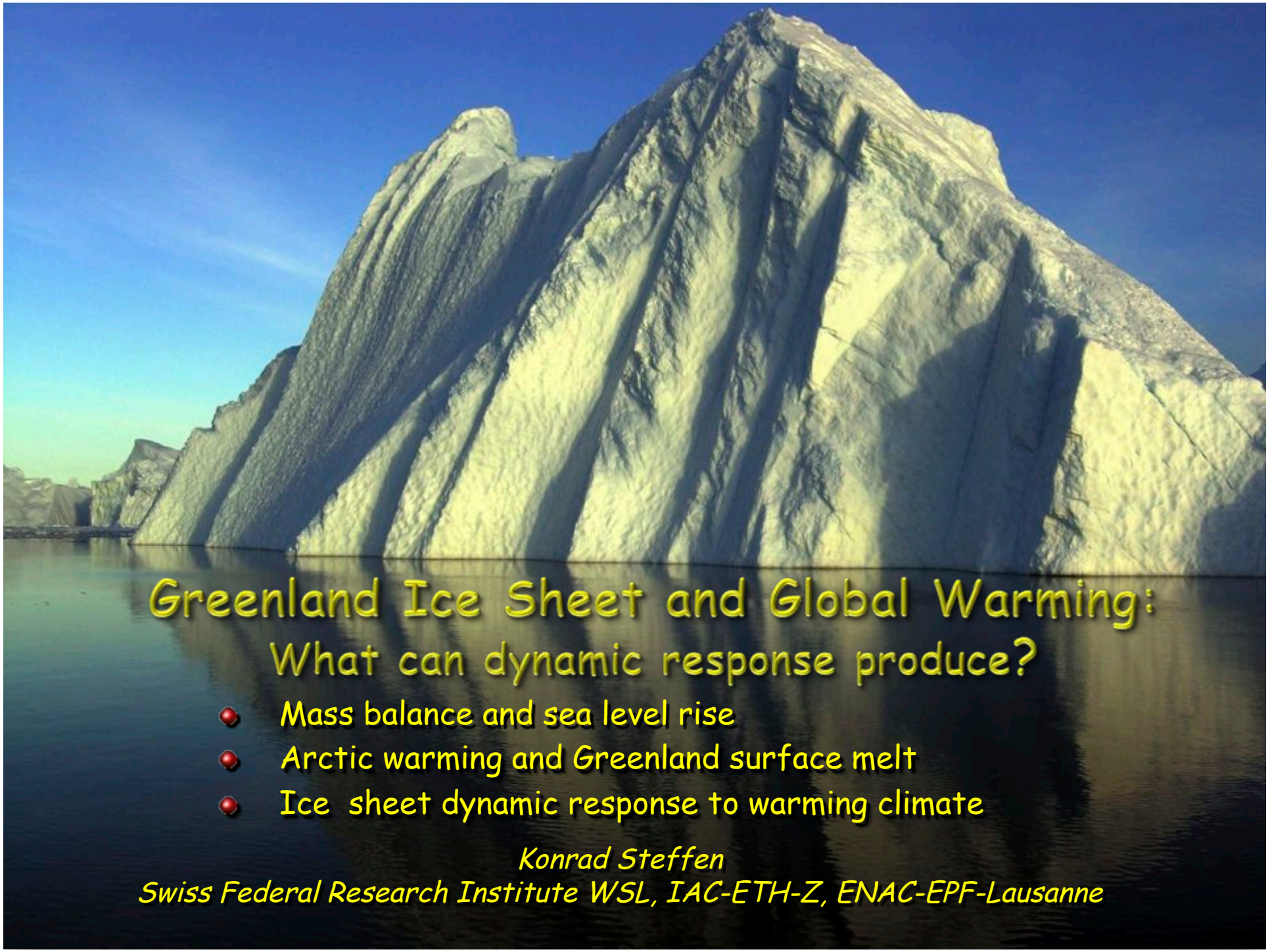
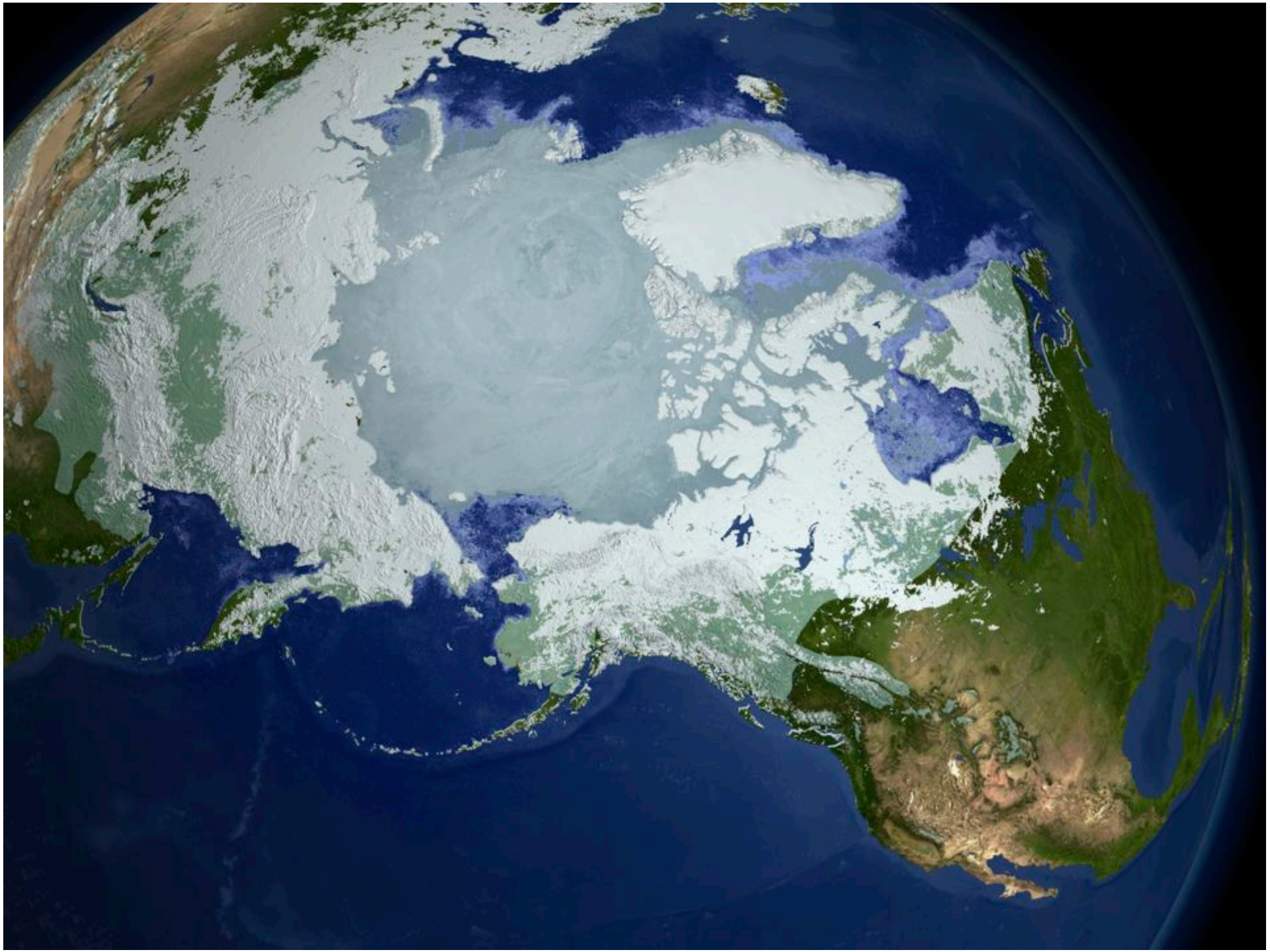


