Important Things Ice Sheets Do, but Ice Sheet Models Don't

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I'll talk about

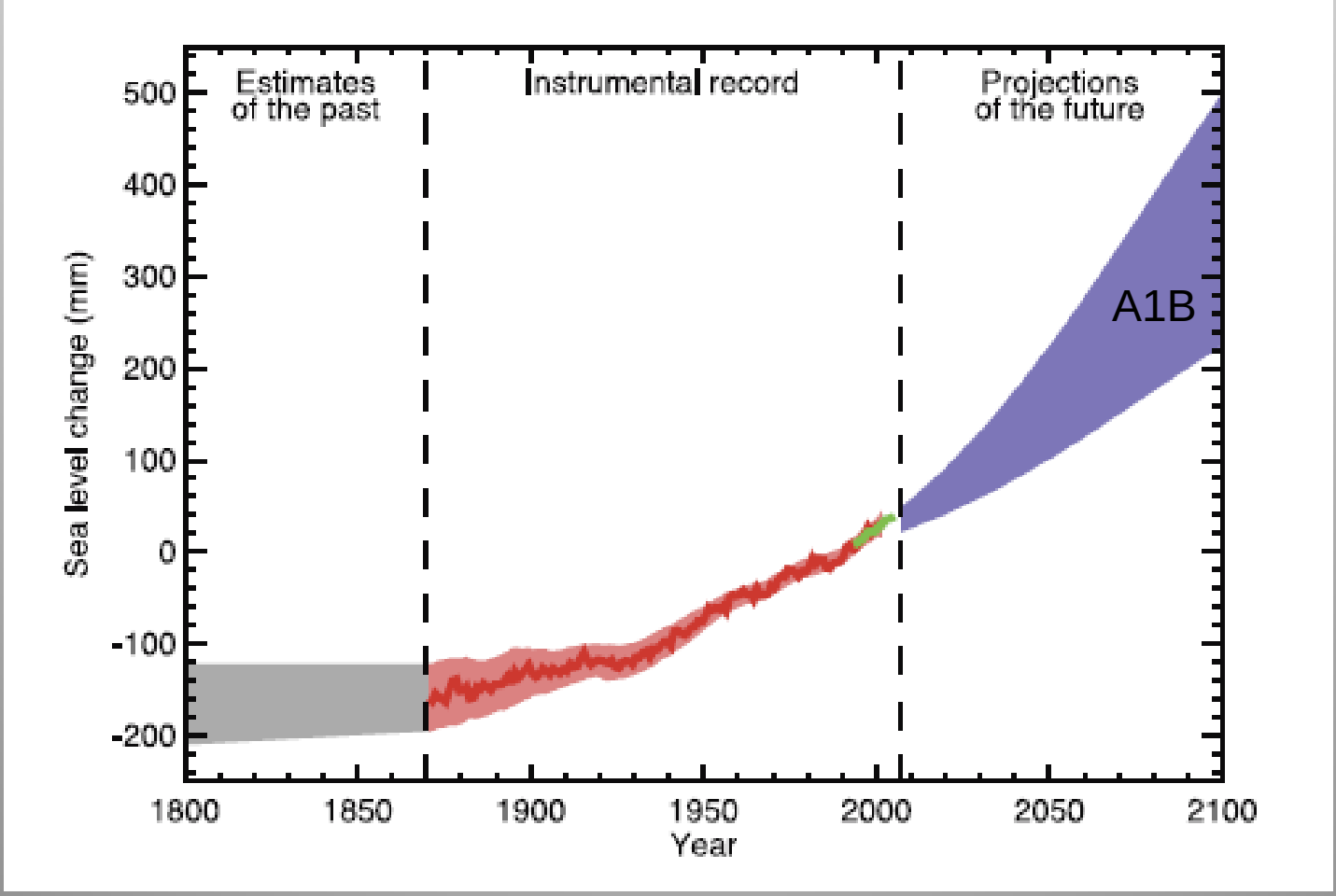
- Why we need models
  - from a non-modeler
- Why we need good models
  - recent observations have destroyed confidence in present models
- Recent ice-sheet surprises
- Responsible physical processes

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

"…understanding of (possible future rapid dynamical changes in ice flow) is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise."

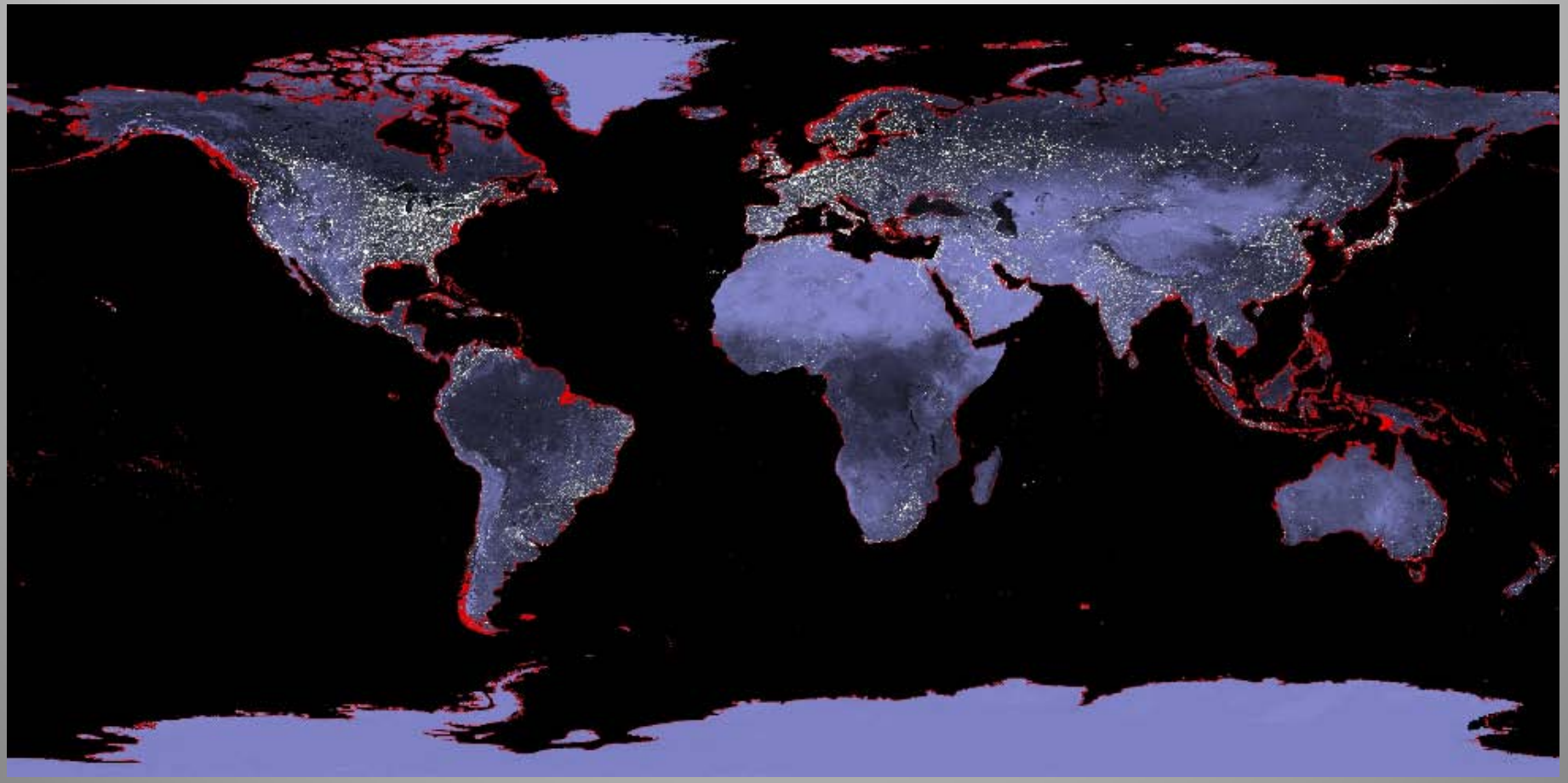
IPCC Fourth Assessment Report, Summary for Policy Makers (2007)

Future Sea Level is likely underestimated



IPCC AR4 (2007)

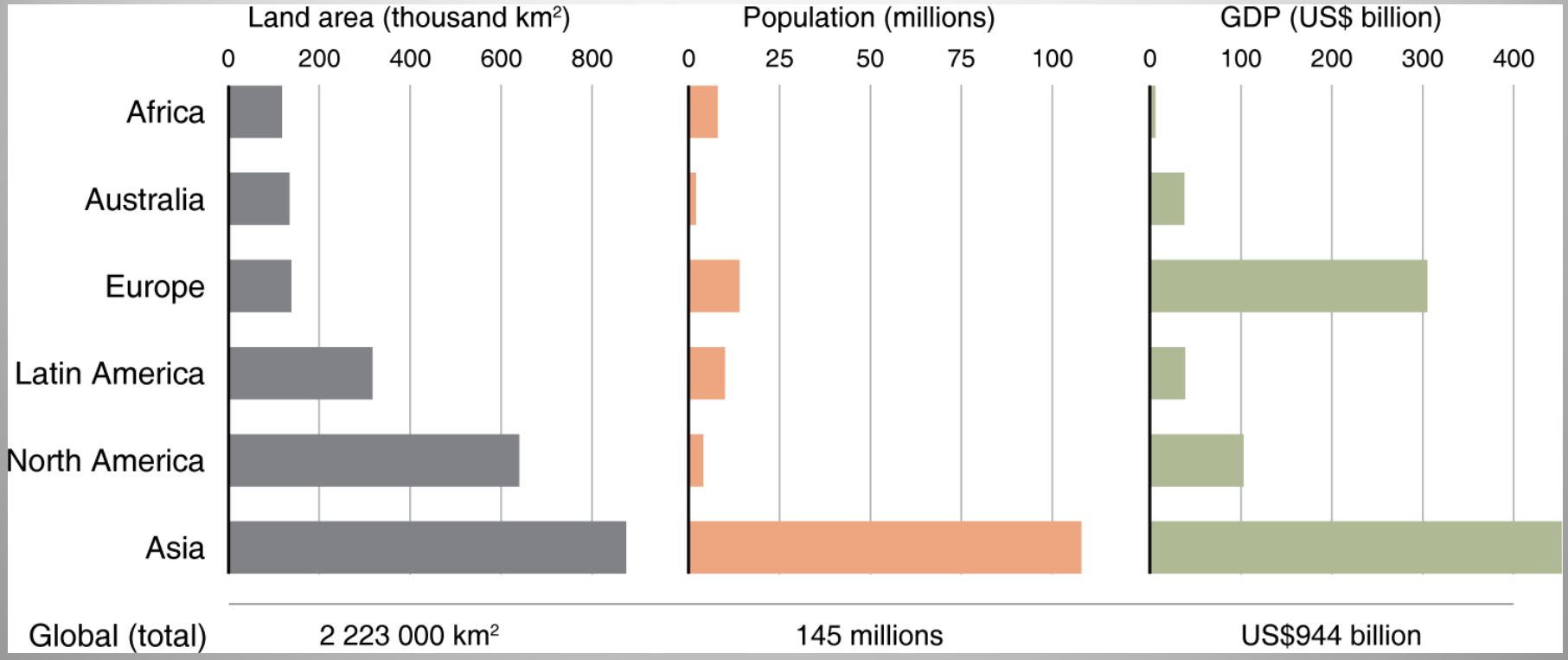
Ice Sheets matter Globally



Source: CReSIS and NASA

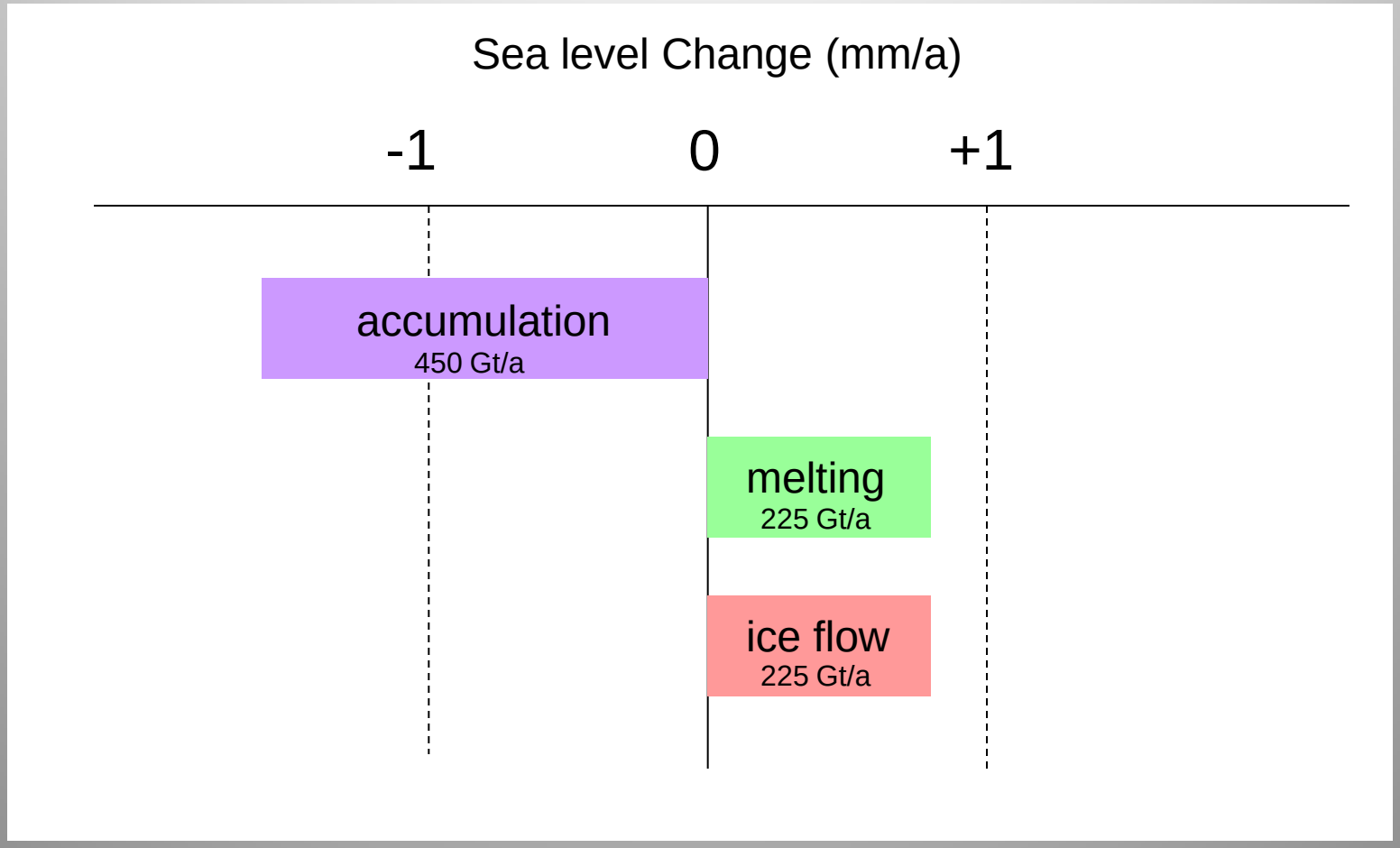
Land area lost by 1-meter rise in sea level

Impact of 1-meter sea level rise:



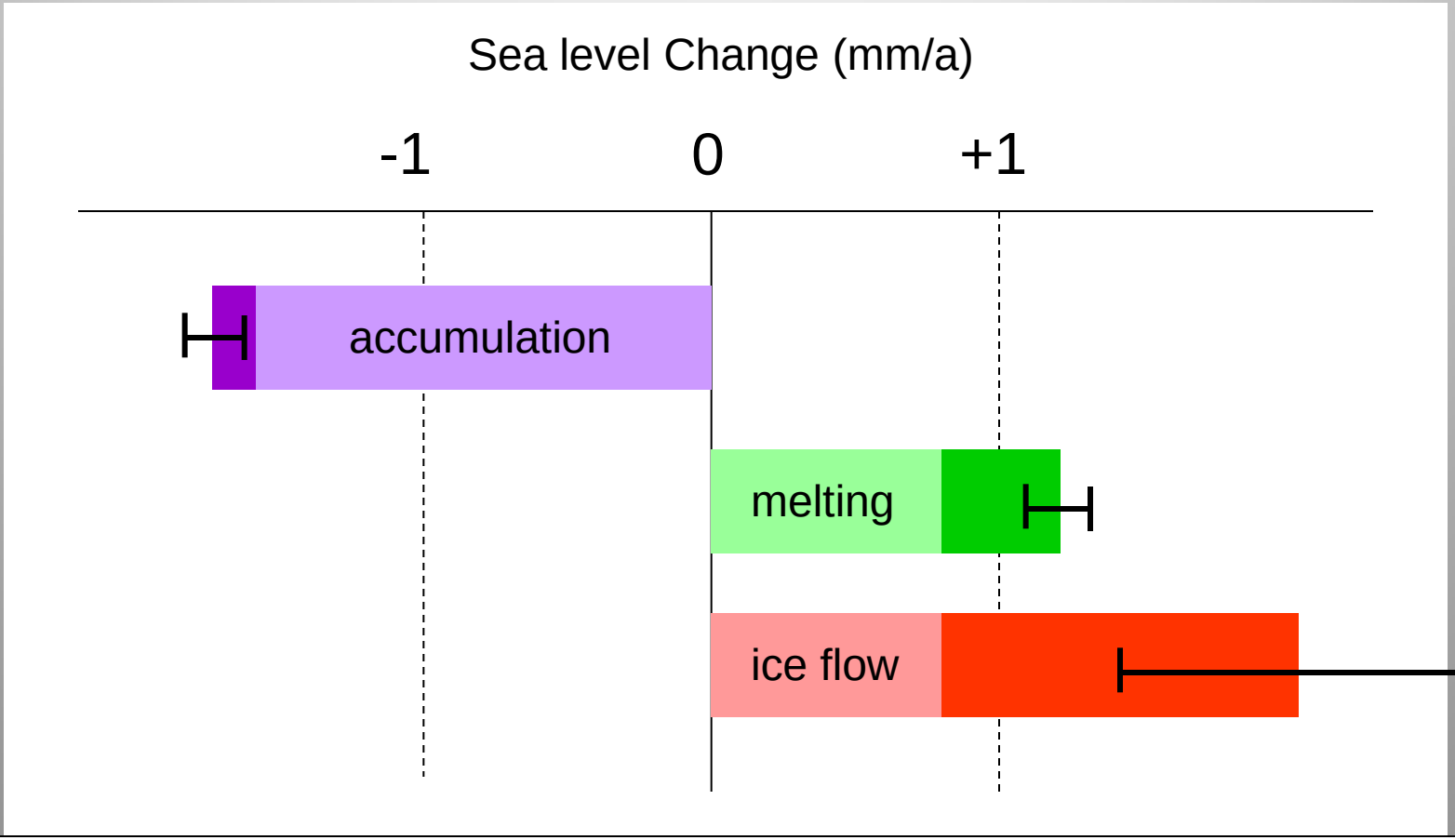
Source: Anthoff et al., 2006

20th Century Greenland Ice Sheet



Approximately in “mass balance”

