 2000

Greenland ice flow patterns and velocities



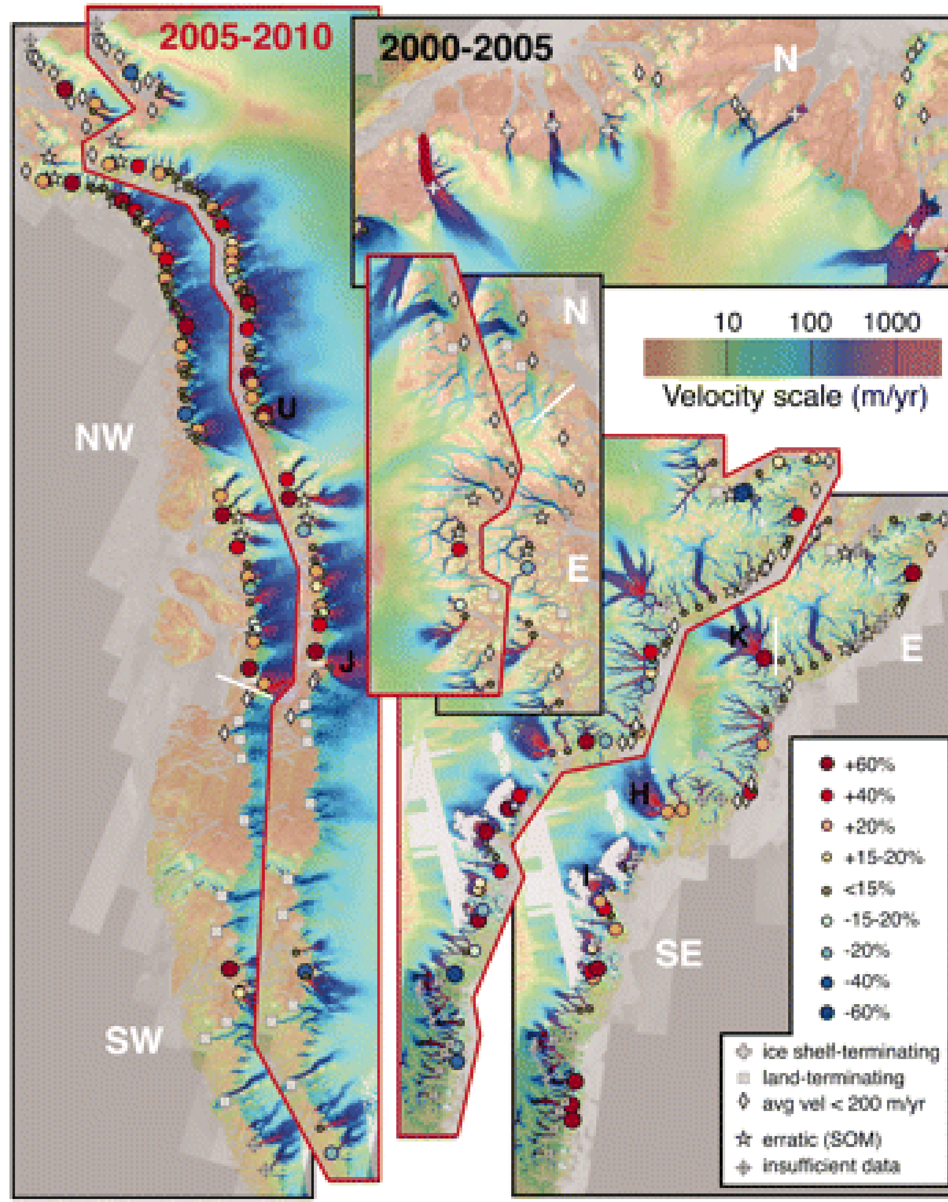
Ice velocity animation

http://en.wikipedia.org/wiki/File:NASA_scientist_Eric_Rignot_provides_a_narrated_tour_of_Greenland%E2%80%99s_moving_ice_sheet.ogv

Changes in flow rates

A recent paper, "21st-century evolution of Greenland outlet glacier velocities", (Moon et al., 2012), presented observations of velocity on all Greenland outlet glaciers – more than 200 glaciers – wider than 1.5km.

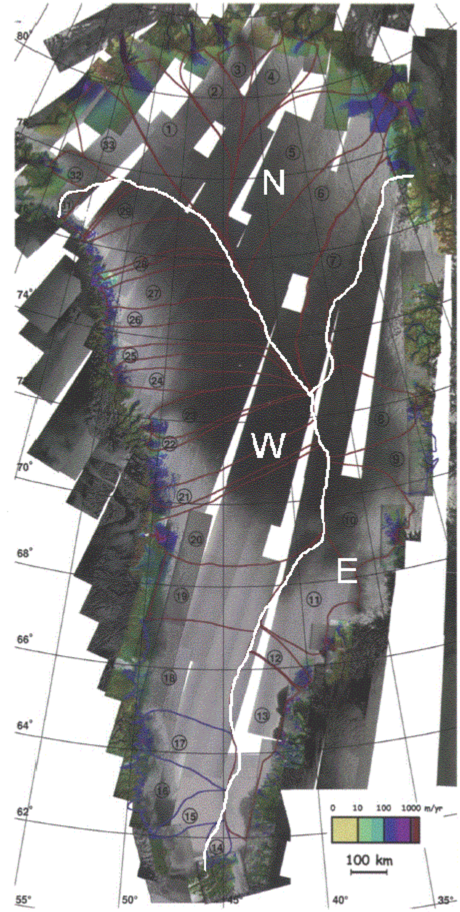
1) Most of Greenland's largest glaciers that end on land saw small changes in velocity.
2) Glaciers that terminate in fjord ice shelves didn't gain speed appreciably during the decade.
3) Glaciers that terminate in the ocean in the northwest and southeast regions of the Greenland ice sheet, where ~80% of discharge occurs, sped up by ~30% from 2000 to 2010 (34% for the southeast, 28% for the northwest).