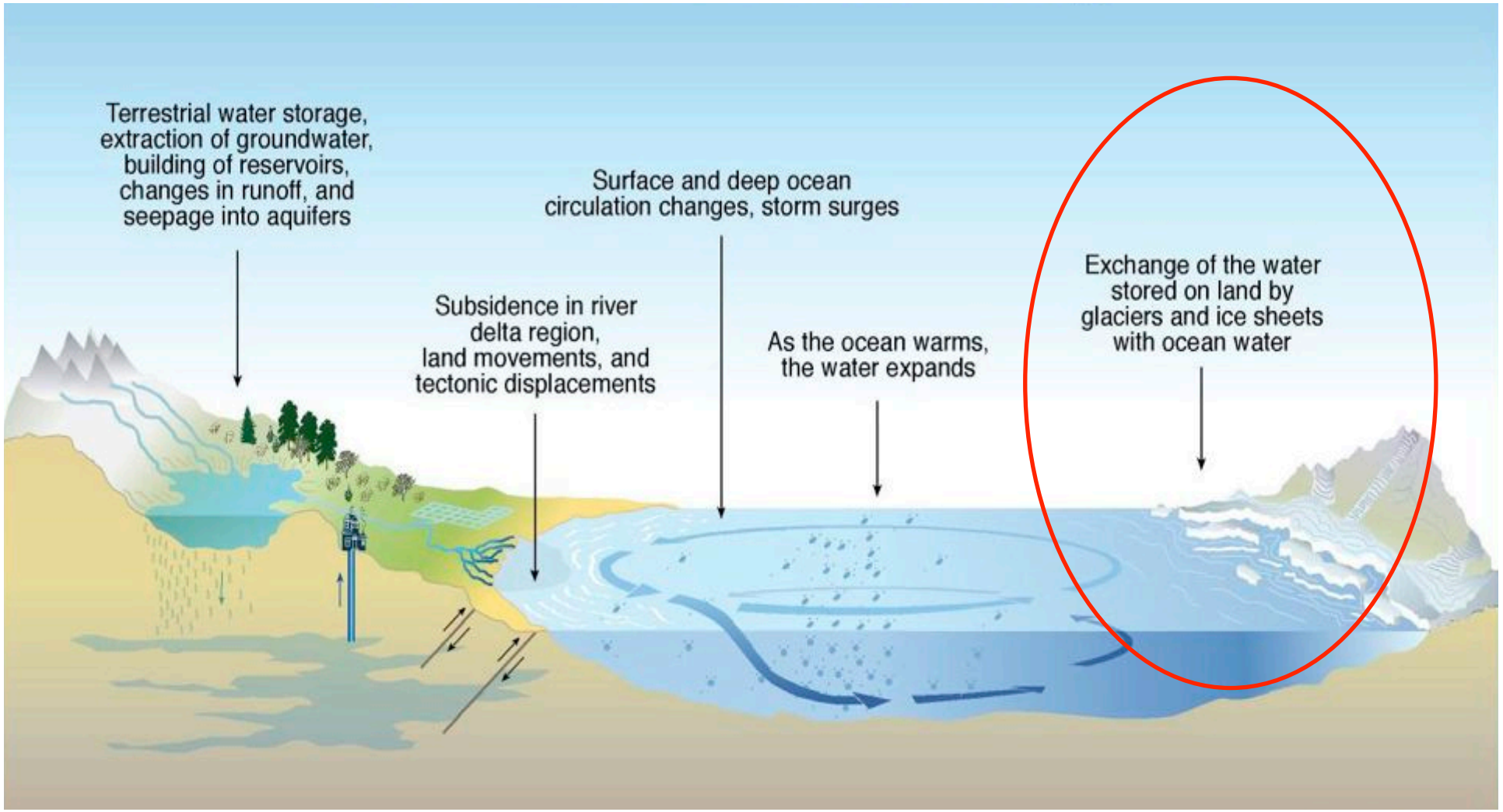
Greenland Ice Sheet and Global Warming:
What can dynamic response produce?