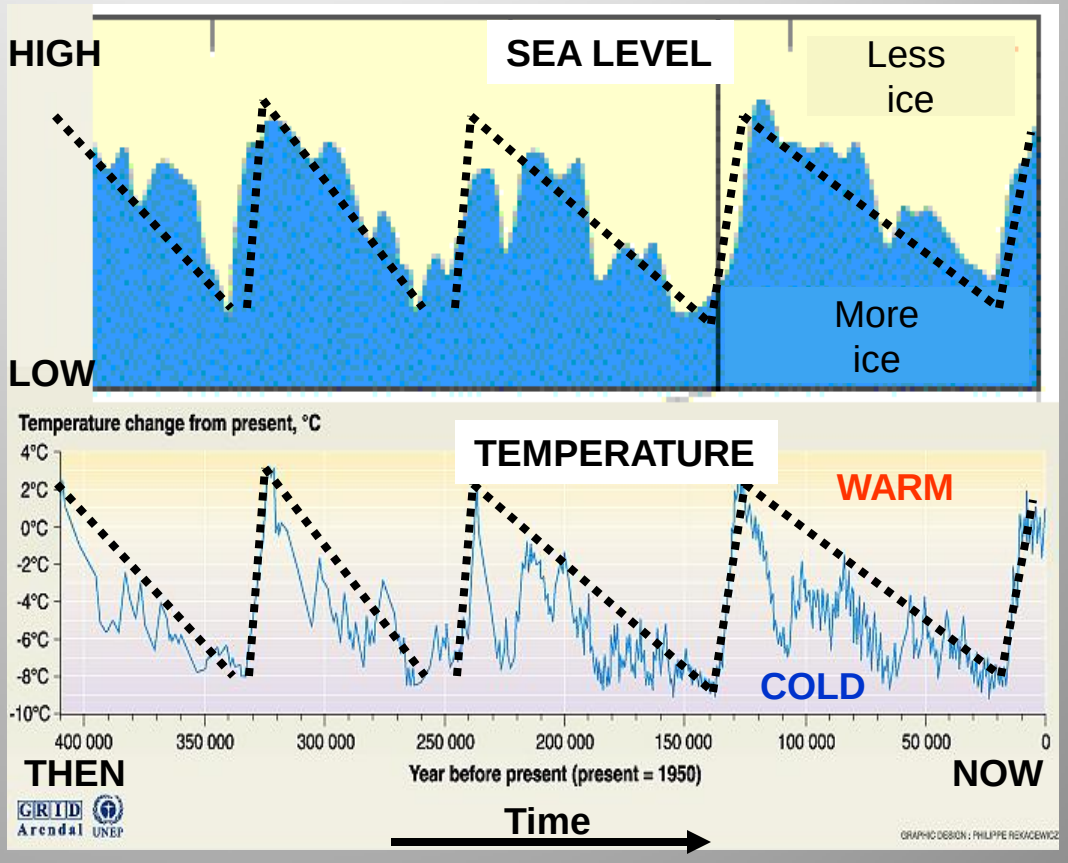
21st Century Greenland Ice Sheet



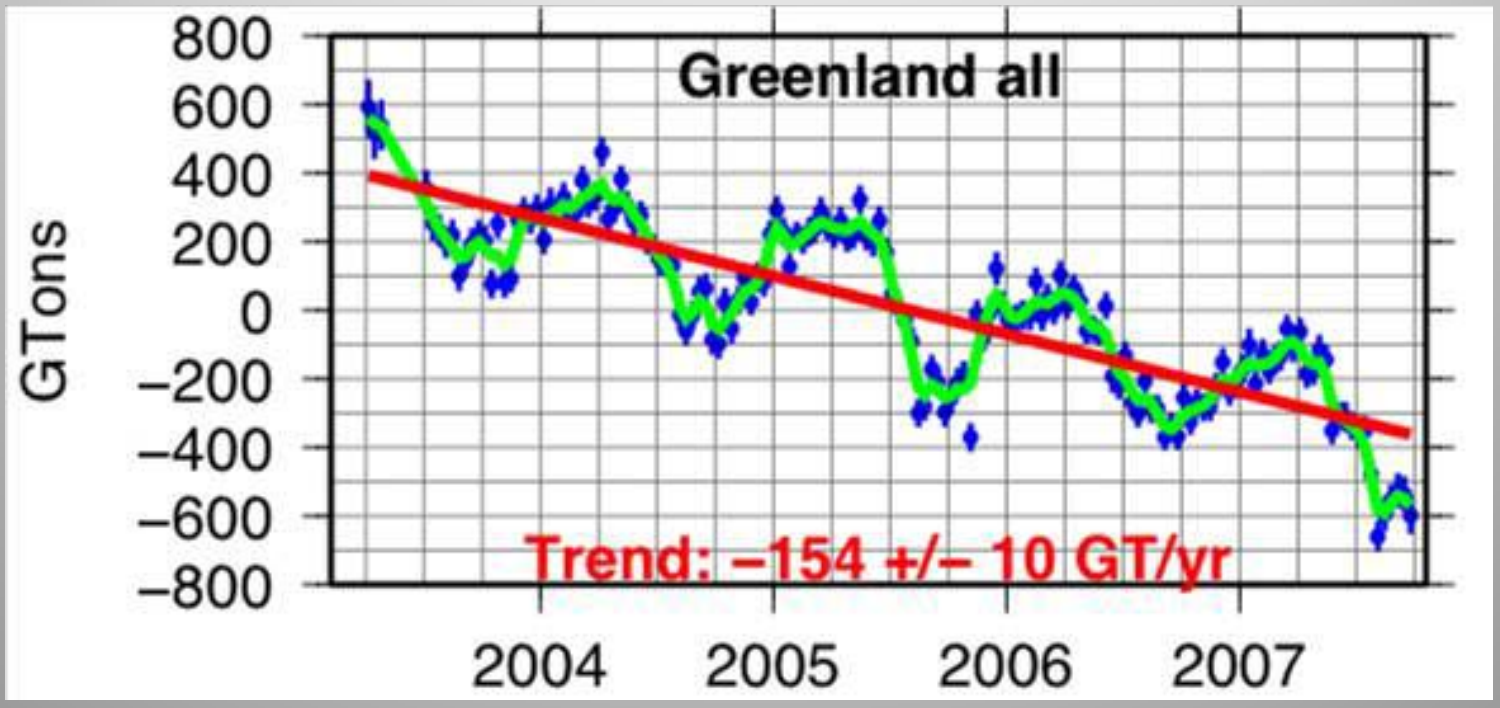
Things could get a little better or a lot worse
Increased <u>ice flow</u> will dominate the future rate of change

A History Lesson

- Less ice in warmer climates
- Ice sheets shrink faster than they grow
- Sea level change is not smooth

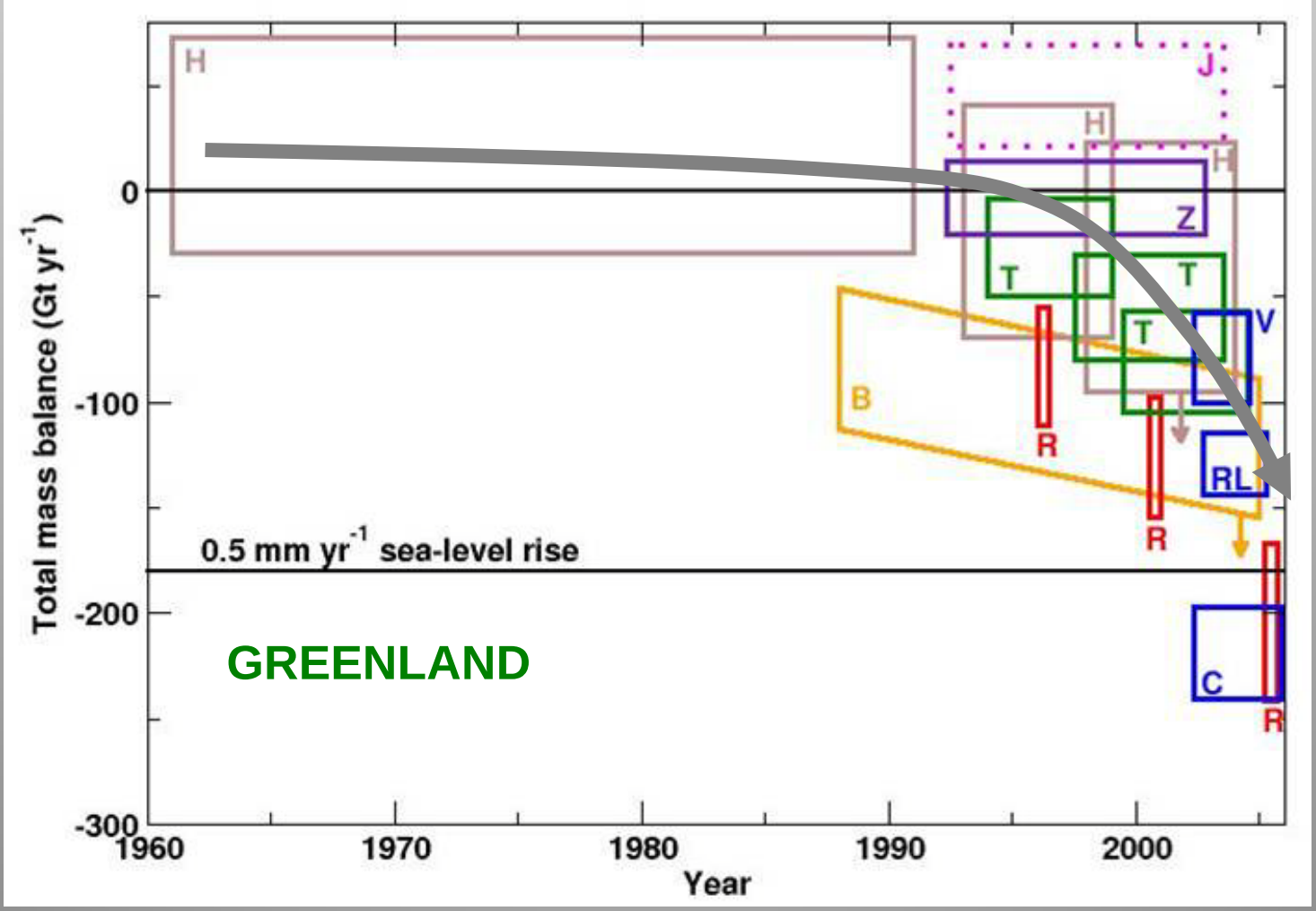


Decreasing Mass Balance



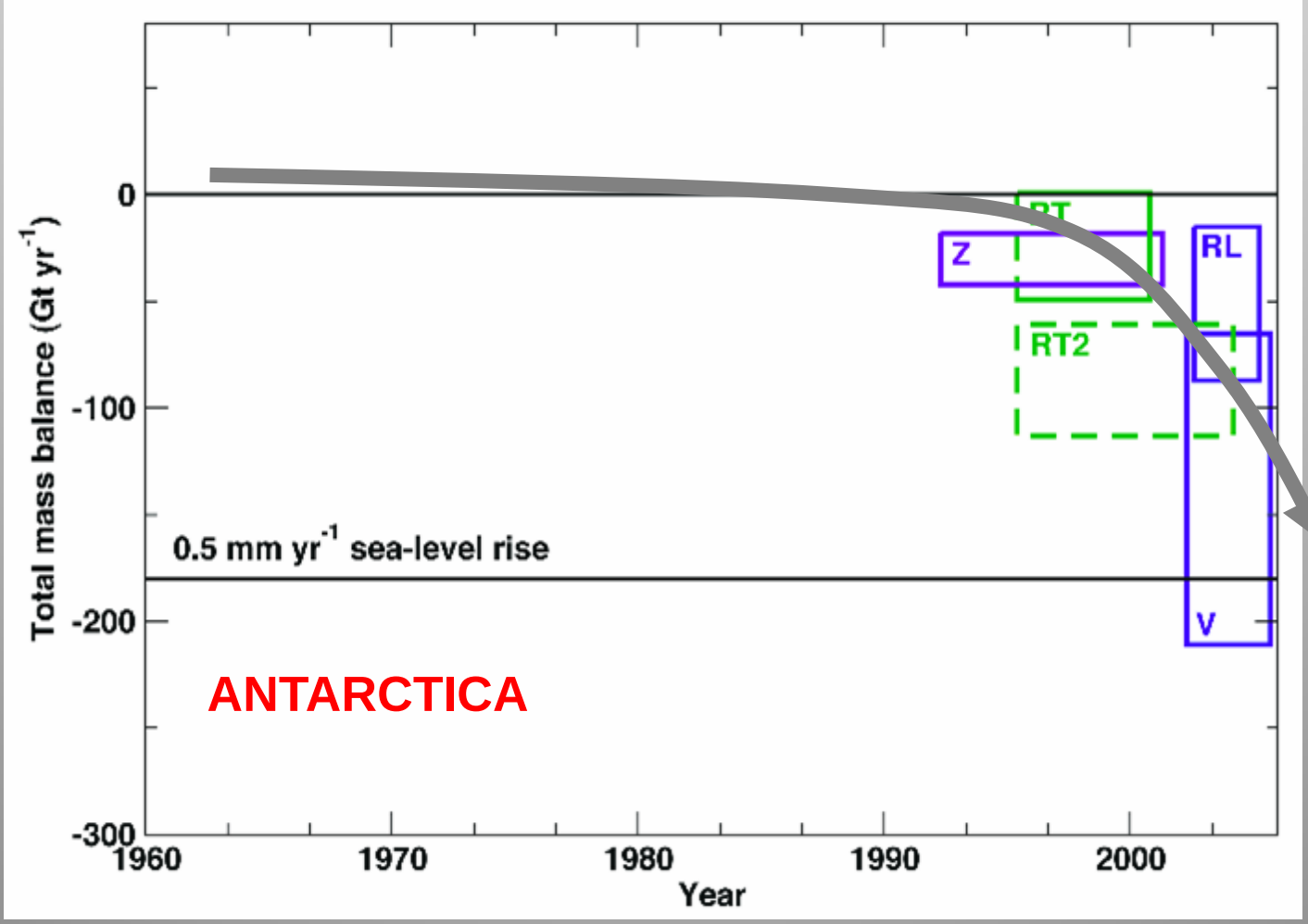
(Source: Luthcke et al., unpub.)

Greenland Ice Sheet Mass Balance



(Source: IPCC FAR)

Antarctic Ice Sheet Mass Balance



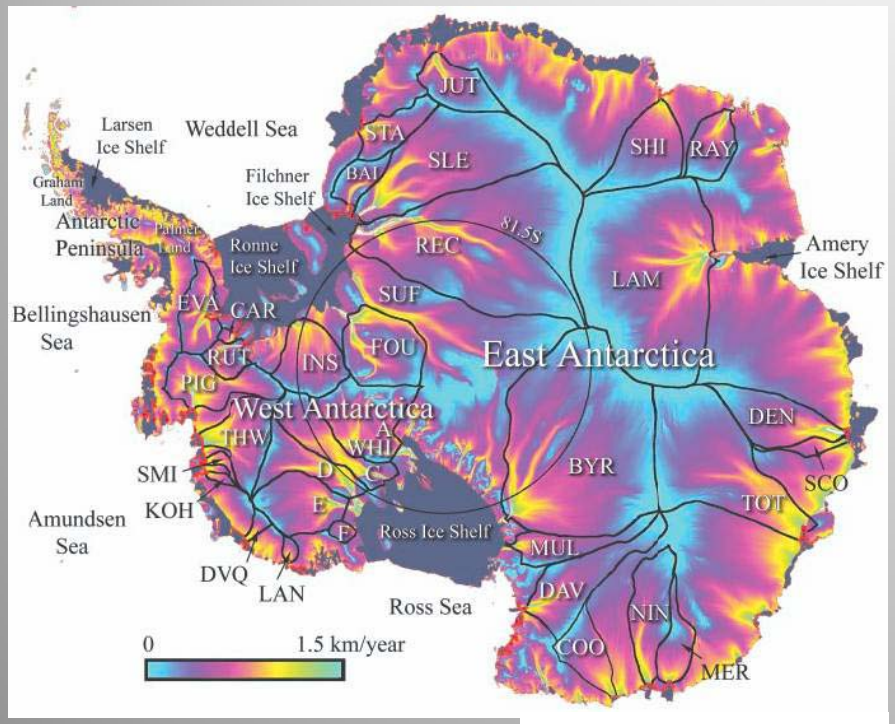
(Source: IPCC FAR)

Pace of ice sheet changes have astonished experts

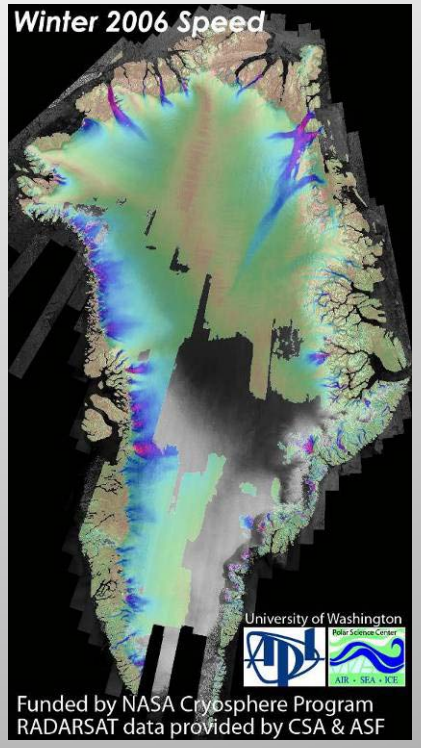
Water is the common agent behind these changes

Ice sheets HATE water!