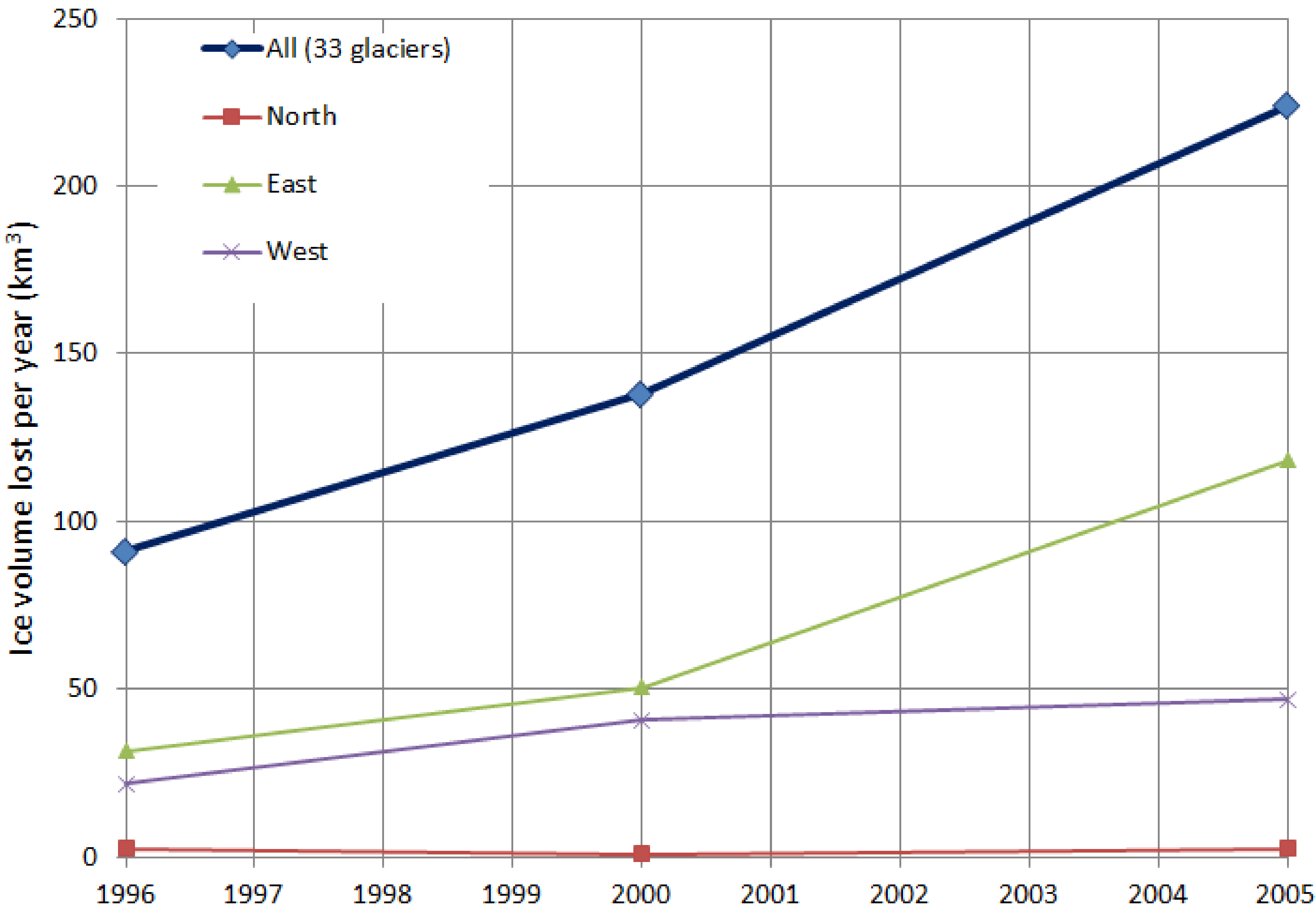
Greenland ice mass-balance data

(from Ringot and Kanagaratnam, 2006)

Fig. 1. Ice-velocity mosaic of the Greenland Ice Sheet assembled from year 2000 Radarsat-1 radar data, color coded on a logarithmic scale from 1 m/year (brown) to 3 km/year (purple), overlaid on a map of radar brightness from ERS-1/Radarsat-1/Envisat. Drainage boundaries for flux gates in Table 1 are in red. Drainage boundaries with no flux estimates but discussed in the text are in blue. Numbers refer to drainage basins in Table 1.



		Volume of ice lost/year (km^3)		
Region	area (km^3)	1996	2000	2005
North	464,876	2.4	0.7	2.3
East	223057	32	51	118
West	521350	22	41	47
Total	1209280	56	92	167
Total corrected		91 (±31)	138 (±31)	224 (±41)