- Mass balance and sea level rise
- Arctic warming and Greenland surface melt
- Ice sheet dynamic response to warming climate

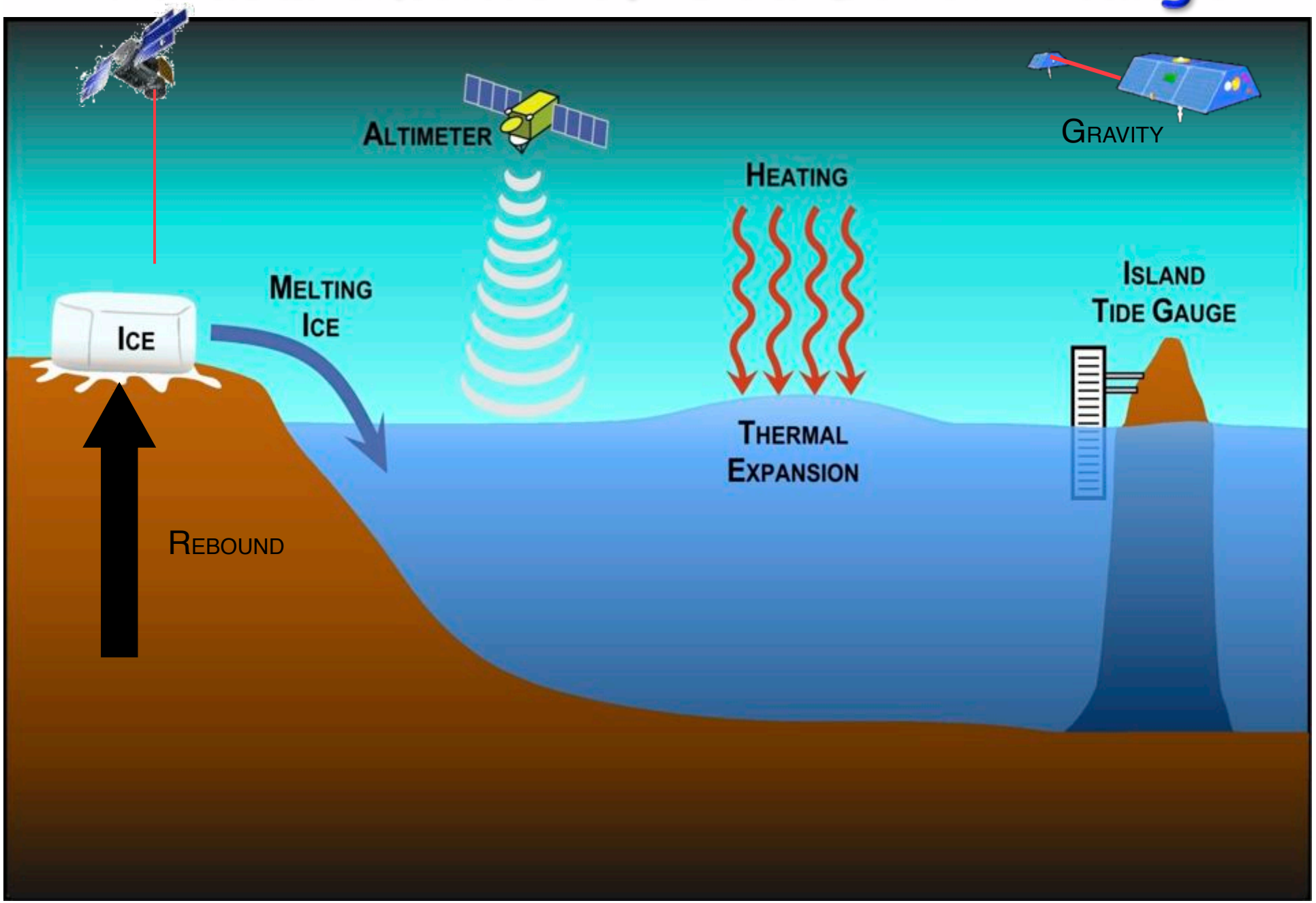
Konrad Steffen
Swiss Federal Research Institute WSL, IAC-ETH-Z, ENAC-EPF-Lausanne



What Causes Sea Level to Change?