Fastest Flow at the Edges



Source: Rignot and Thomas



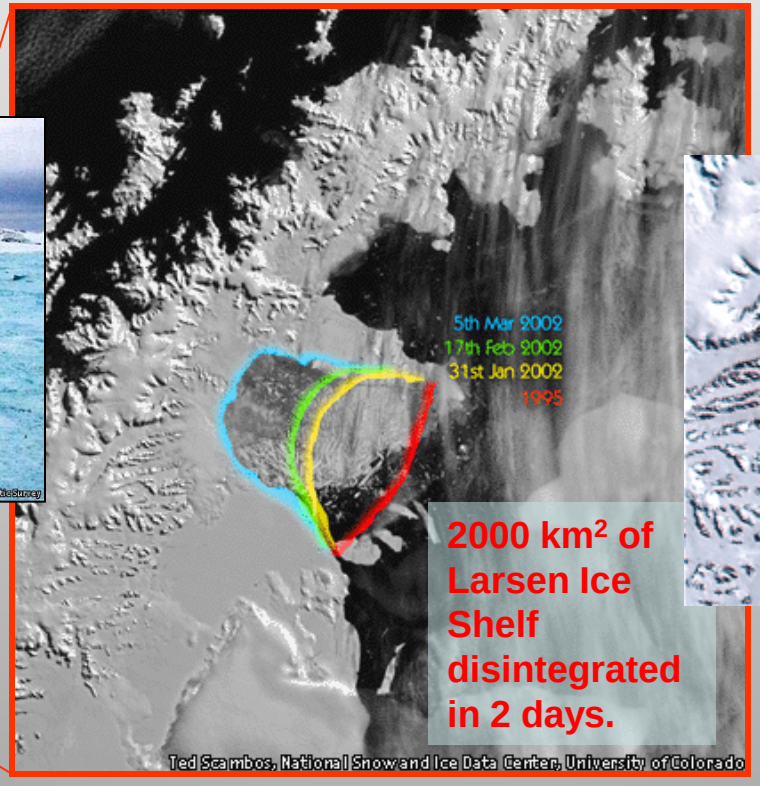
<u>Interior</u>: 1000's meters thick and slow

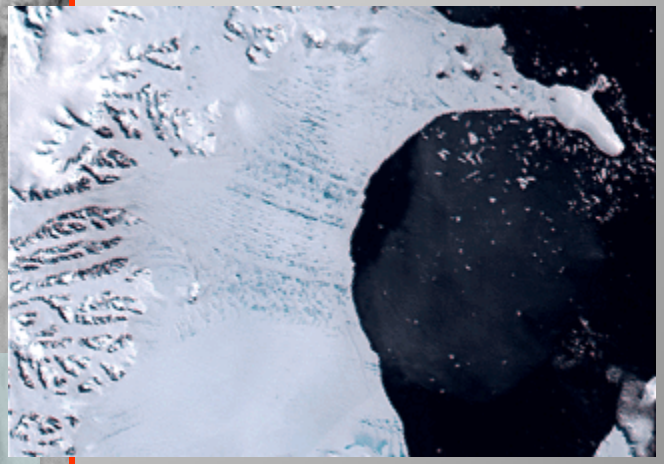
<u>Perimeter</u>: 100's meters thick and fast

Response time and speed of perturbation propagation are tied directly to ice flow speed

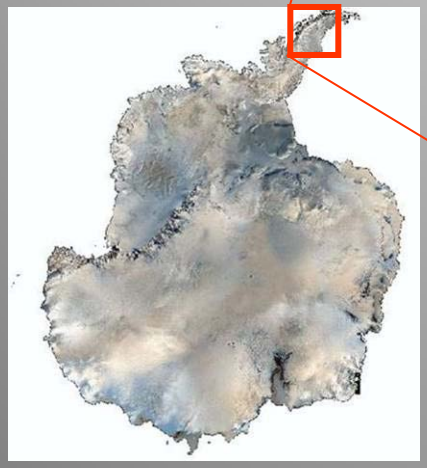
1. Disintegrating Ice Shelves

Since the mid-1980s



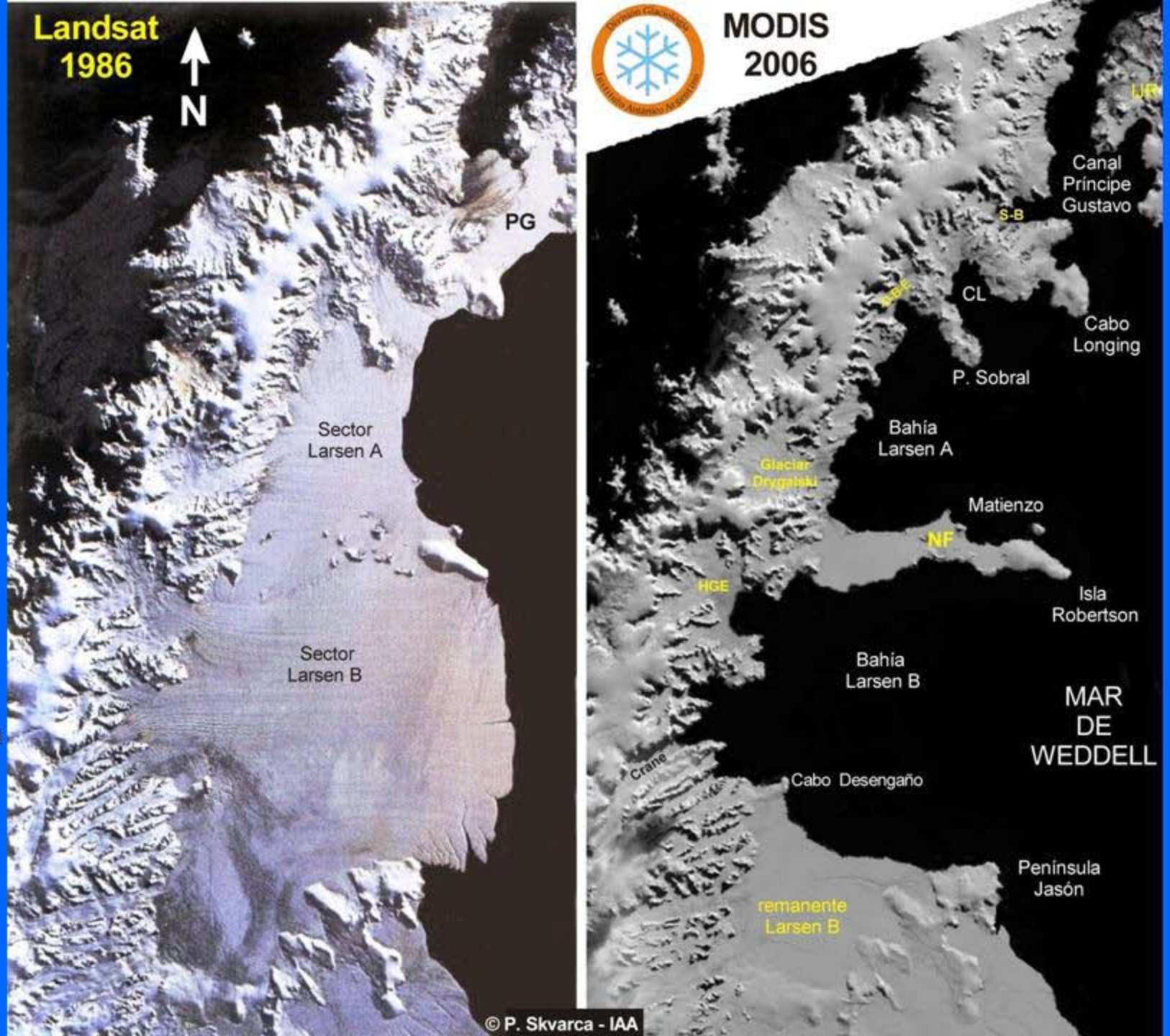


Source: T. Scambos

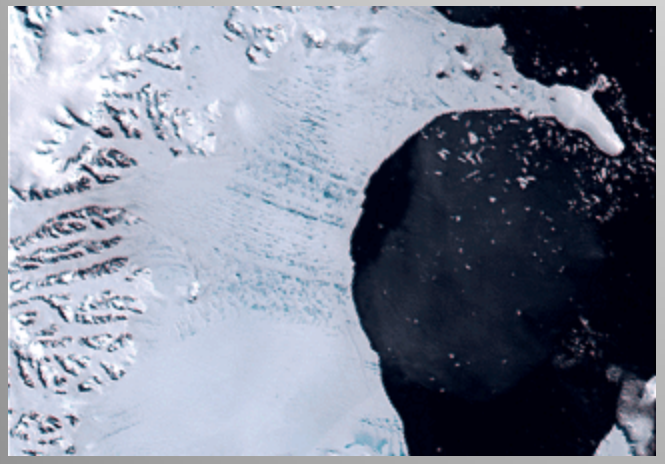


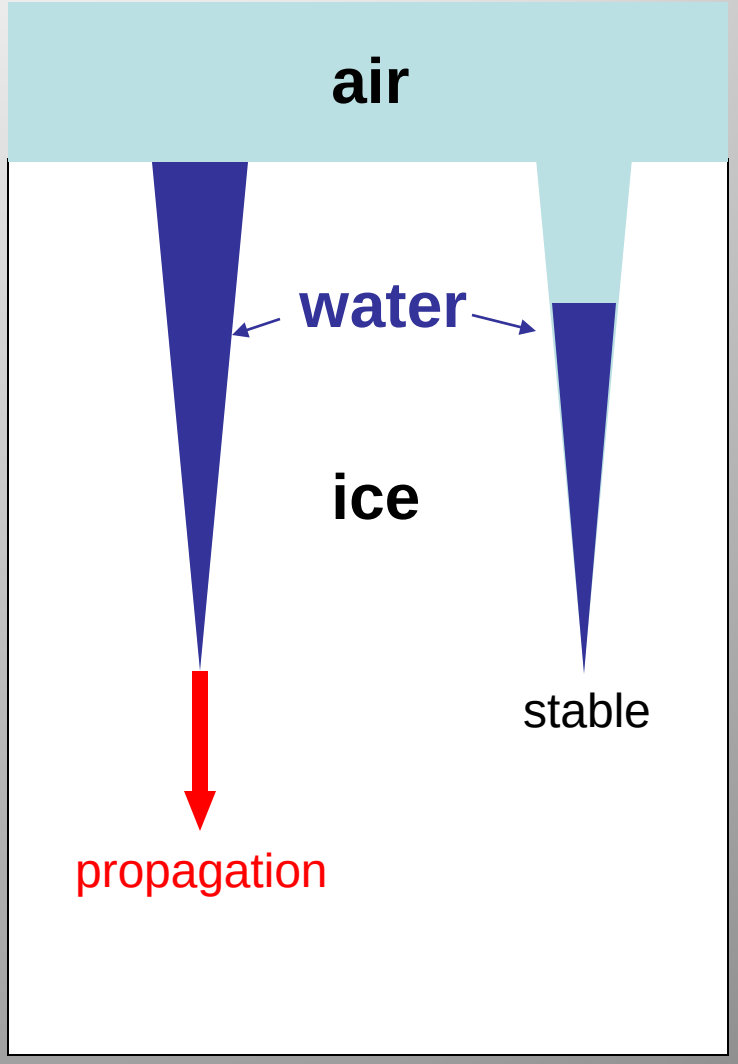
Require >10,000 years to form

Disintegrate in weeks

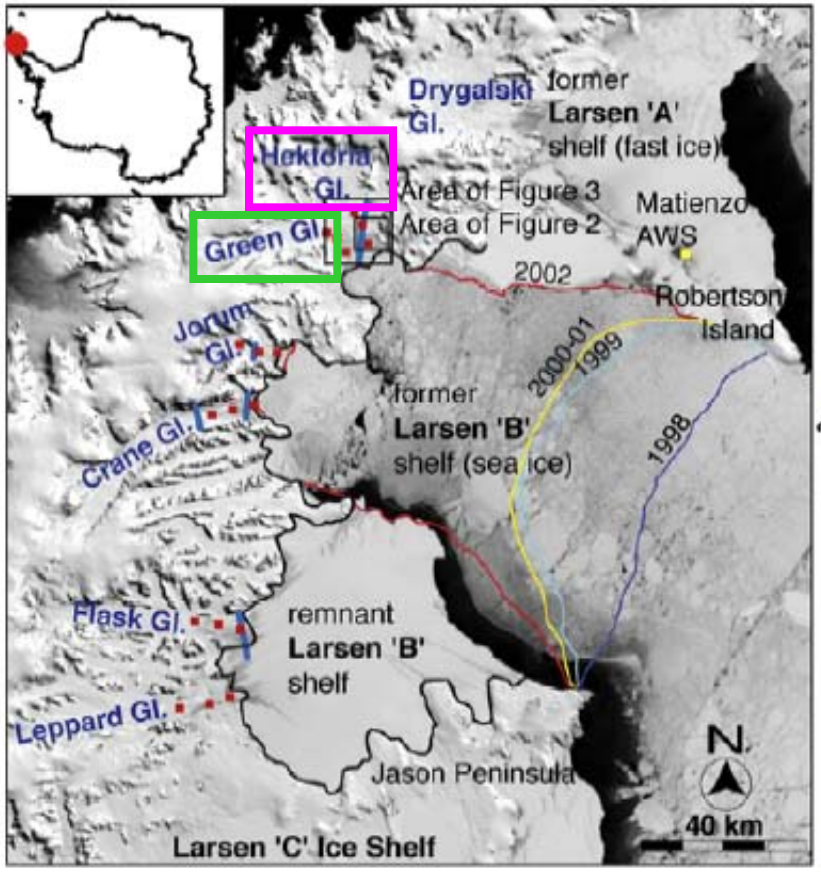

Landsat
1986
N
PG
Sector
Larsen A
Sector
Larsen B
100 km
MODIS
2006
Canal
Príncipe
Gustavo
S-B
CL
Cabo
Longing
P. Sobral
Bahía
Larsen A
Glaciar
Drygalski
Matienzo
NF
HGE
Isla
Robertson
Bahía
Larsen B
MAR
DE
WEDDELL
Crane
Cabo Desengaño
Península
Jasón
remanente
Larsen B
© P. Skvarca - IAA

Water as a Wedge

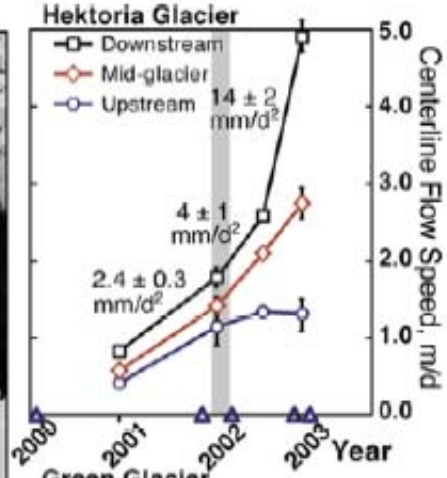




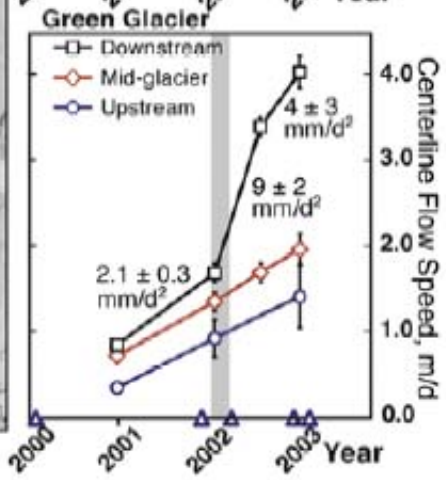
Consequence of Ice Shelf Loss



(Scambos et al., 2004)