From data in Ringot and Kanagaratnam, 2006

Region	area (km^3)	Volume of ice lost/year (km^3)		
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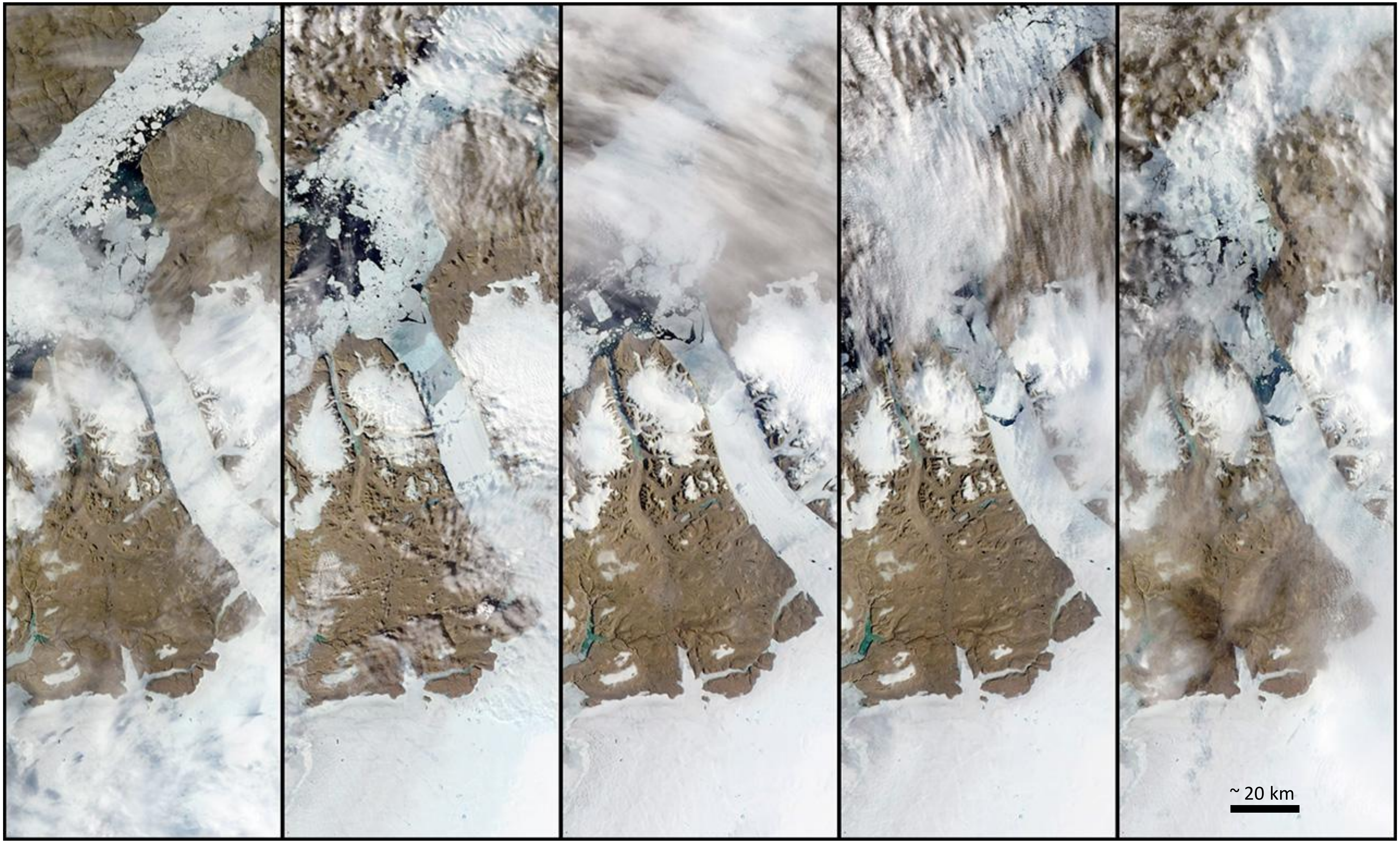
The sum of the interpolated mass loss over the 10-year period from 1996 to 2005 is 1518 km^3.

The total volume of Greenland's ice sheet is about 2,900,000 km^3 This 10 years of loss is equivalent to 0.05% of that volume.

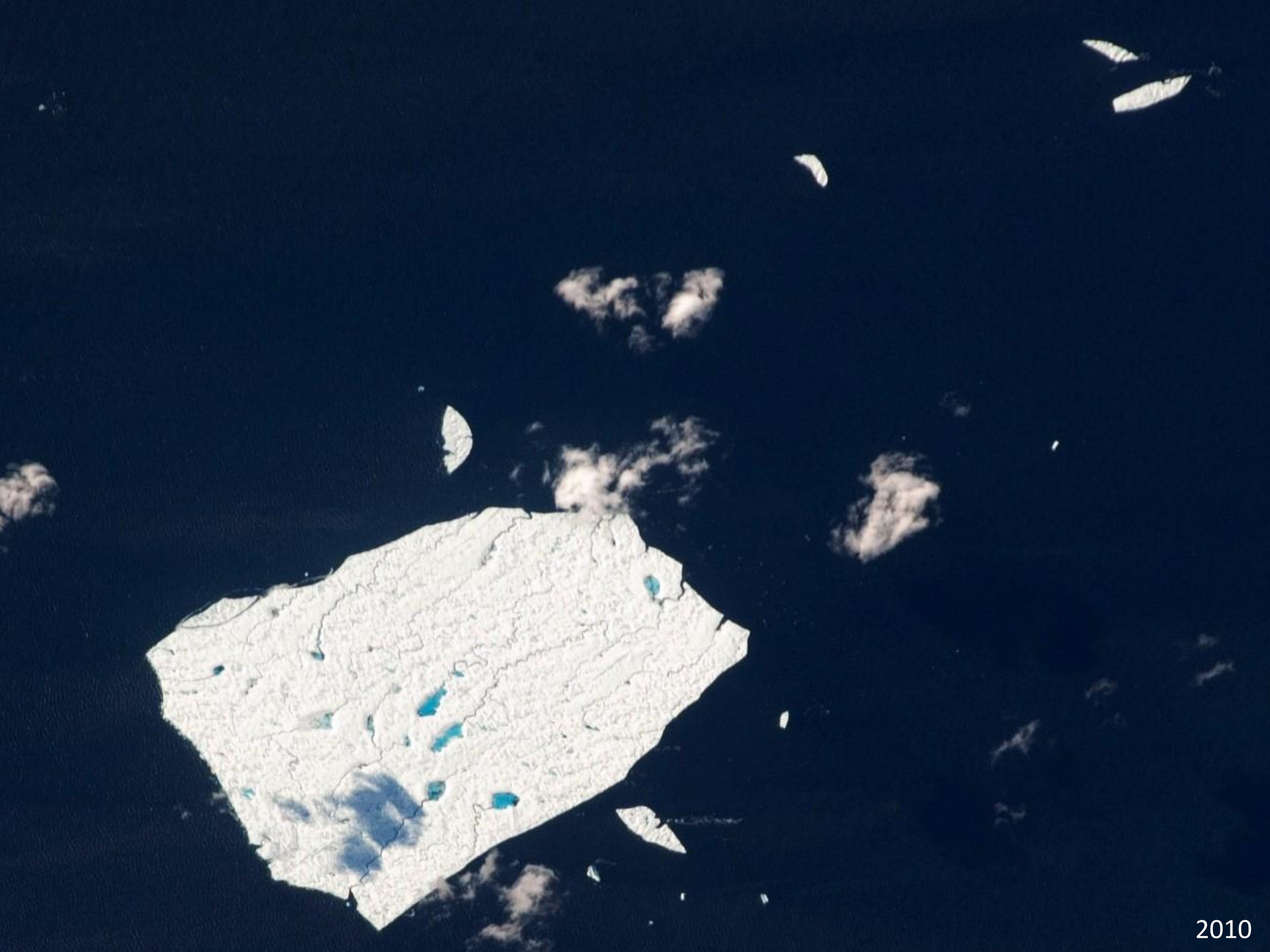
However, mass-loss rates are increasing, and the cumulative loss by the end of this century is likely to be a few per cent.