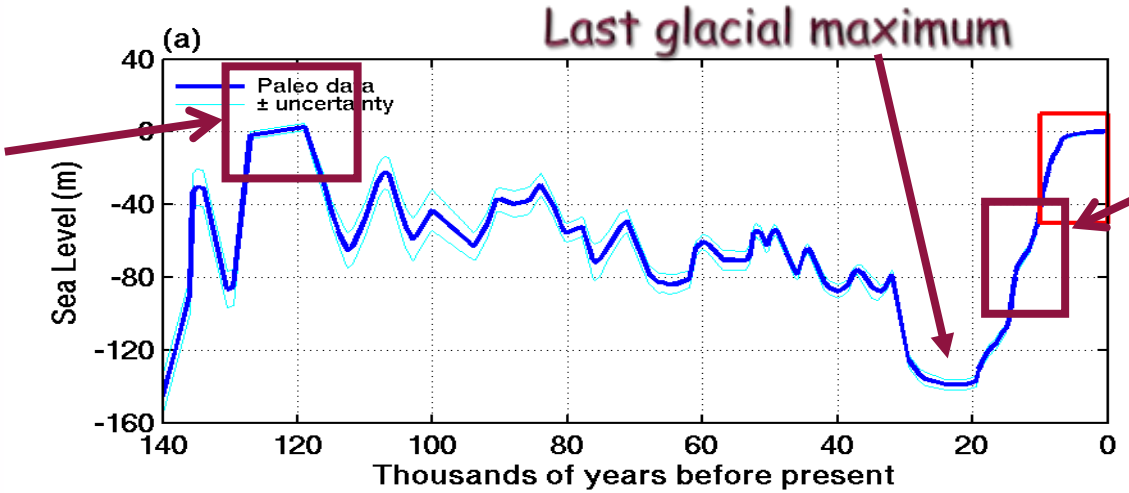


Measurements of Sea Level Change

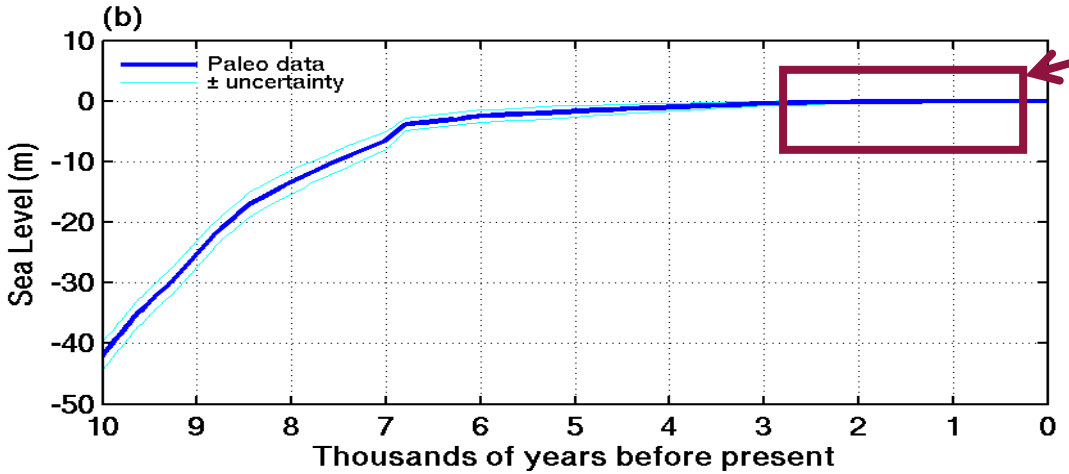


Sea level rose more than 120 m since the last glacial maximum

- Sea level higher than today,
- At temperature similar to what we expect by 2100