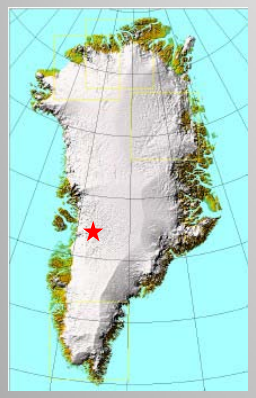
up to 510% faster in 2 years



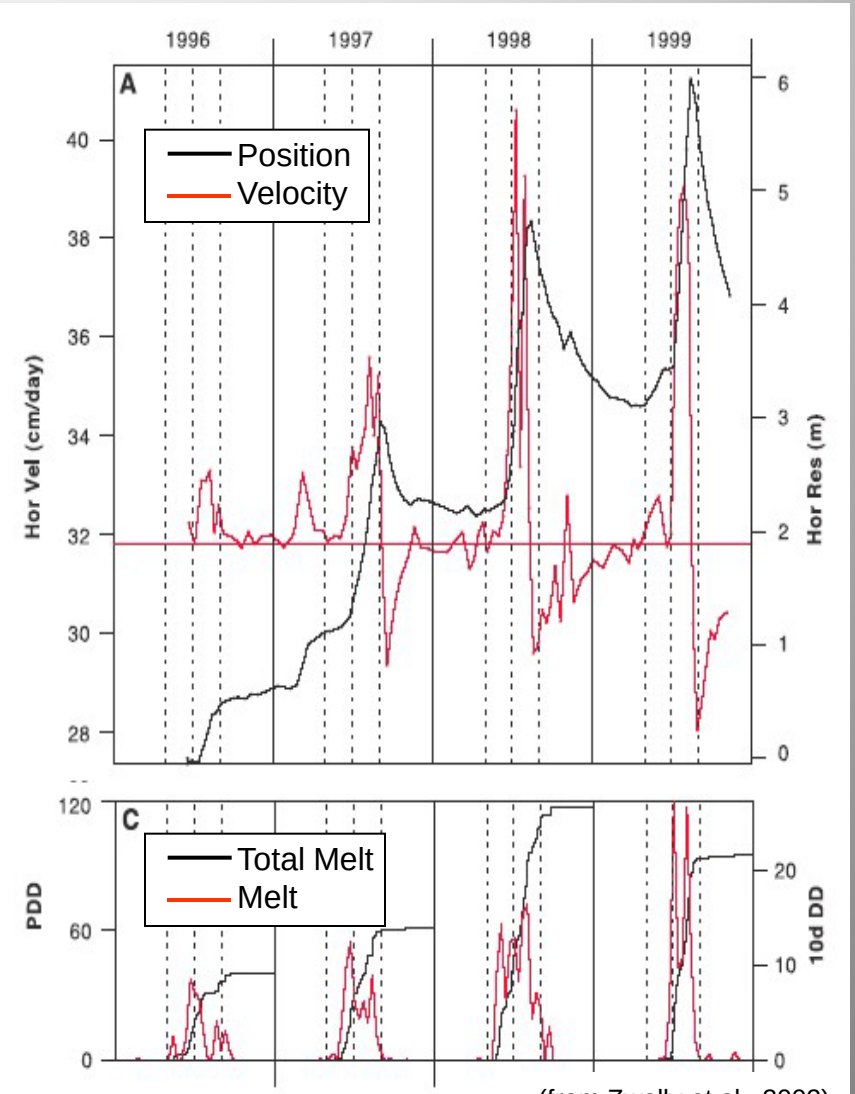
up to 400% faster in 2 years

Formerly buttressed glaciers accelerate

2. Summer acceleration of Greenland's margins



Water as a lubricant

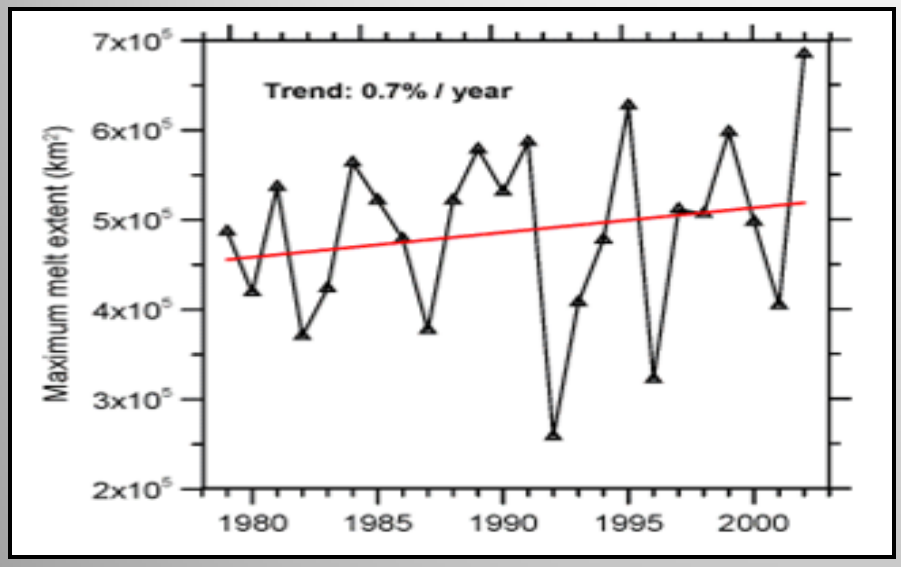


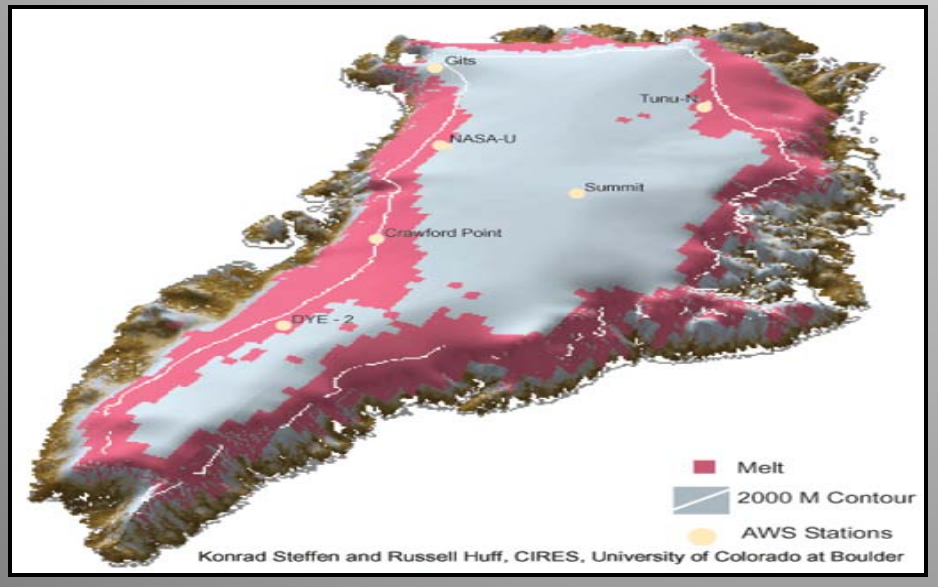
Glacier flow increases 10-15%
Slower ice increases up to 70%

(from Joughin et al., 2008)

(from Zwally et al., 2002)

Greenland melt extent is increasing

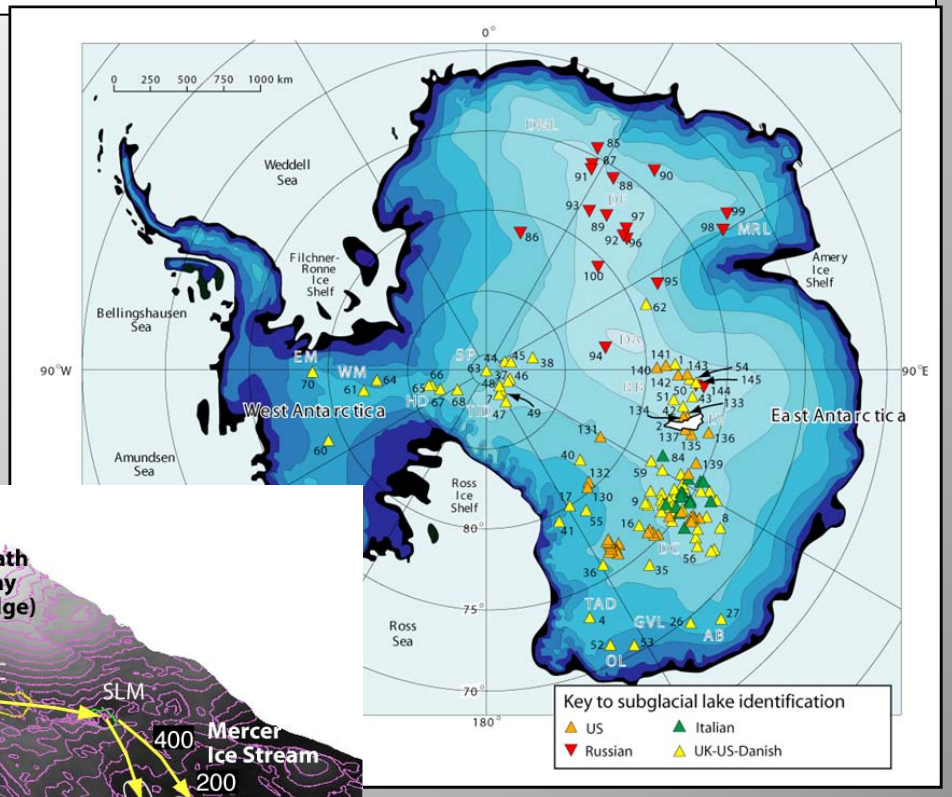


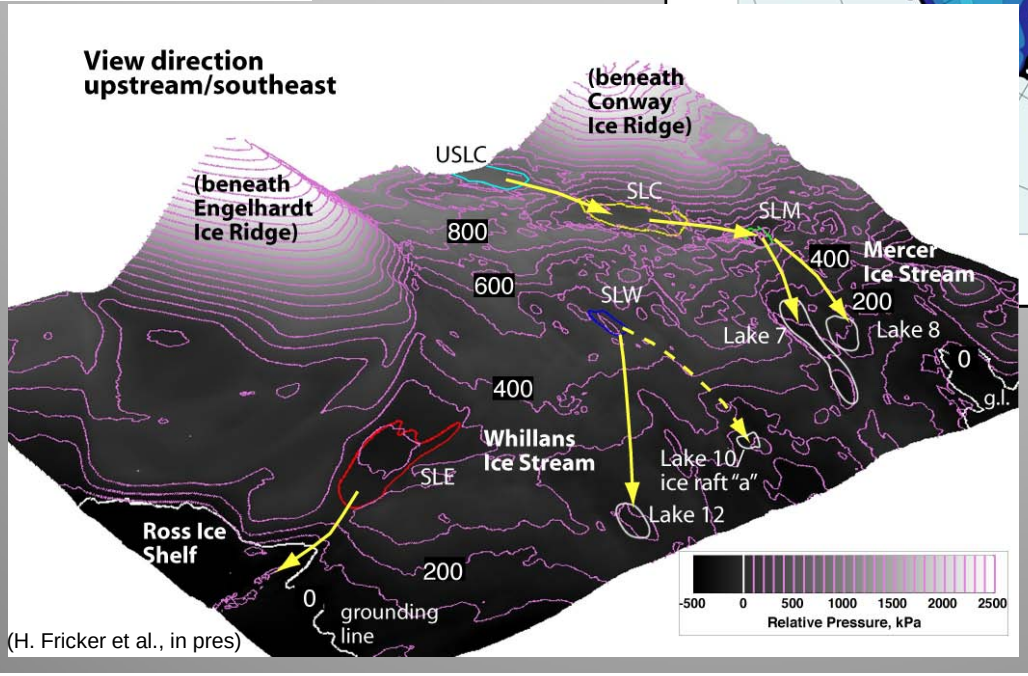


Flow increase is proportional to amount of melt

3. Subglacial Lakes

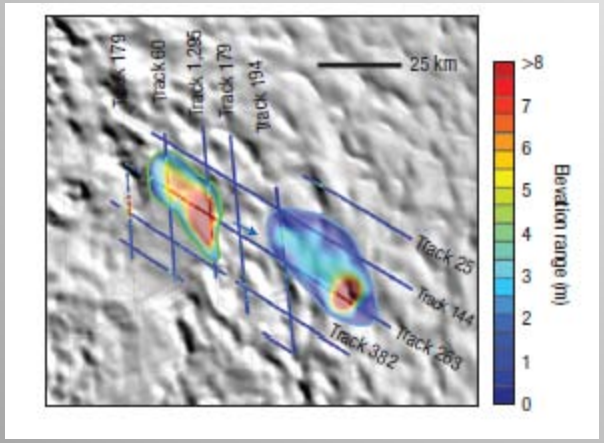
Subglacial hydropotential field beneath Whillans Ice Stream



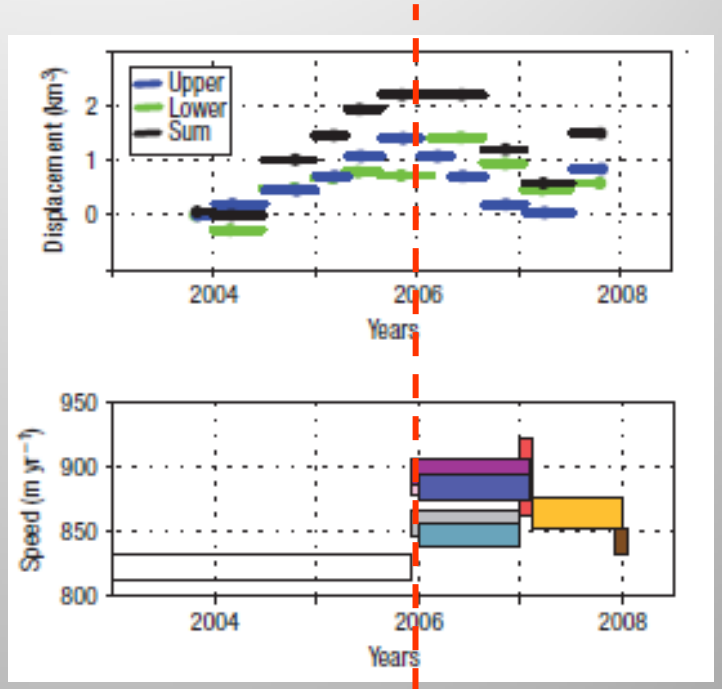


(H. Fricker et al., in pres)

Role in ice flow?



(Stearns et al., 2008)