The loss of 5% of Greenland's ice would be equivalent to a sea-level rise of ~35 cm.

Petermann Glacier (NW) July 11, 15, 17, 18 and 18, 2012

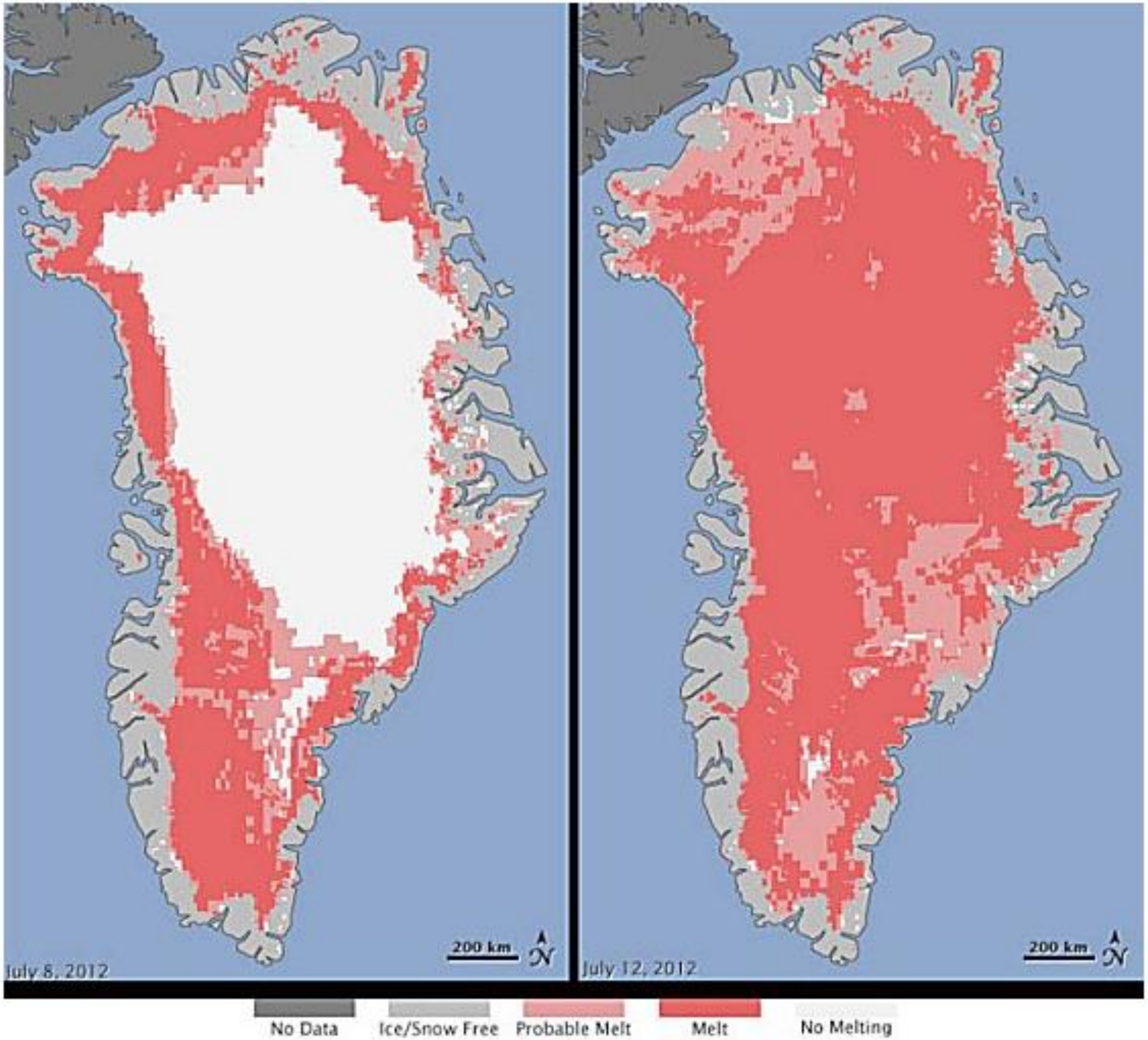


Ice-shelf calving is typically caused by warmer air and water, but it can contribute to increased ice-sheet velocities.