- Rates of rise up to 4 m/ century

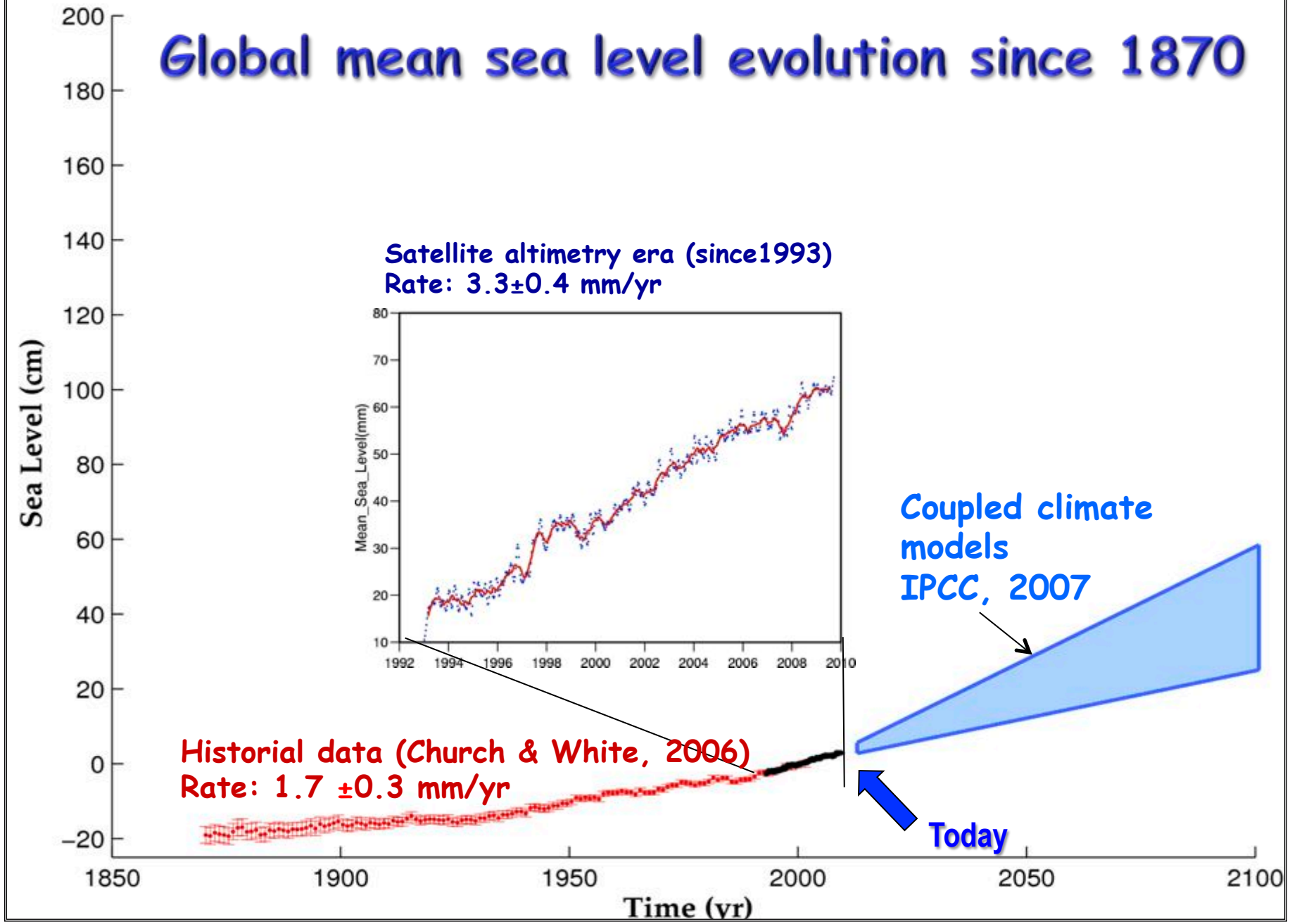


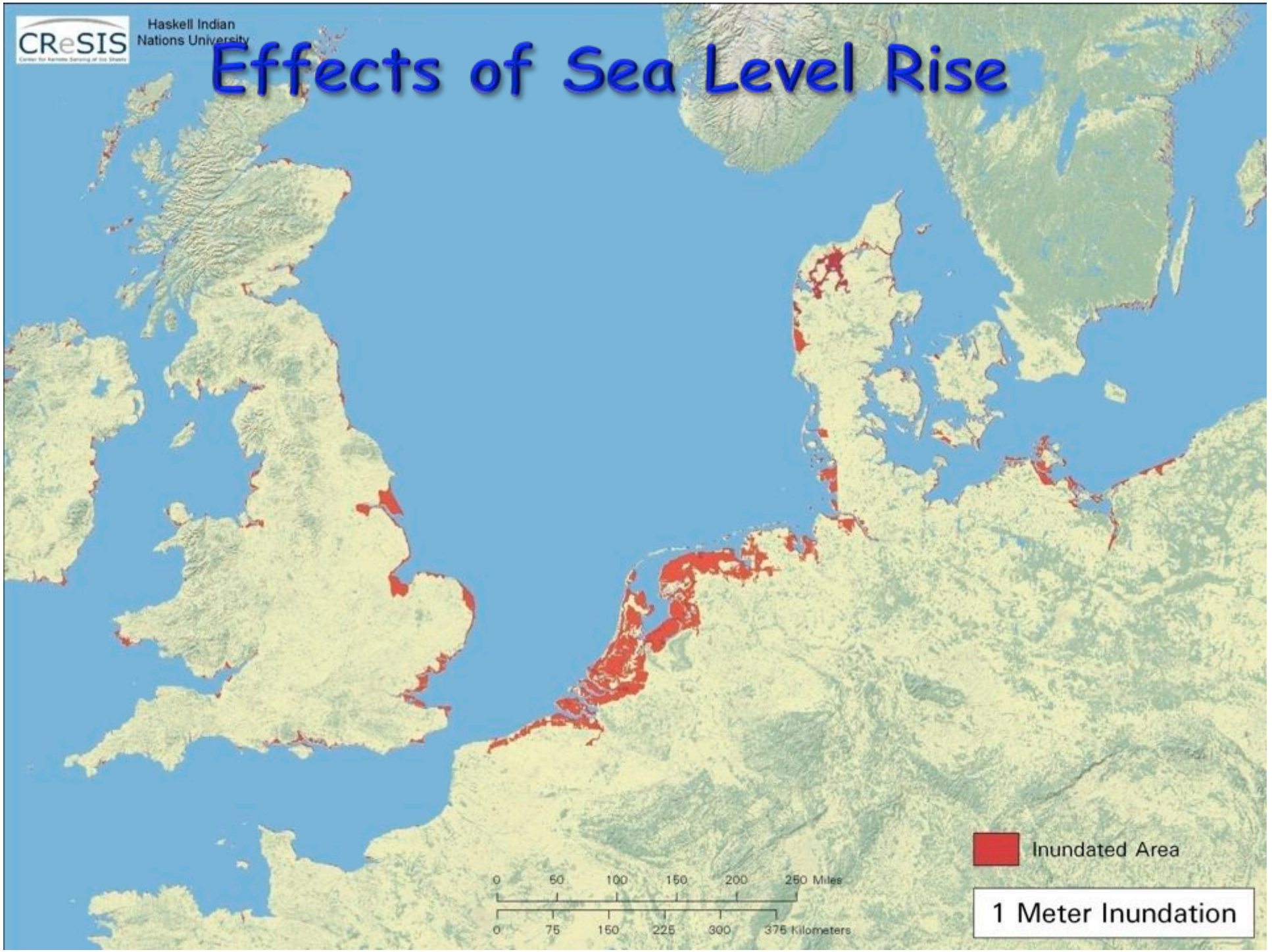
- Our coastal society developed in a time of stable sea level