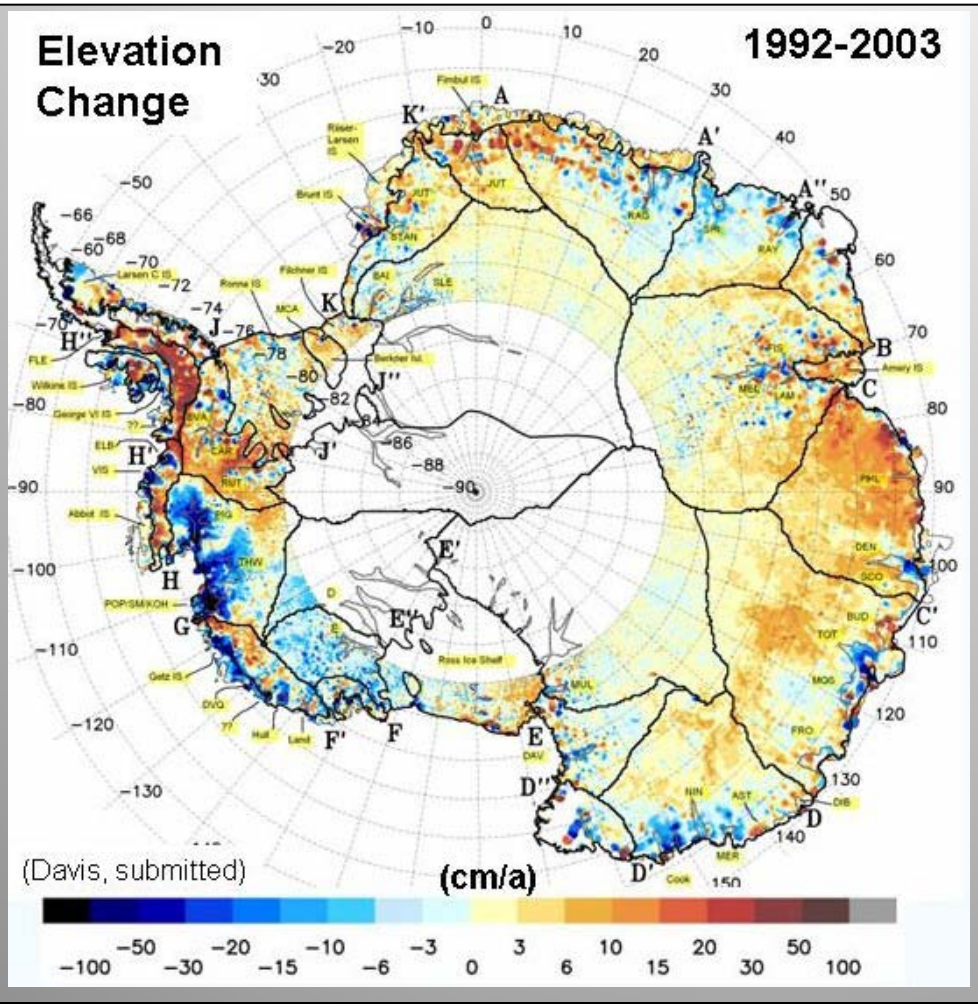


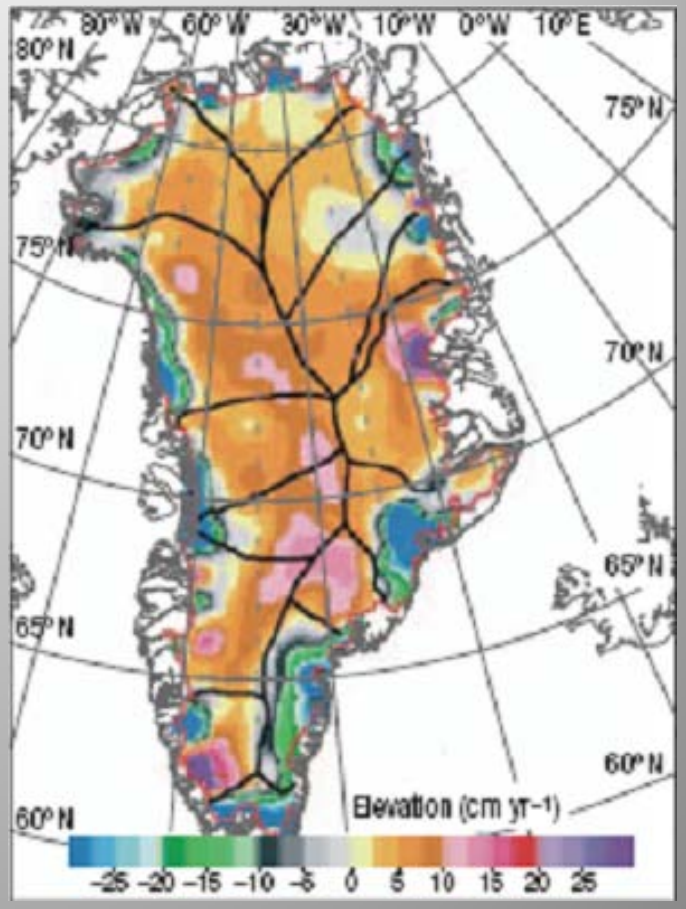
Lake Level

Speed

Lake drainage coincided with increase in ice flow speed

4. Thinning, Acceleration and Retreat at Ice-Sheet Margins

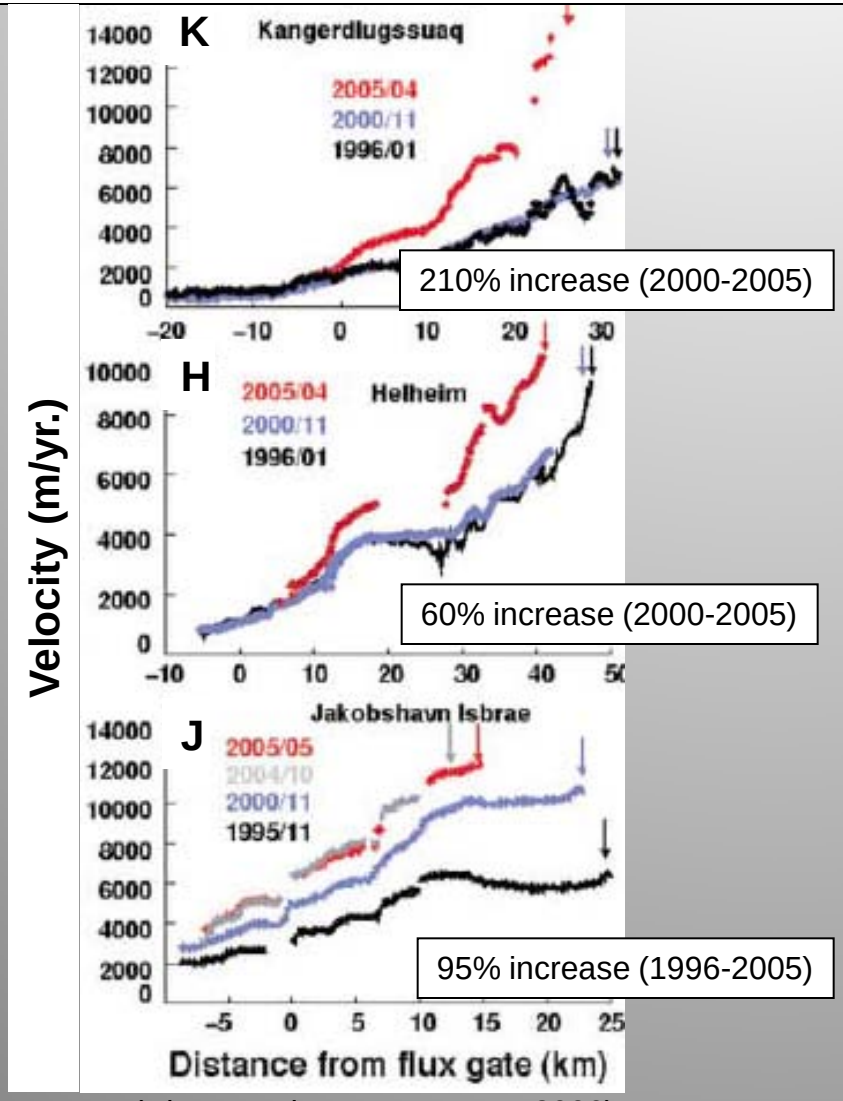




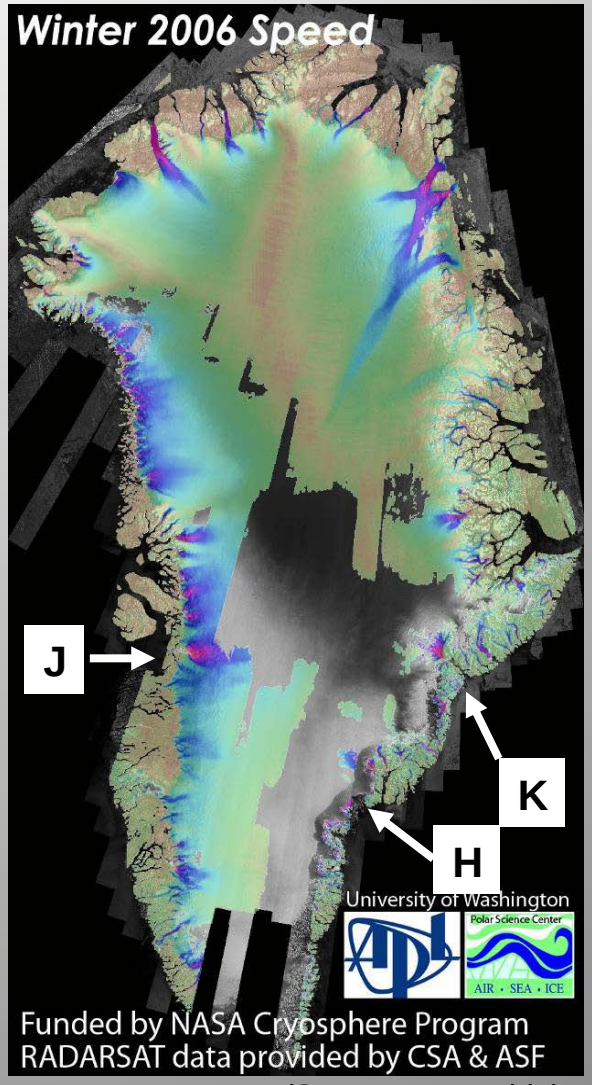
The deepest outlet glaciers exiting into the ocean are responding most.

Accelerating Outlet Glaciers

Since the mid-1990s



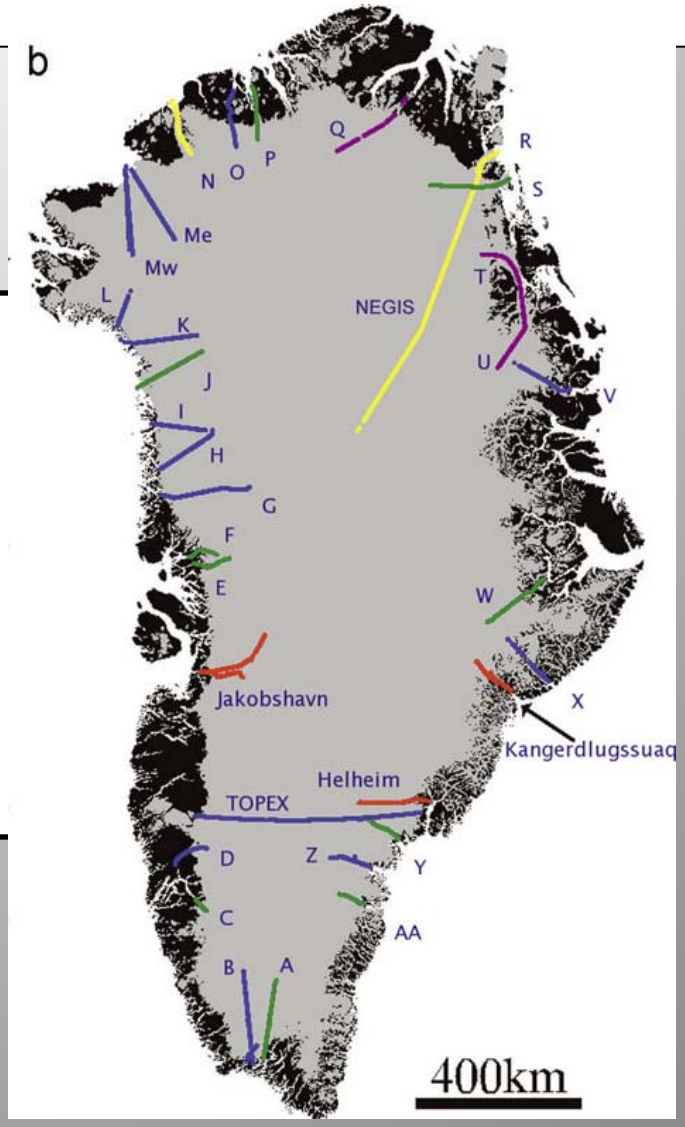
(Rignot and Kanagaratnam, 2006)



(Source: I. Joughin)

Variety of Responses

- Change within ΔSMB
- Change beyond ΔSMB
- Increasing change beyond ΔSMB
- Surge recovery
- not categorized



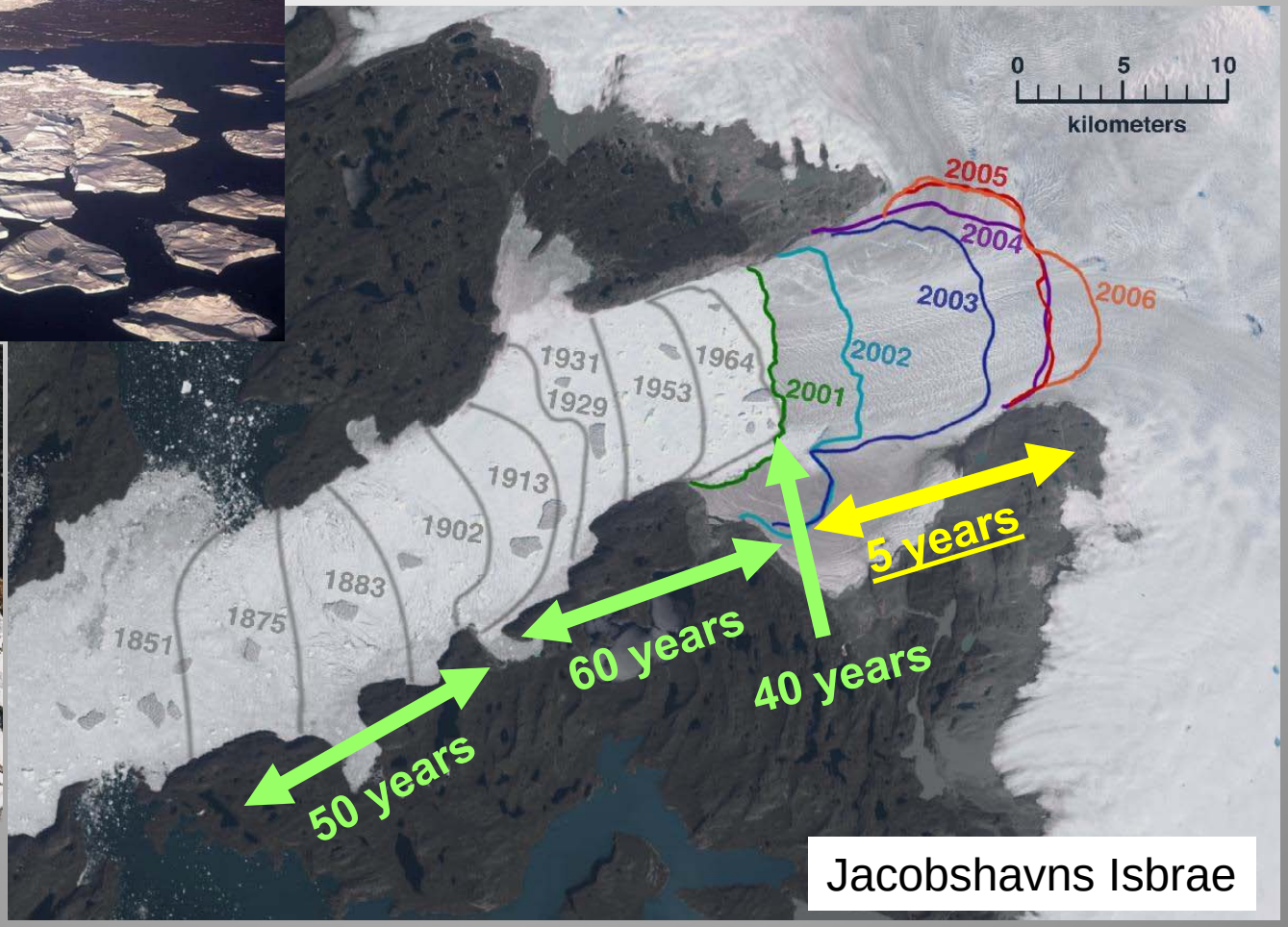
Thomas et al., 2009

Rapid Retreat

Since the mid 1980s

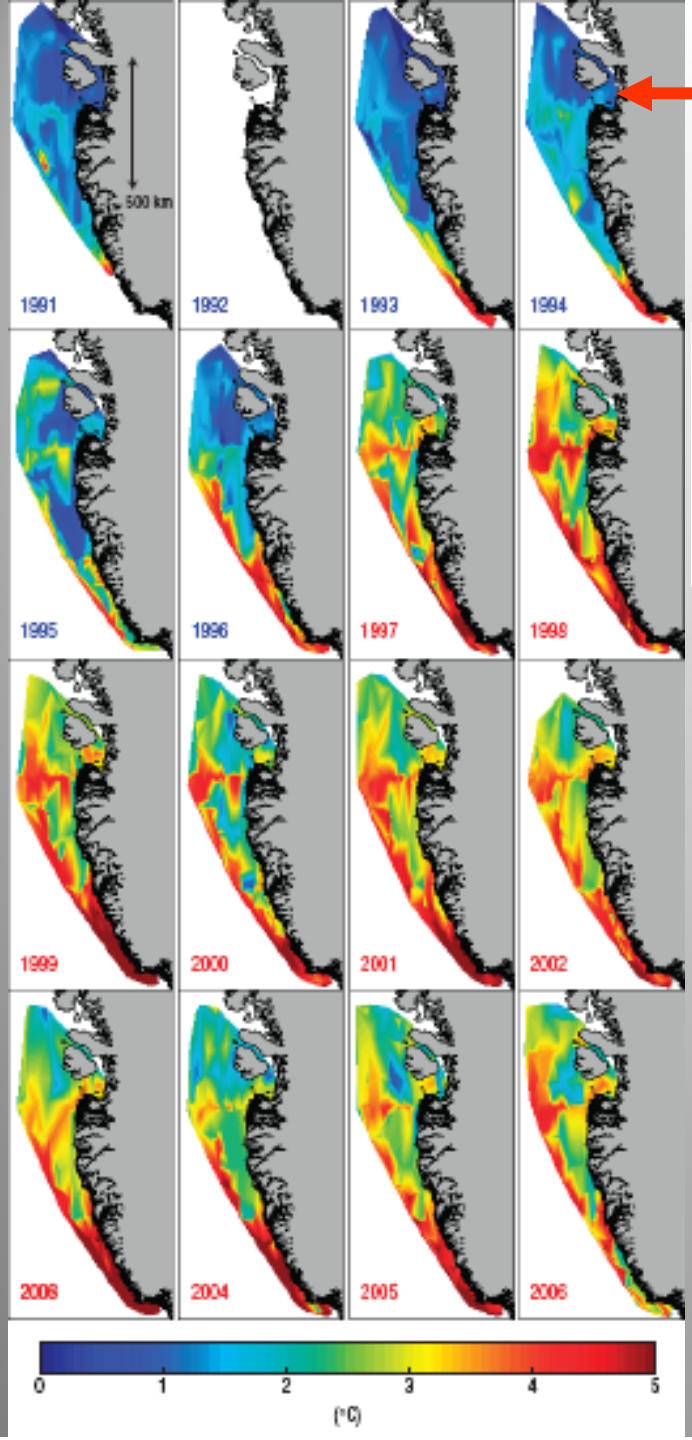
Jacobshavns Isbrae

Kangerdlugssuaq Glacier



Jacobshavns Isbrae

(Source: NASA)



Jakobshavns

Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters

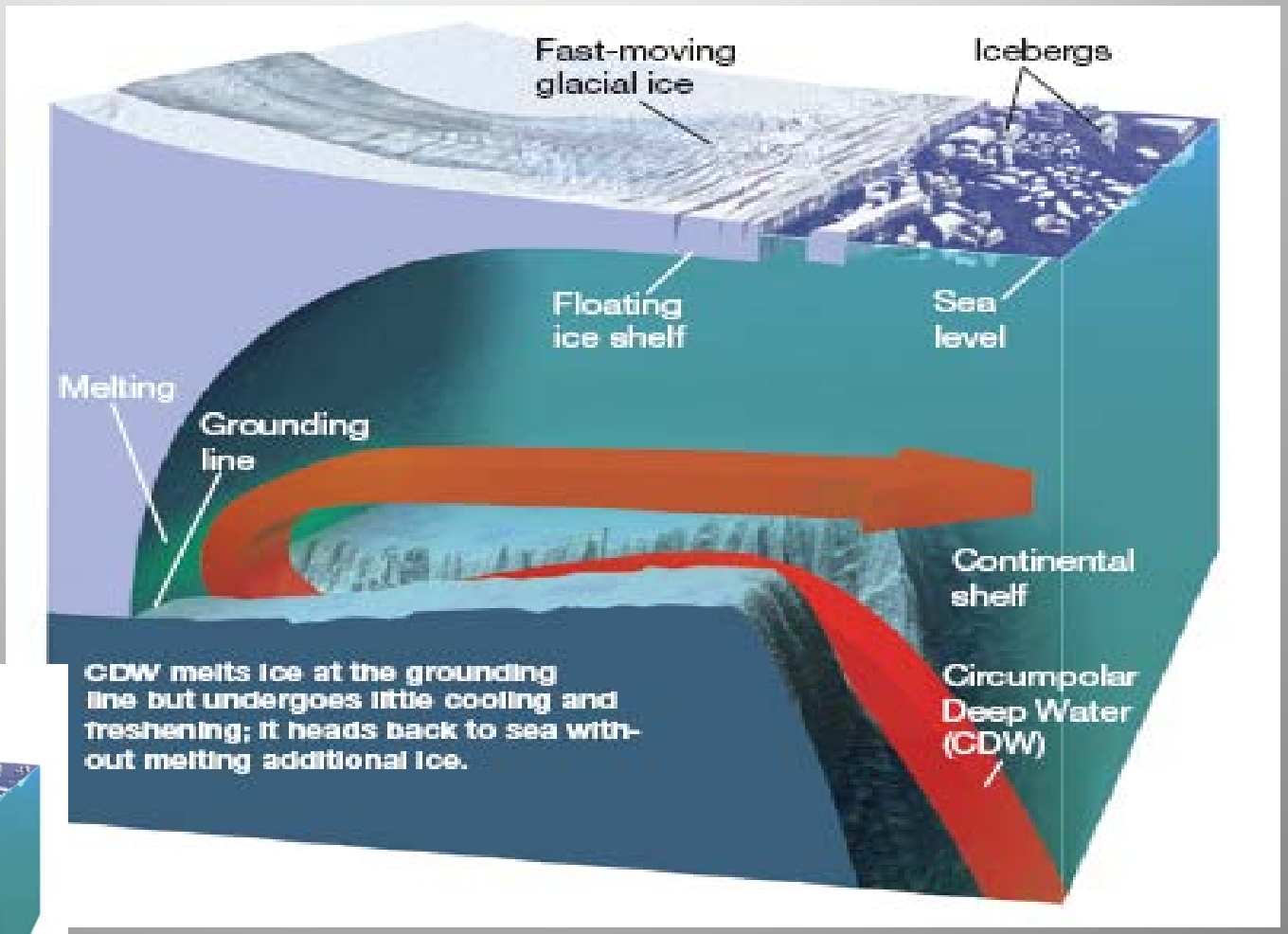
DAVID M. HOLLAND[1]*, ROBERT H. THOMAS[2], BRAD DE YOUNG[3], MADS H. RIBERGAARD[4] AND BJARNE LYBERTH[5]

nature geoscience | ADVANCE ONLINE PUBLICATION | www.nature.com/naturegeoscience

Published online: 28 September 2008; doi:10.1038/ngeo316

Figure 4 Subsurface ocean temperatures over the west Greenland continental shelf. Data were recorded by the trawl fisheries[6] (150–600 m depth-averaged) during the period 1991–2006. Wherever water depth is less than 150 m, the temperature (in °C) is interpolated from the nearest neighbour with water depth of 150 m, or deeper. Data for 1992 are missing. The survey region corresponds to the area outlined by the yellow trapezoid in Fig. 1a. Cold water years in Disko Bay are numbered in blue (1991–1996); warm water years in red (1997–2006). A jump in subsurface water temperature occurred in 1997, with warm waters flooding Disko Bay, and subsequently the Jakobshavn ocean fjord.