2010

Changes in surface melt extent

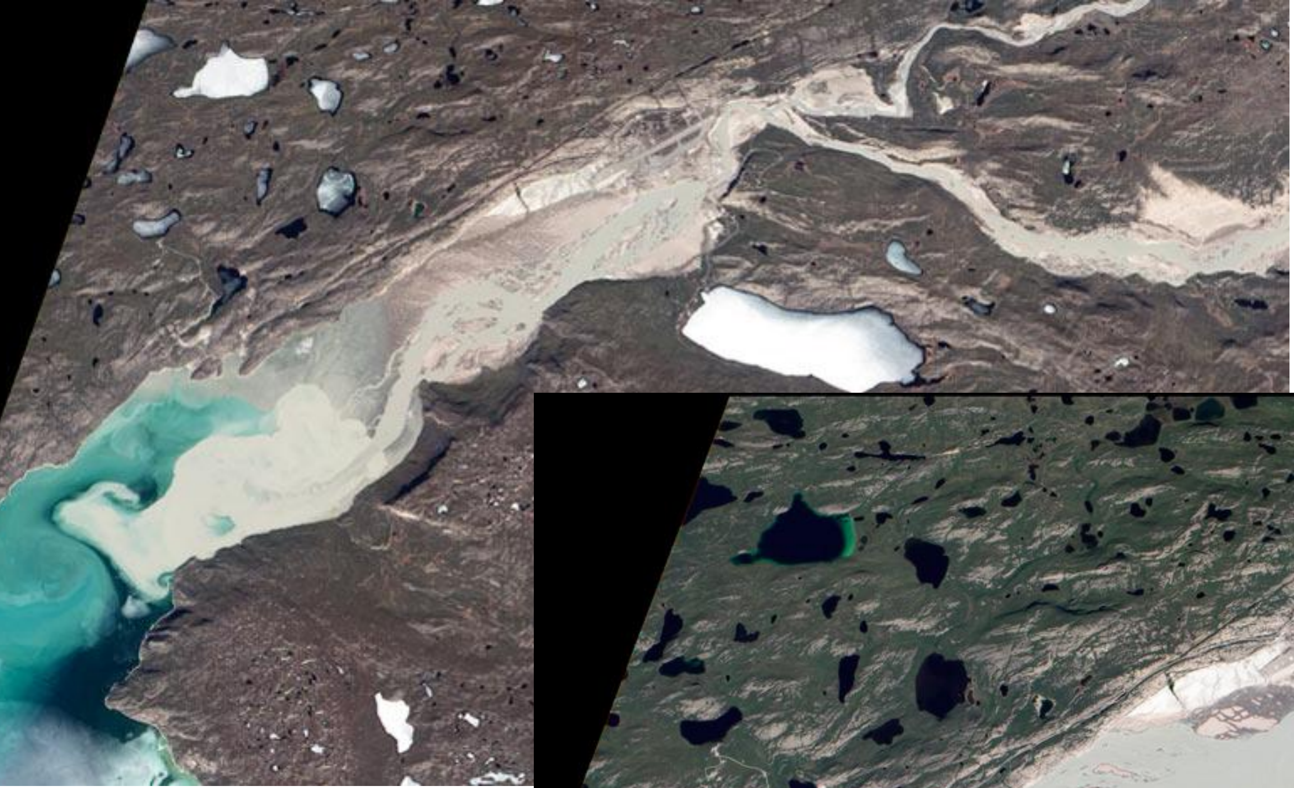
GREENLAND MELTING: To some extent, there has always been seasonal melting, and moulins (meltwater) have formed in the past. But those formations were nothing like what is happening now. In recent years, the melting has accelerated dangerously. In 1992 scientists measured this amount of melting in Greenland as indicated by the red areas on the map. Ten years later, in 2002, the melting was much worse. And in 2005 it accelerated dramatically yet again. If Greenland melted or broke up and slipped into the sea -- or if half of Greenland and half of Antarctica melted, sea levels worldwide would increase by between 18 and 20 feet.