Church et al. 2008

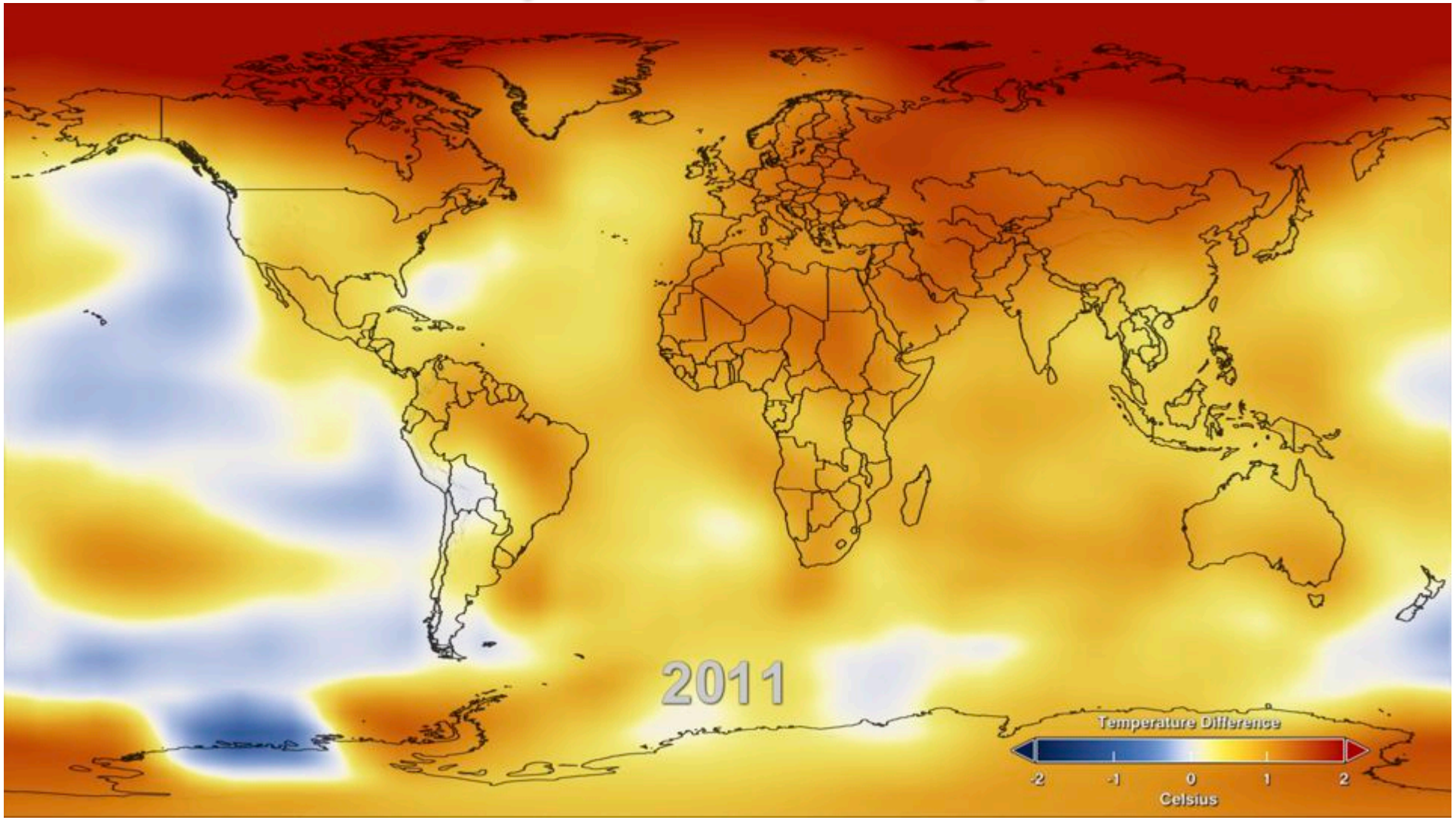
D. Dahl Jensen et al., Nature 2013

Global mean sea level evolution since 1870




CReSIS
Haskell Indian Nations University
Effects of Sea Level Rise
Inundated Area
1 Meter Inundation
0 50 100 150 200 250 Miles
0 75 150 225 300 375 Kilometers