Antarctic Ocean-Ice Interaction



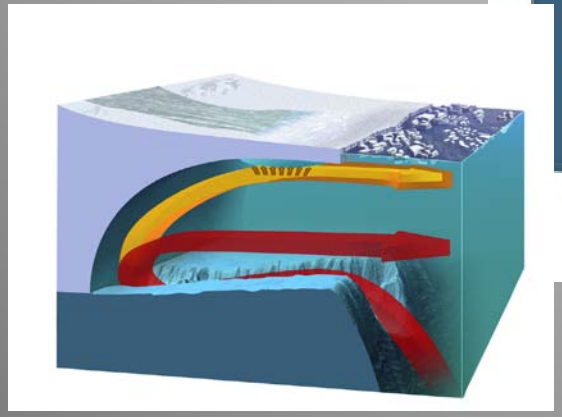
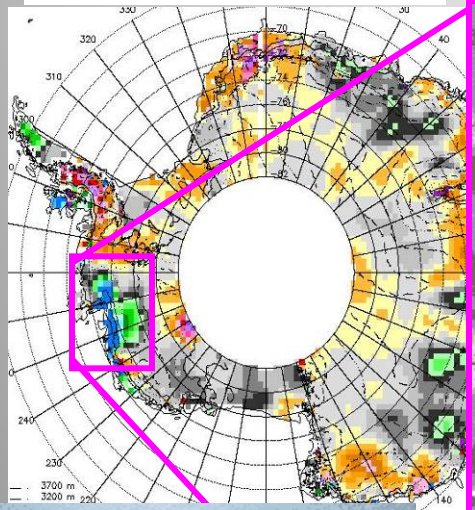


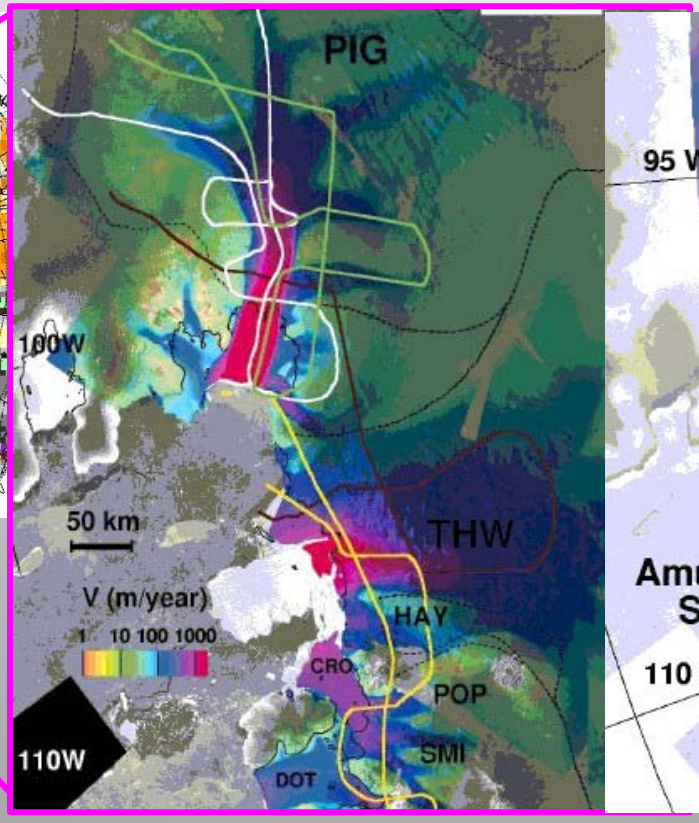
Illustration (c) Frank Ippolito

Focus on Amundsen Sea Sector

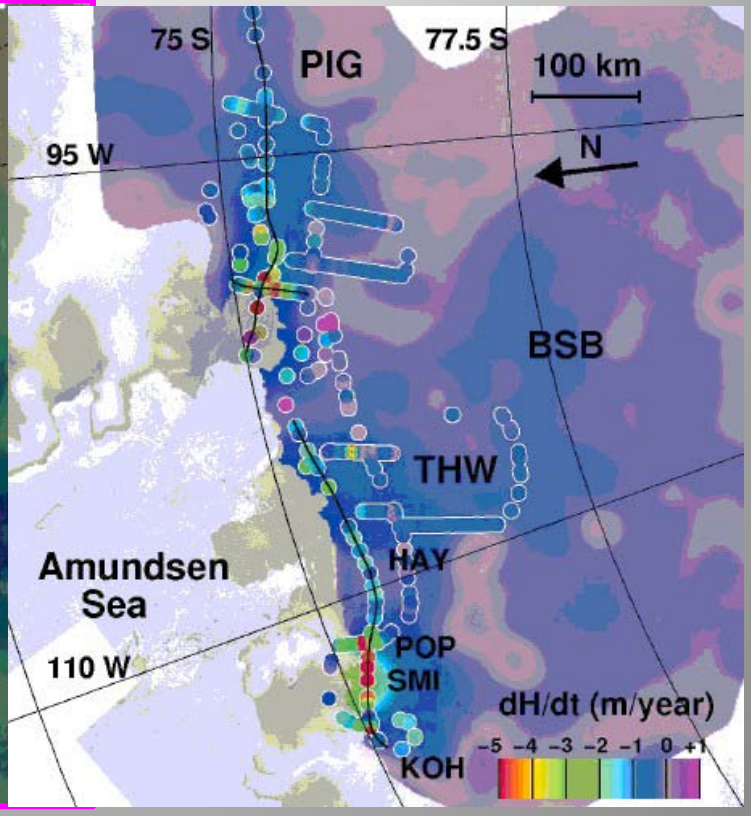
Elevation Change



Velocity

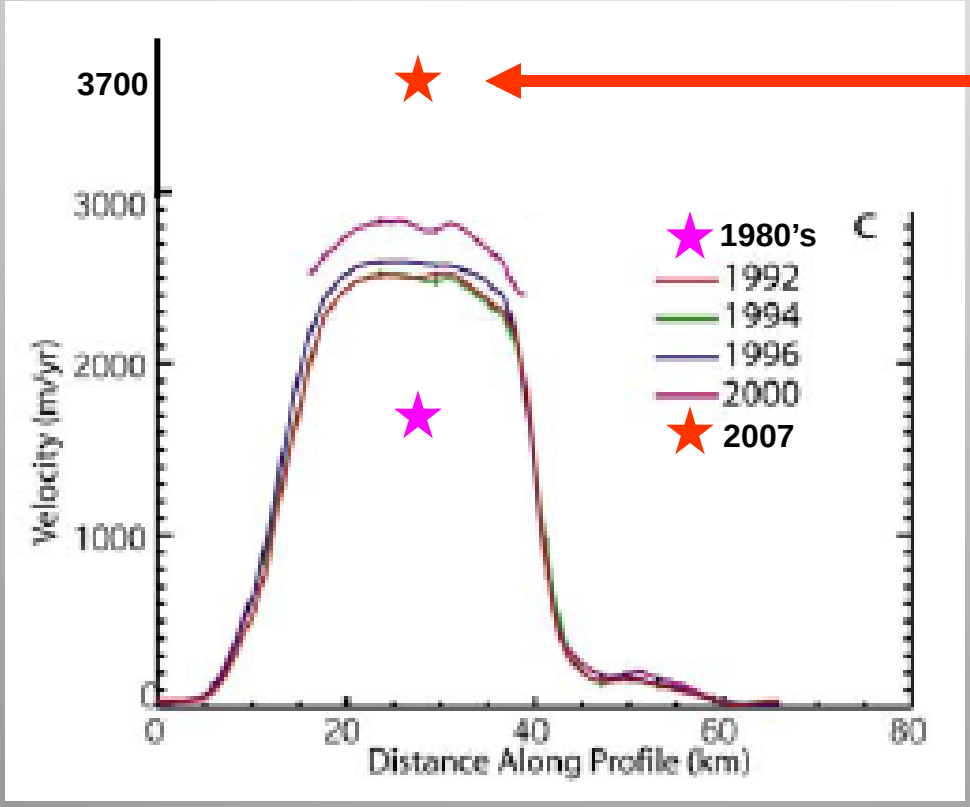


Change in Elevation Change



Pine Island, Thwaites and Smith Glaciers exhibit expected signs of collapsing:

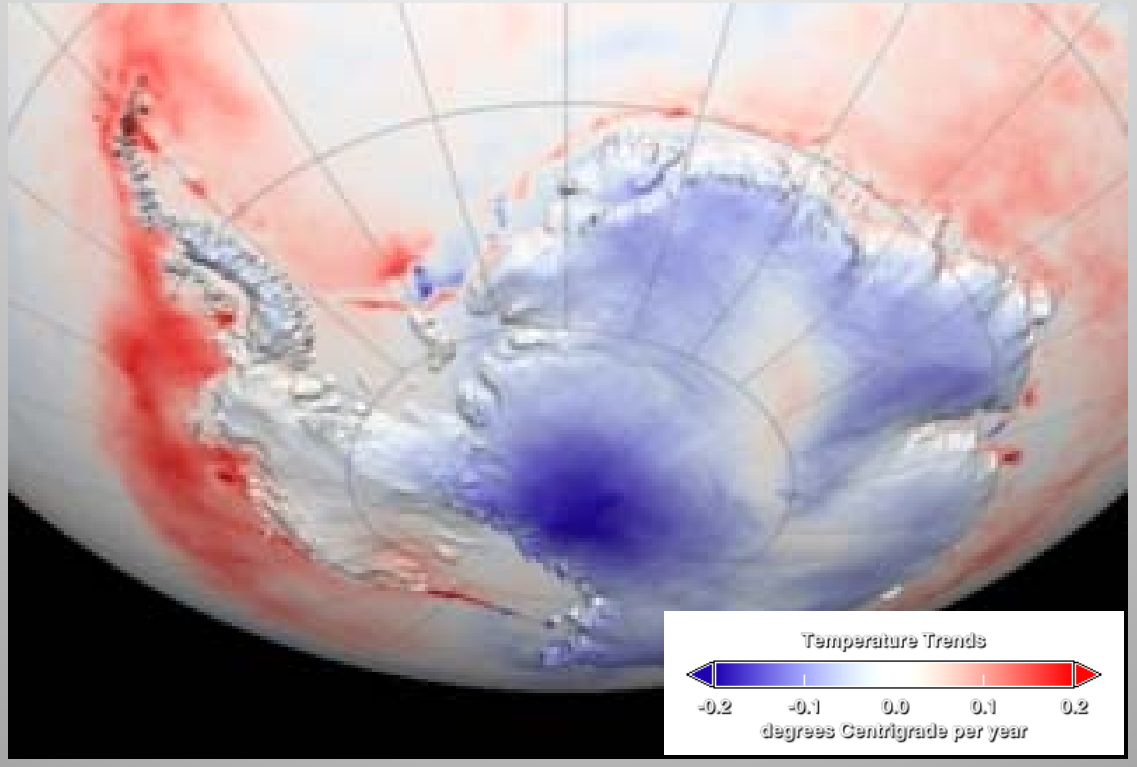
Pine Island Glacier Acceleration



Now moving >one foot per hour!!