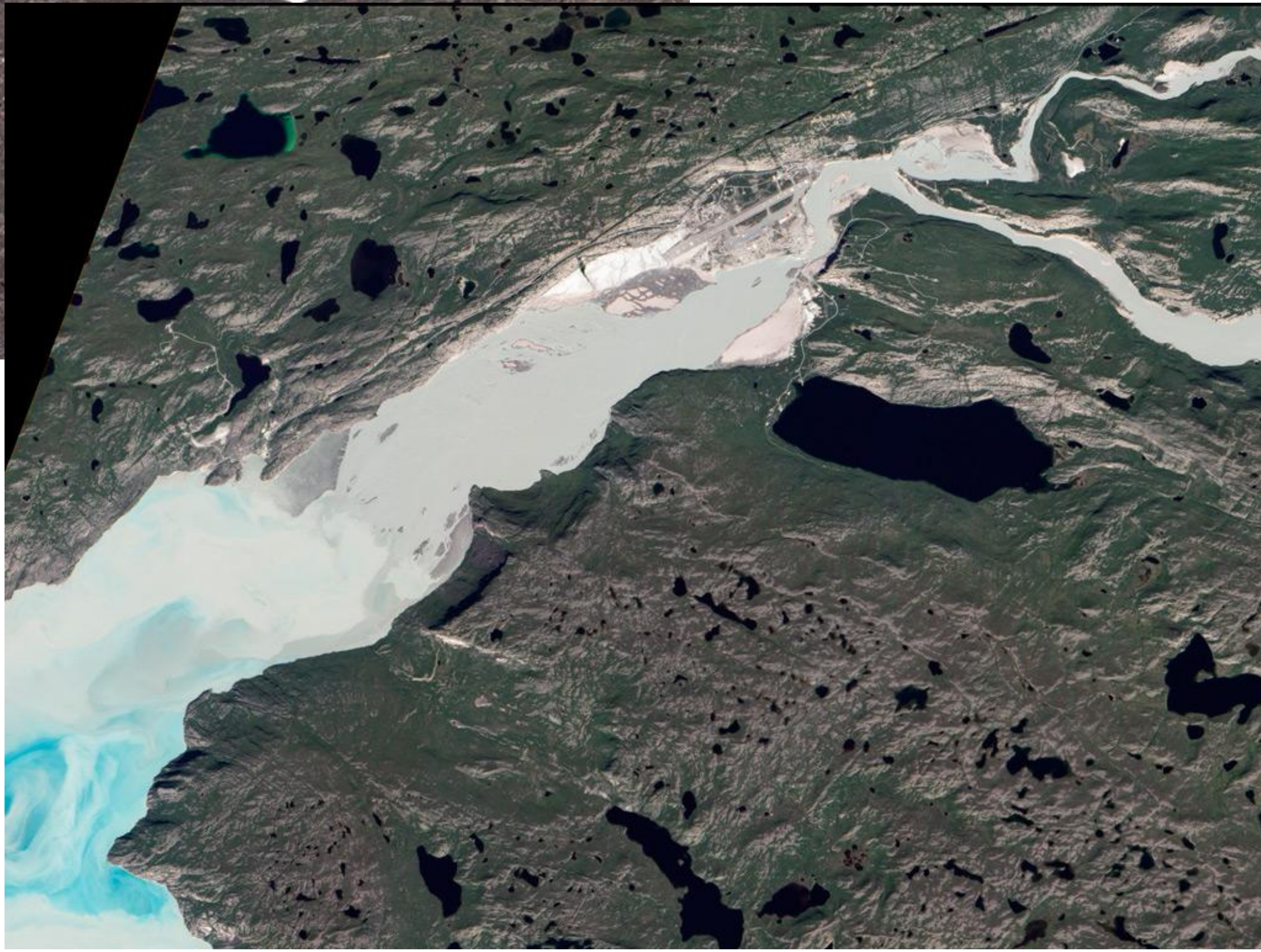

200 km
N
July 8, 2012
200 km
N
July 12, 2012
No Data
Ice/Snow Free
Probable Melt
Melt
No Melting

Moulin

Just kidding!