Global Temperature Anomaly in 2011



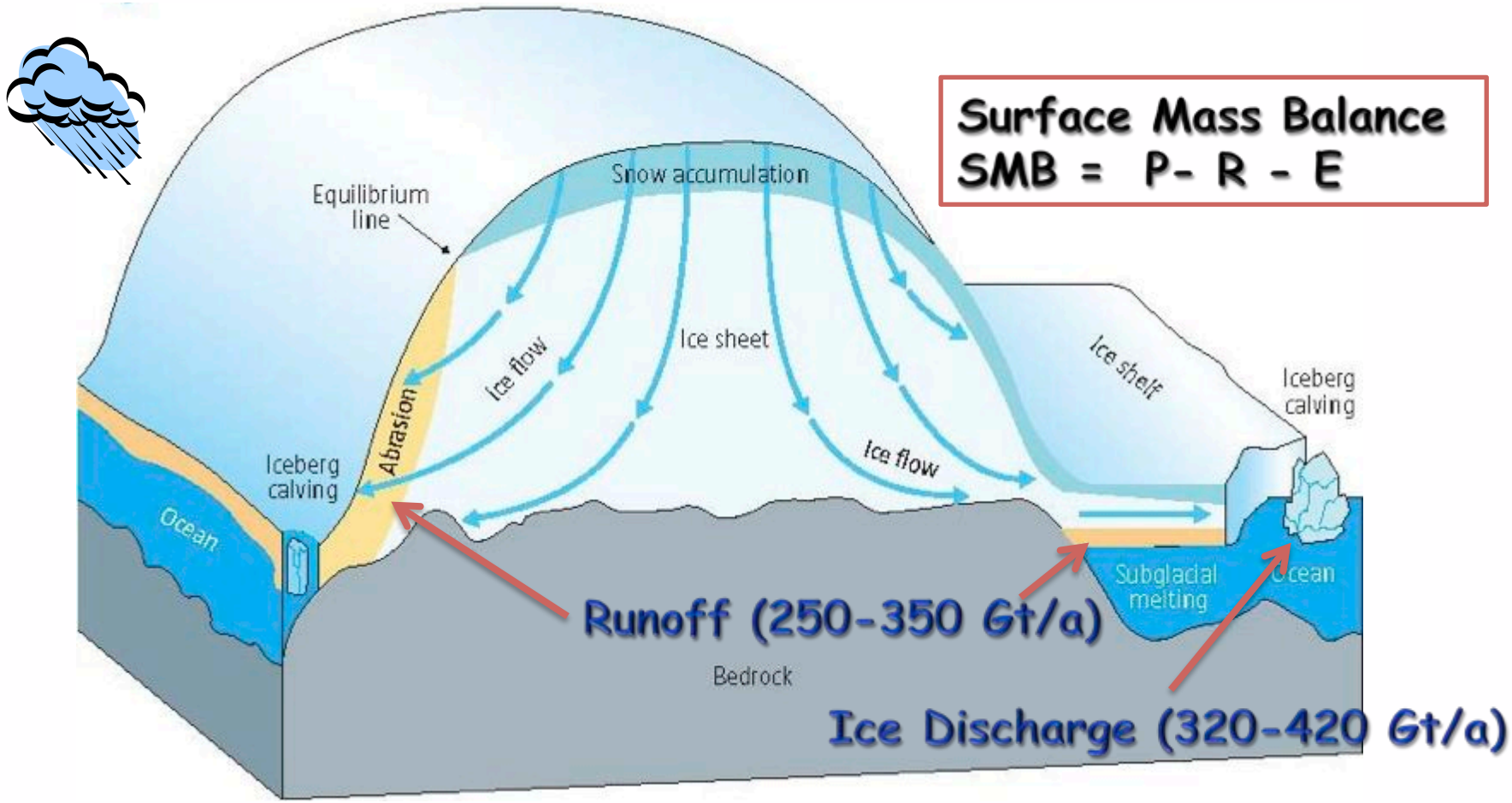
Compared against 30-year mean (1980-2010)

James Hansen (NASA/GSFC GISS)

Greenland Mass Balance

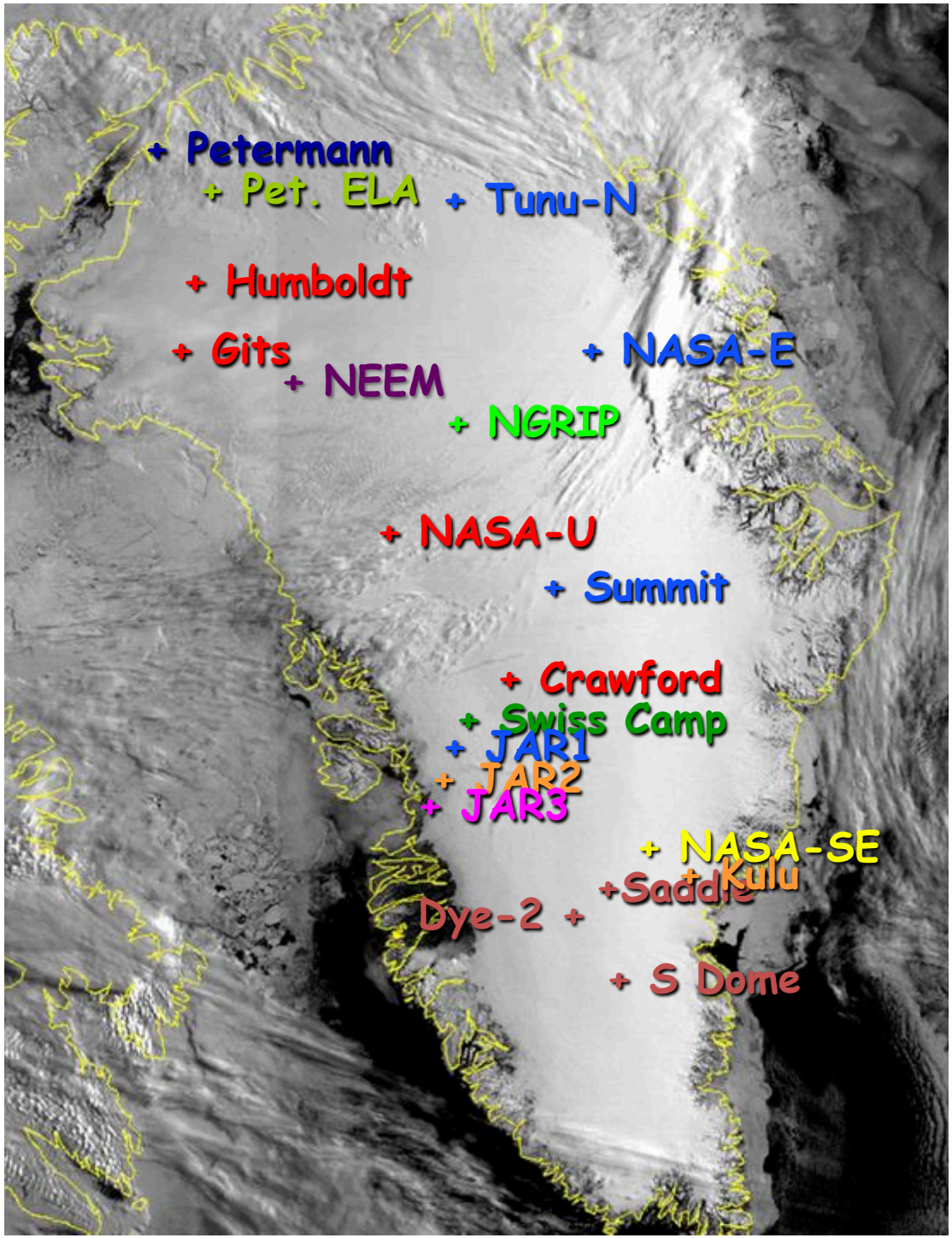
Precipitation (550-640 Gt/a)