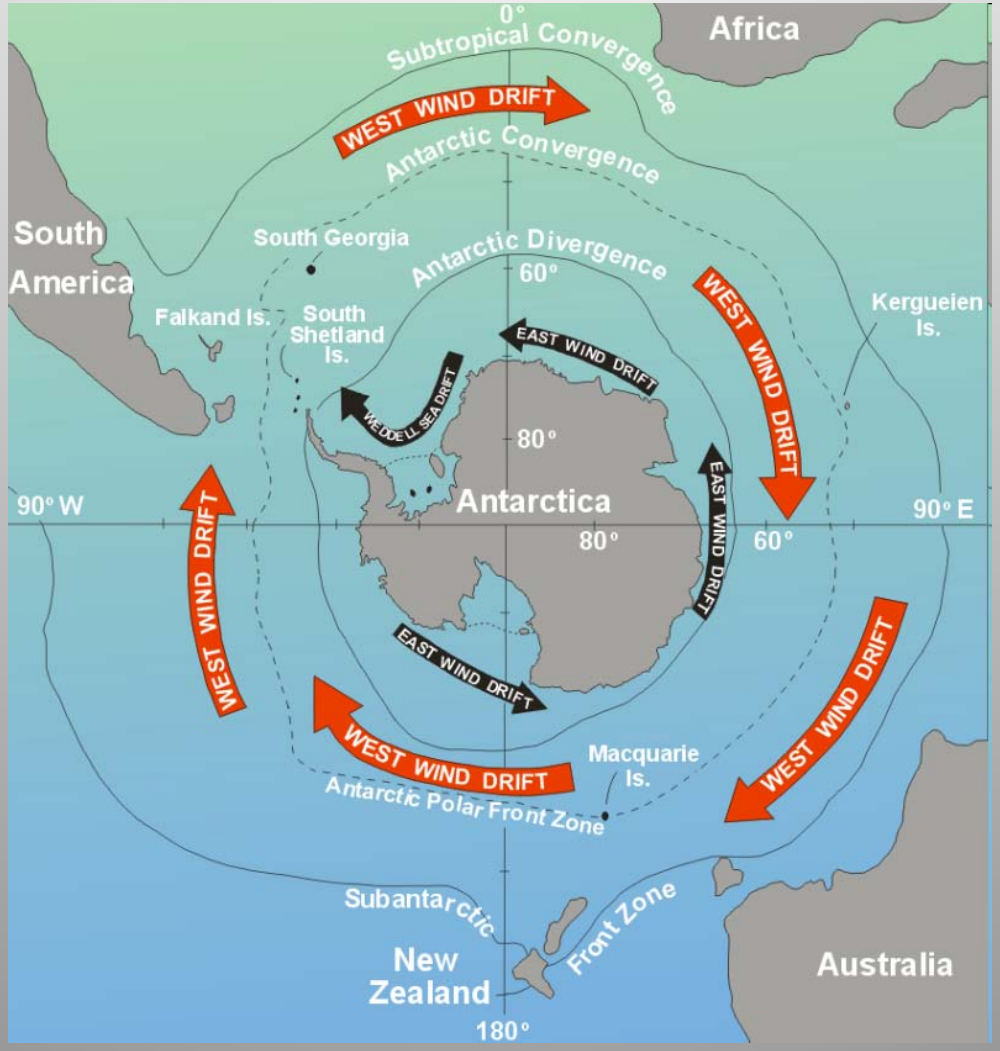
adapted from Joughin et al., 2003

Start in the Atmosphere

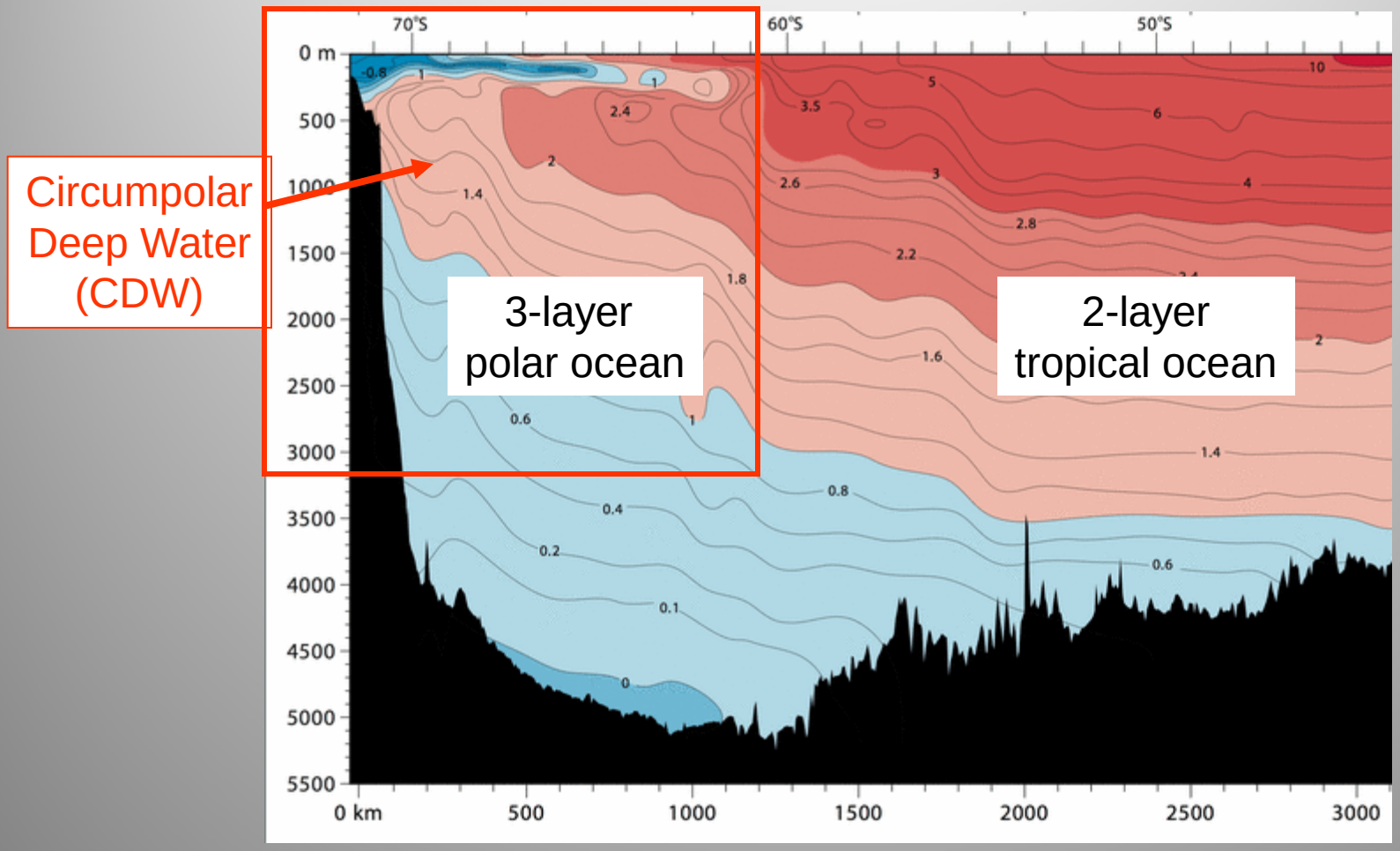


Increased temperature gradient increases circumpolar winds

Now Some Oceanography

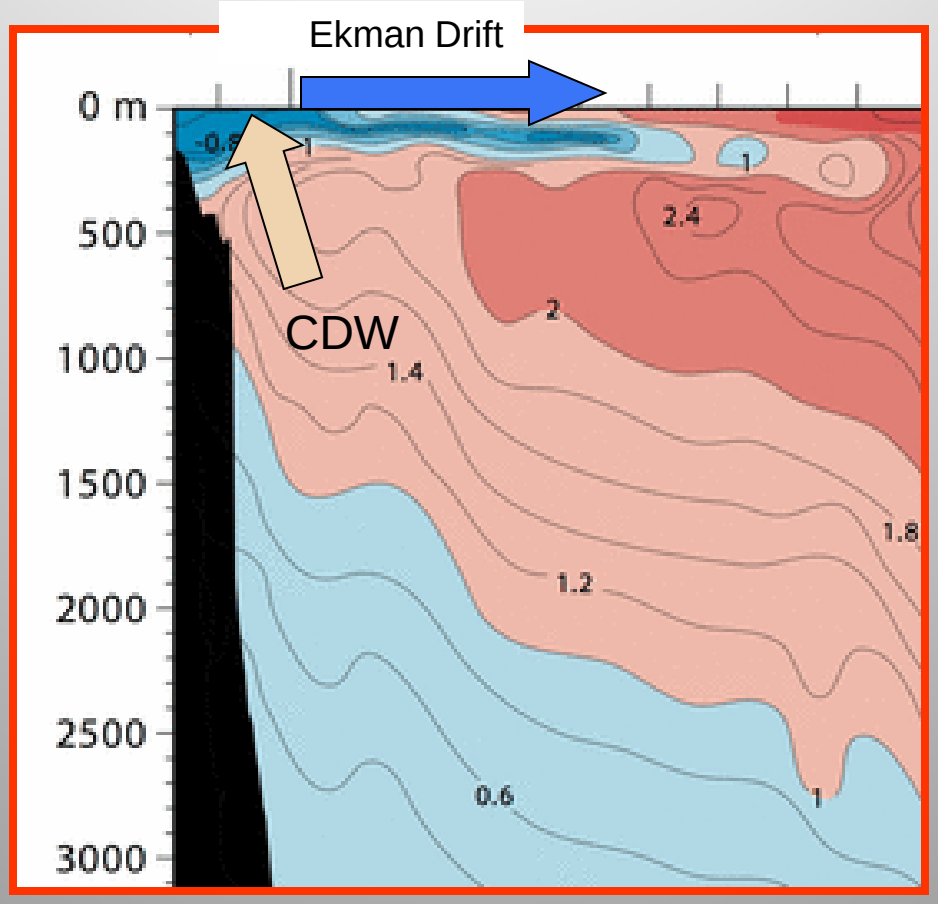


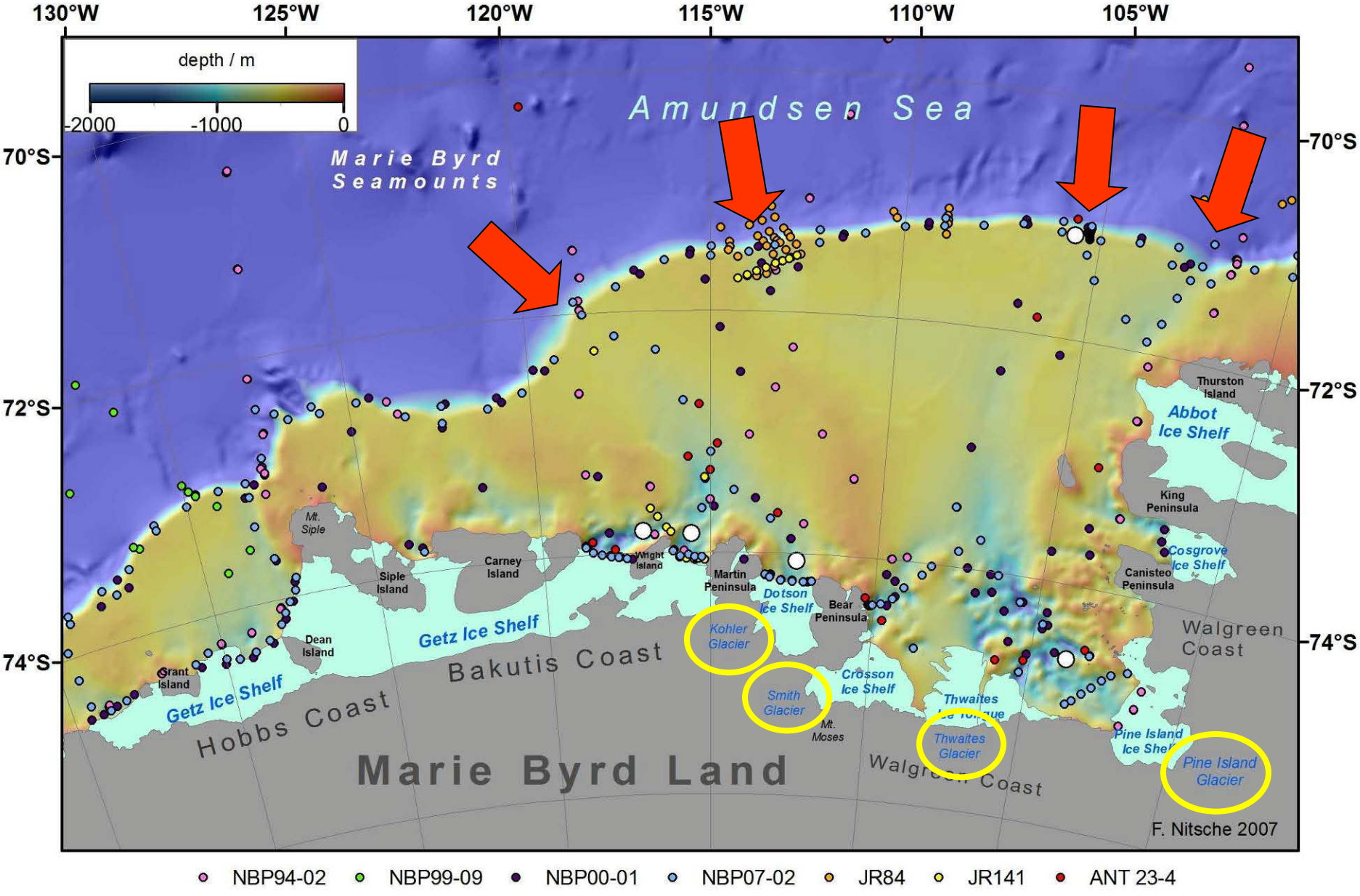
Some More Oceanography



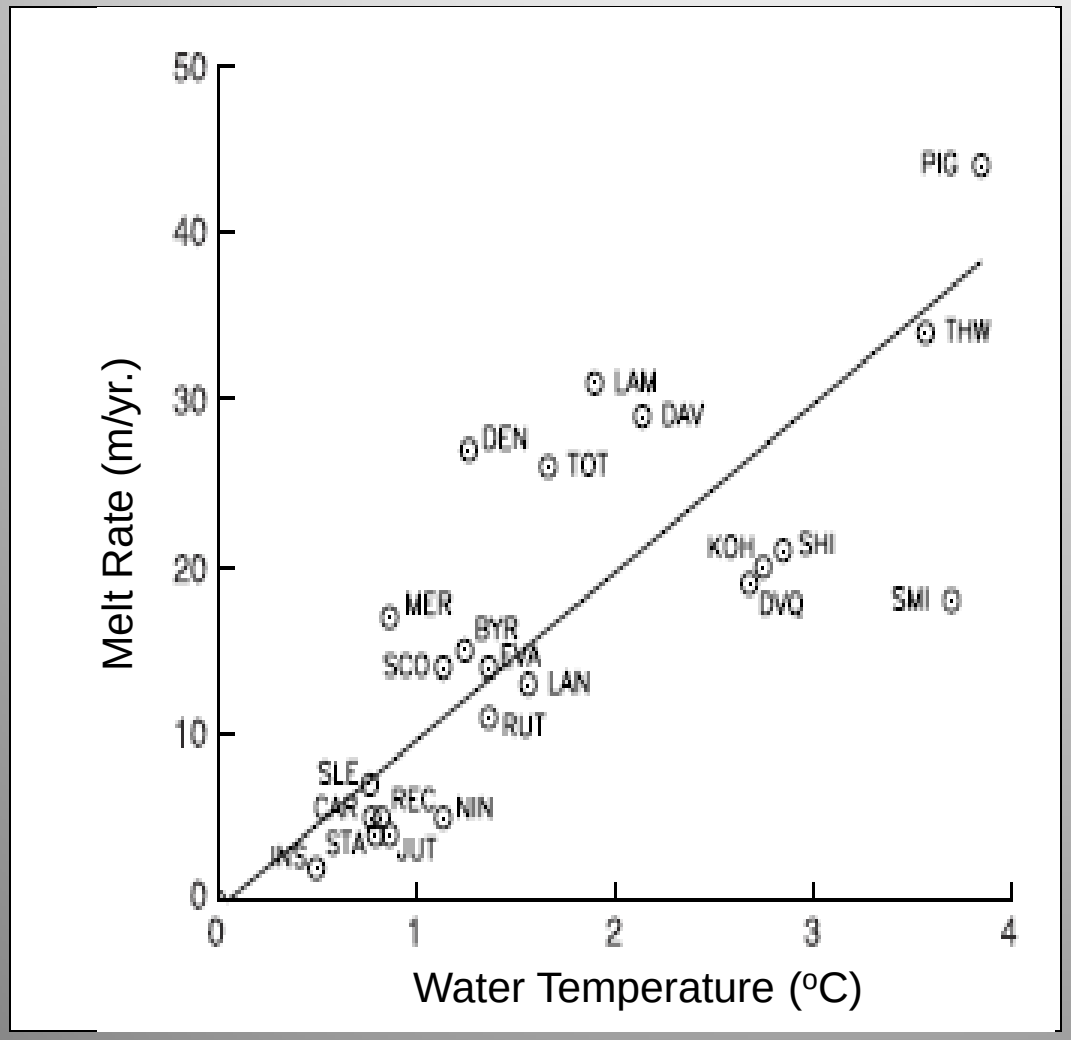
Source: S. Jacobs

Upwelling of CDW




130°W
125°W
120°W
115°W
110°W
105°W
70°S
72°S
74°S
depth / m
-2000
-1000
0
Amundsen Sea
Marie Byrd Seamounts
Thurston Island
Abbot Ice Shelf
King Peninsula
Cosgrove Ice Shelf
Canisteo Peninsula
Walgreen Coast
Mt. Siple
Siple Island
Carney Island
Wright Island
Martin Peninsula
Dotson Ice Shelf
Bear Peninsula
Kohler Glacier
Smith Glacier
Mt. Moses
Crosson Ice Shelf
Thwaites Ice Tongue
Thwaites Glacier
Pine Island Ice Shelf
Pine Island Glacier
Dean Island
Grant Island
Getz Ice Shelf
Bakutis Coast
Hobbs Coast
Marie Byrd Land
Walgreen Coast
F. Nitsche 2007
NBP94-02
NBP99-09
NBP00-01
NBP07-02
JR84
JR141
ANT 23-4

Thermal Sensitivity of Ice Shelves



Small water temperature increase causes large melt rate increase

(Rignot and Jacobs, 2002)

Have we already seen the future?

Muir Glacier, Alaska

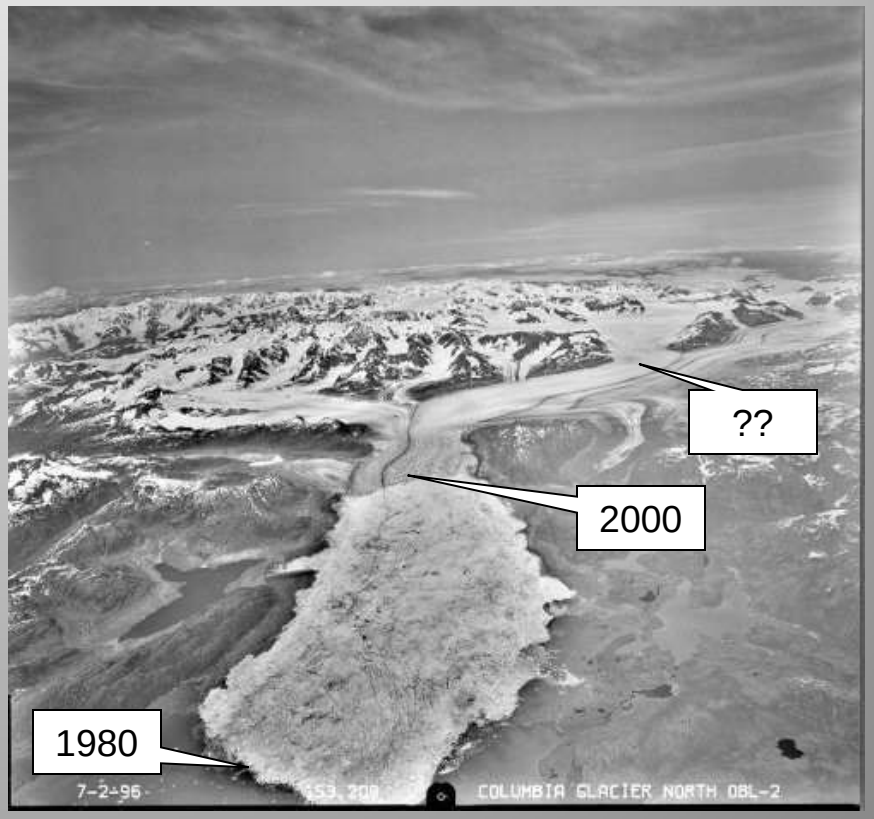
Tidewater glaciers are a good analogue to margins of modern ice sheets

Large outlet glaciers are displaying classic “drastic retreat” traits similar to Alaskan tidewater glaciers

Helheim Glacier, Greenland

2007 image (GoogleEarth)