Kangerluss, May 3rd and July 12th, 2012

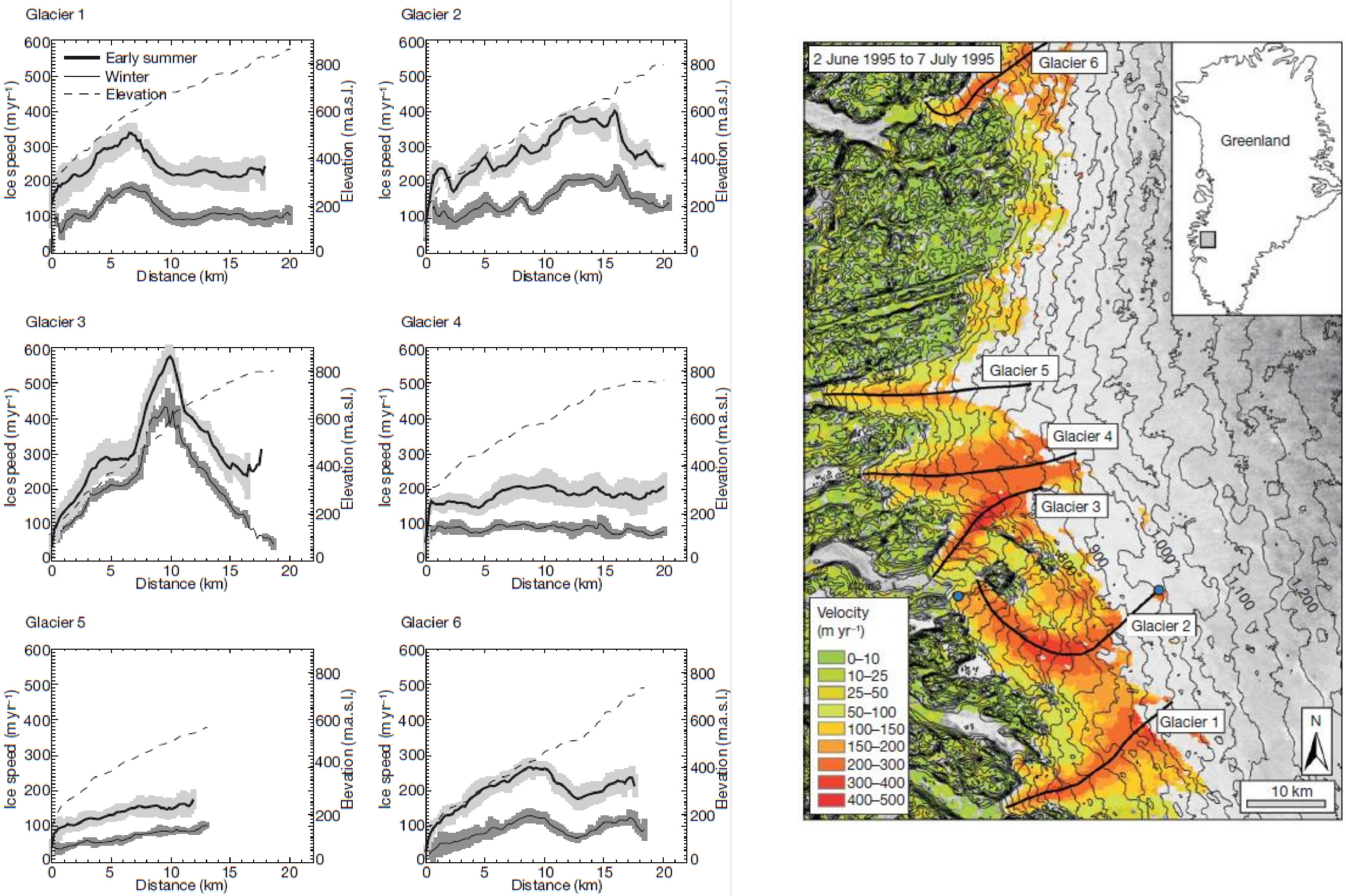




Impact of melting on ice-flow rates

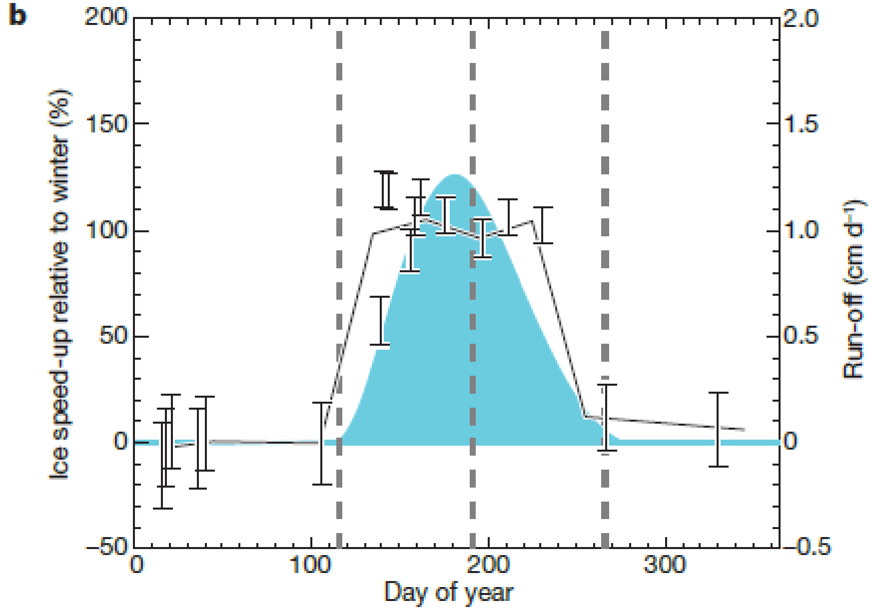
- A large proportion of surface melt-water is transmitted to the base of the ice sheet, either in small cracks or larger conduits (moulins)
- At the ice-rock contact this water helps to lubricate the sliding surface, and if it's under pressure from water above, it can significantly reduce the friction, resulting in dramatically increased ice-flow rates

Summer ice-flow velocities are up to twice that of winter velocities



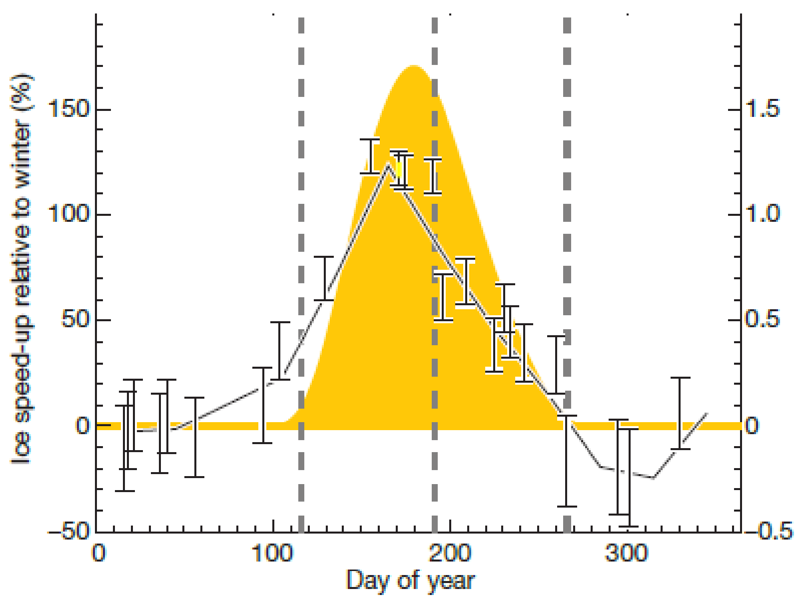
Sundal et al., 2011, Melt-induced speed-up of Greenland ice sheet offset by efficient subglacial drainage, Nature, V. 469

Flow rates can be directly linked to runoff rates



Run off (blue) versus ice velocity (bars) for years with <u>low melting rates</u>

But flow rates decrease later in the melt season in years of high runoff

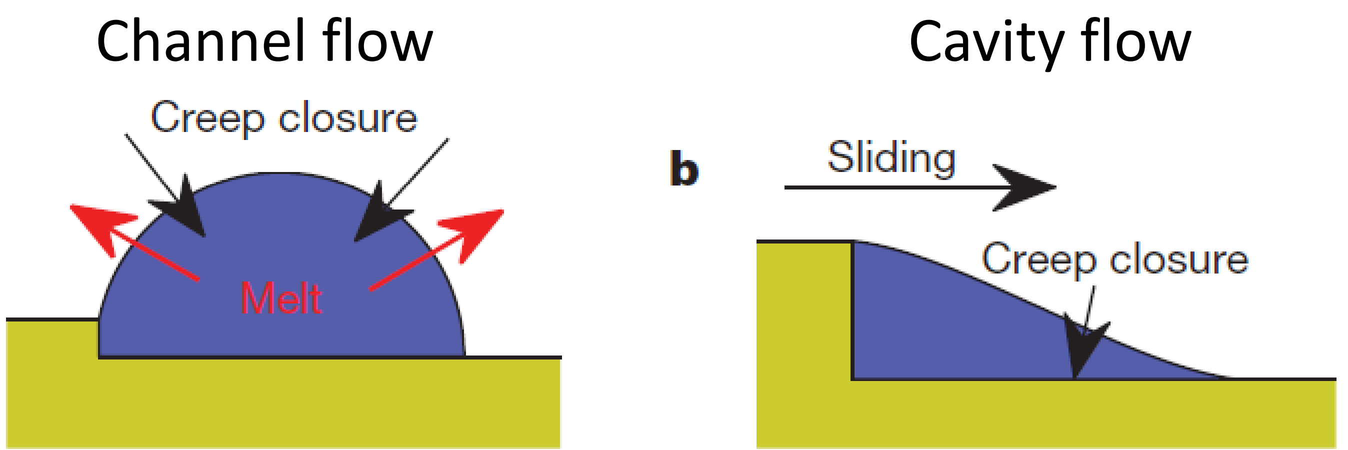


Run off (yellow) versus ice velocity (bars) for years with <u>high melting rates</u>

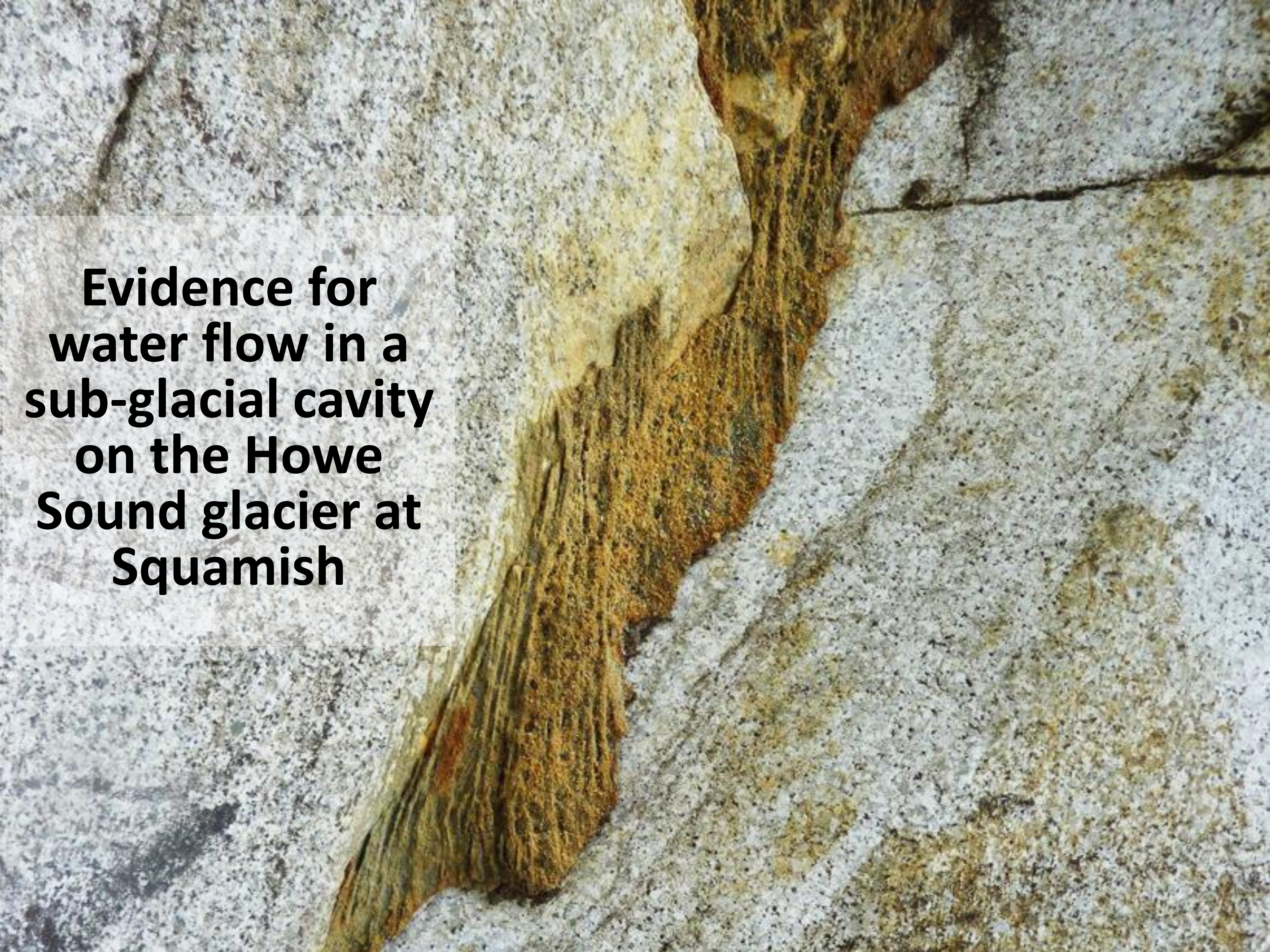
Sundal et al., 2011

The important factor appears to be the nature and timing of the melt-water flow

- Early during the melt season, and when flow rates are relatively low, the flow will be diffuse (through small fractures) and this will ensure that water pressure remains high
- Later in the season, or if there is a strong melting event, the flow becomes focussed into sub-ice channels and since the drainage is more efficient, the effective water pressure drops and the ice slows down



Schoof, C, 2010, Ice-sheet acceleration driven by melt supply variability, Nature, V. 468


Evidence for water flow in a sub-glacial cavity on the Howe Sound glacier at Squamish

In general, melting promotes rapid ice-advance, but very strong melting can lead to channelization of sub-glacial water and a drop in water pressure (which slows the ice down).

Rapid ice advance is favoured at relatively low melt rates, or if the melting is episodic over the melt season, and channels do not develop fully.