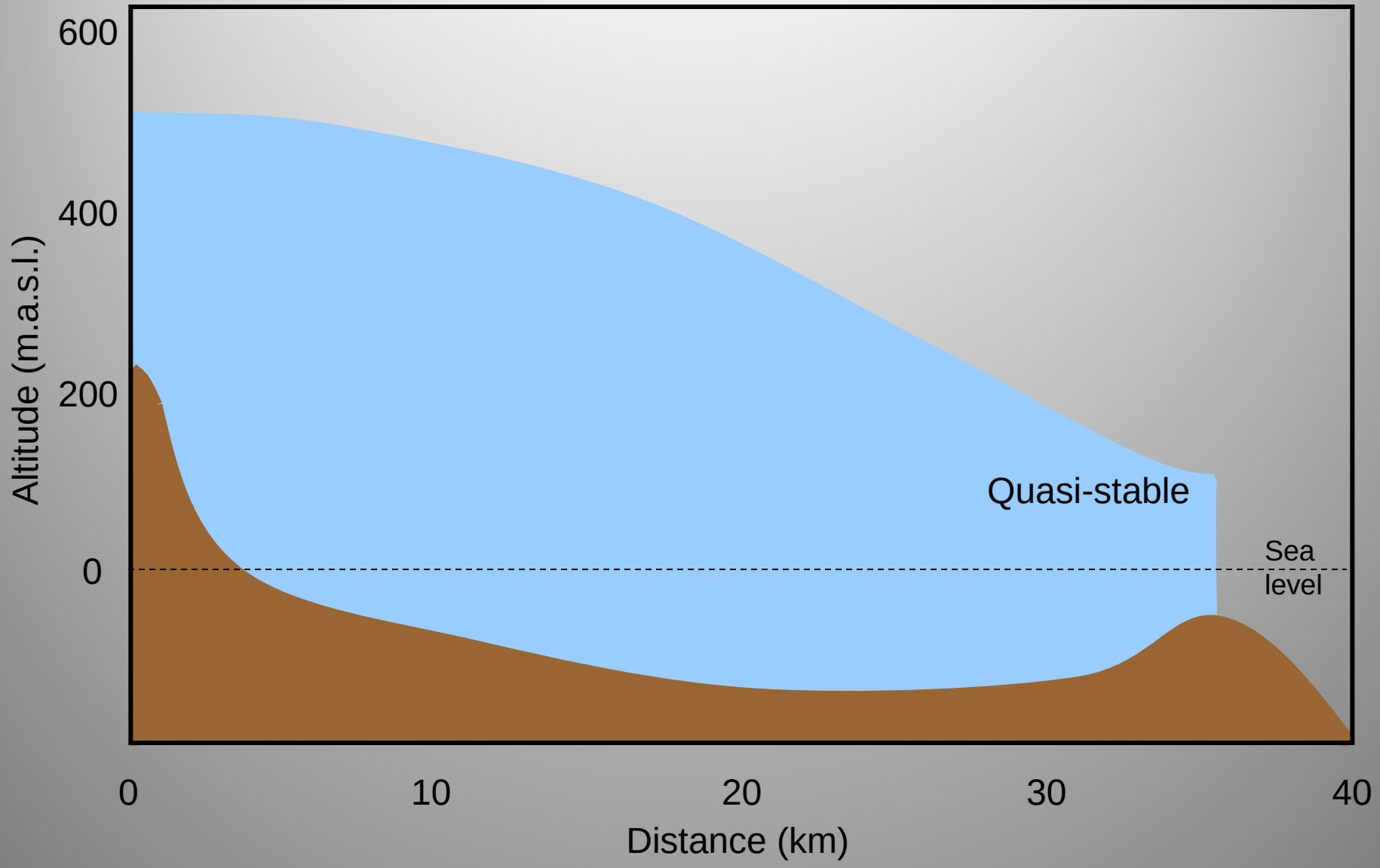
Columbia Glacier, Alaska



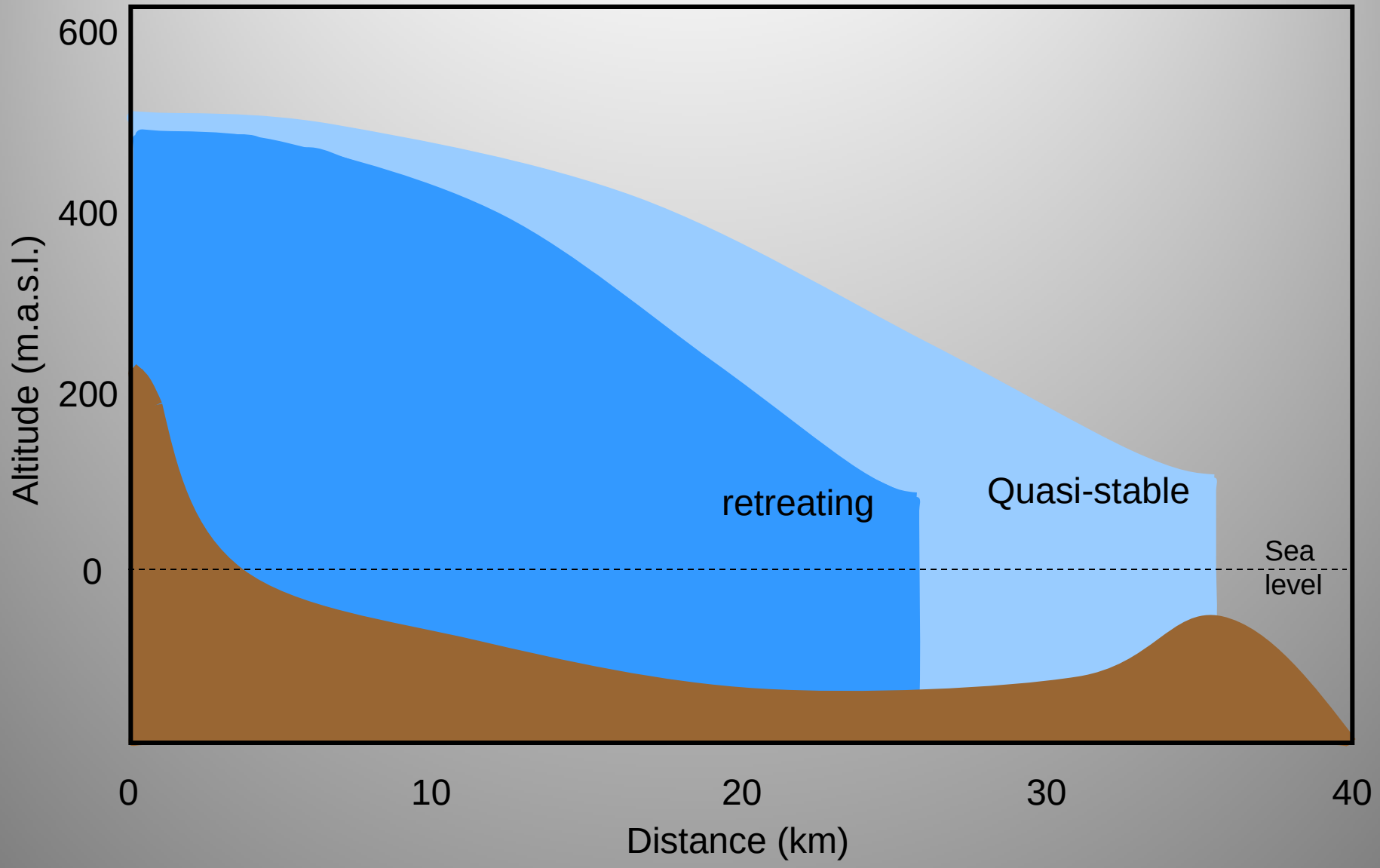
Source: USGS

1996 aerial photograph

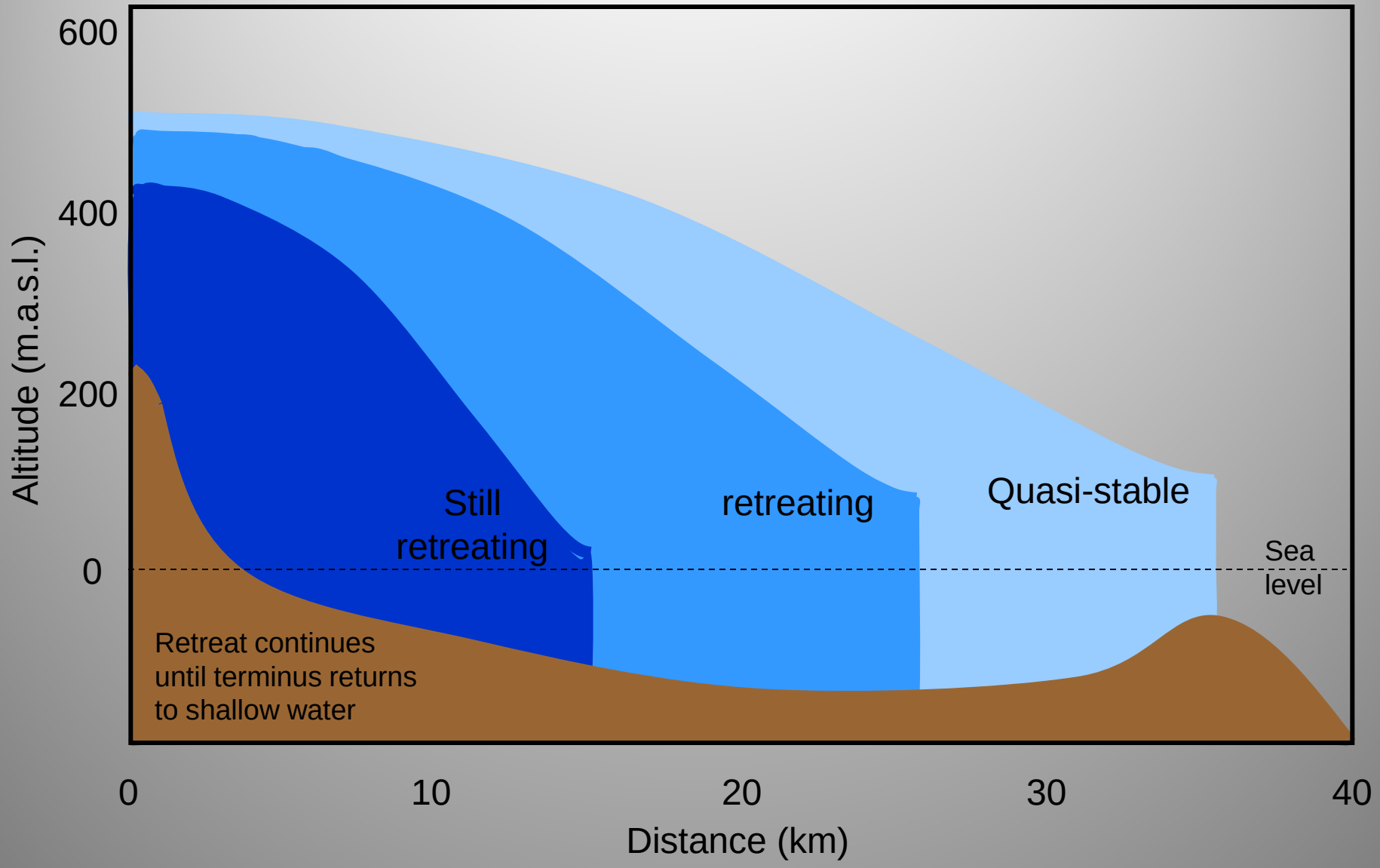
Tidewater Glacier “Drastic Retreat”



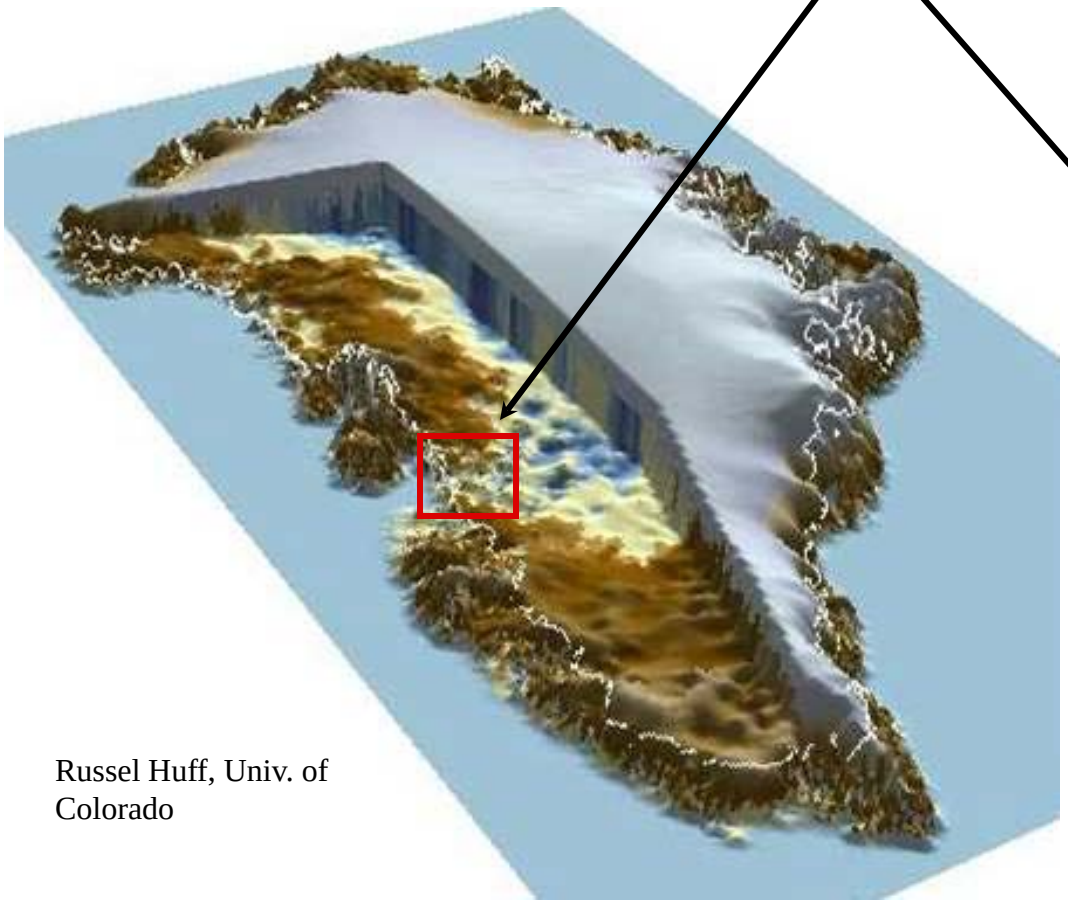
Tidewater Glacier “Drastic Retreat”

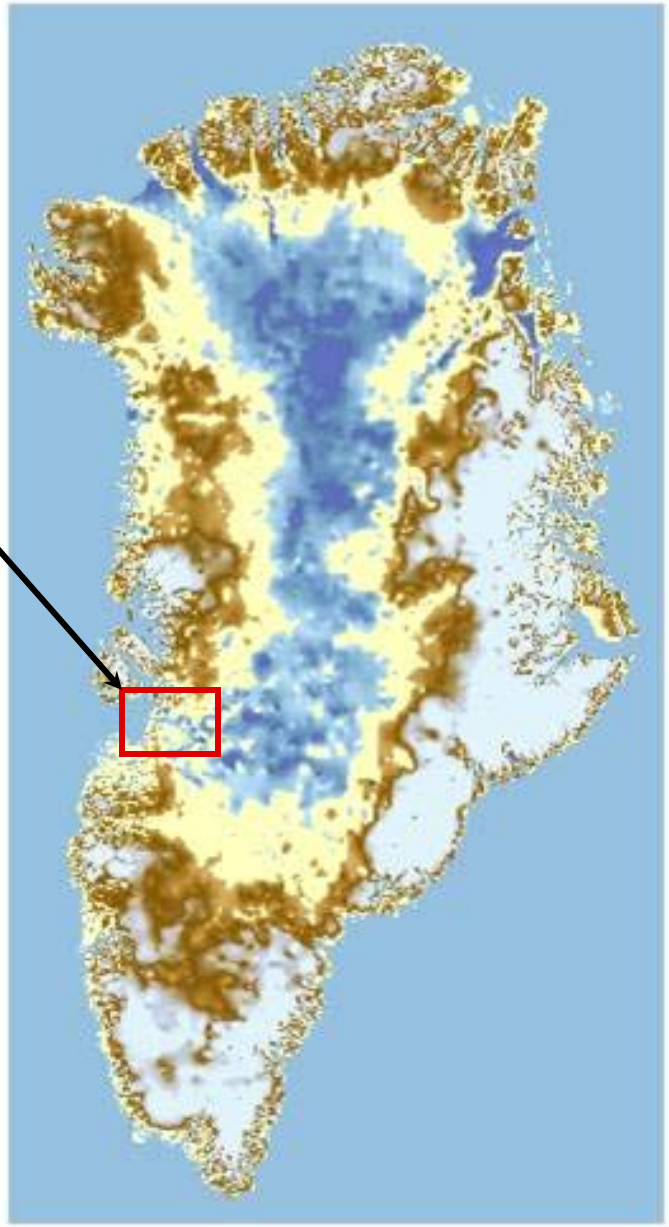


Tidewater Glacier “Drastic Retreat”



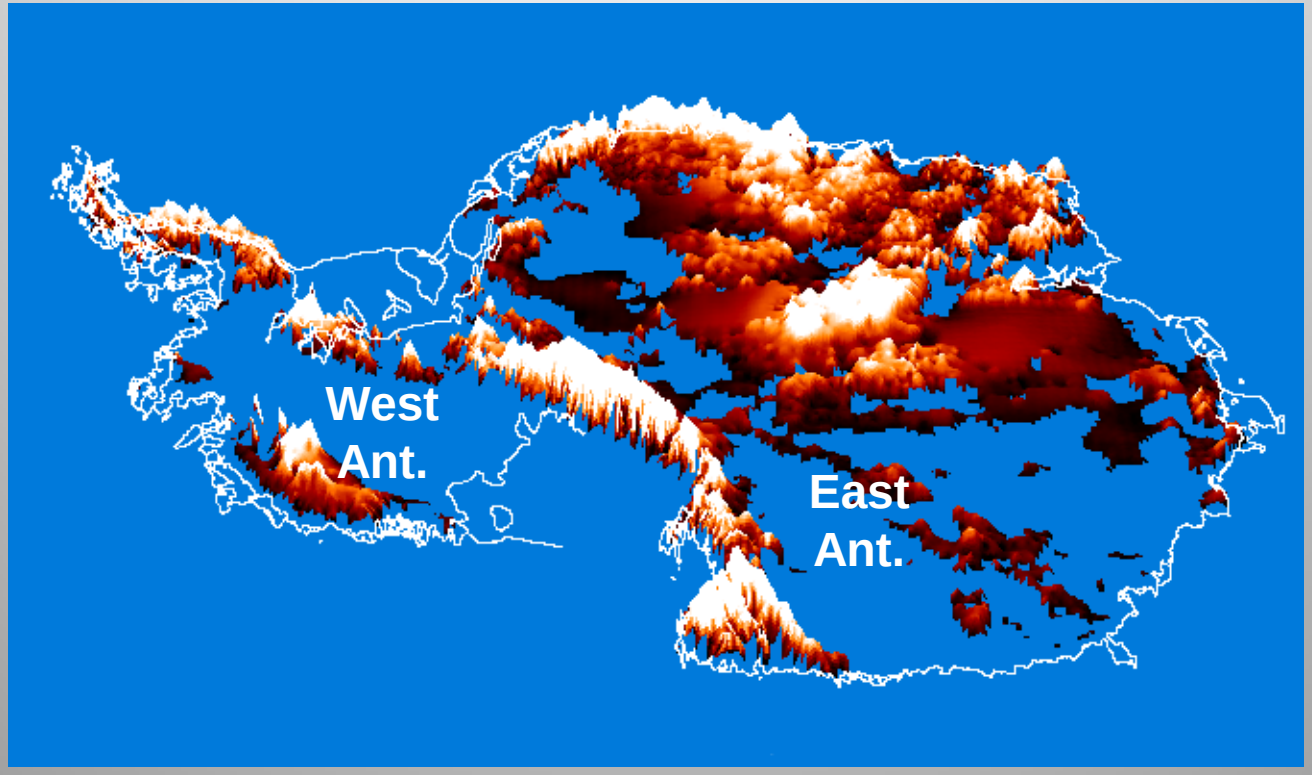
- Central region of Greenland is below sea level
- Jacobshavns Isbrae occupies subglacial channel connected to central depression





Russel Huff, Univ. of Colorado

Antarctica



Nearly all of West Antarctica ice sheet and much of East Antarctica ice sheet rests on bed below sea level

5. Calving

Photo by J. Amundson

Not a “simple” process; or is it?

Summary

- We (the global “we”) need better ice sheet models to predict future sea level
- Key processes are known, but poorly characterized
  - Most involve water
  - Some involve links to other external conditions
- Field studies of key processes are underway
- Modeling can’t wait for field answers and can contribute to effective field programs

Thank you!

Photo: I. Joughin

Questions?