Evaporation (10-45 Gt/a)



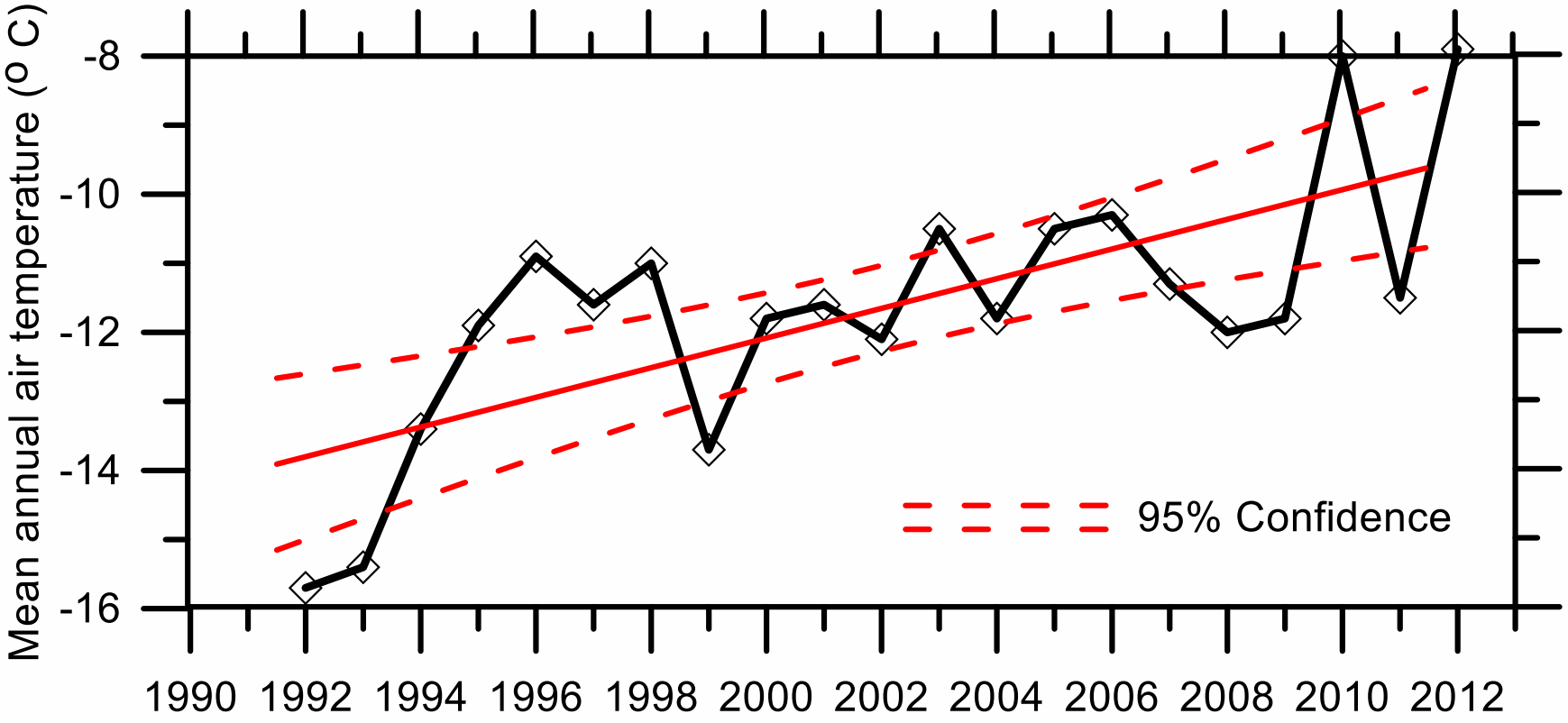
Negative Balance (-50 to - 200 Gt/a)

GC-Net Greenland Climate Network



Mean Annual Air Temperatures

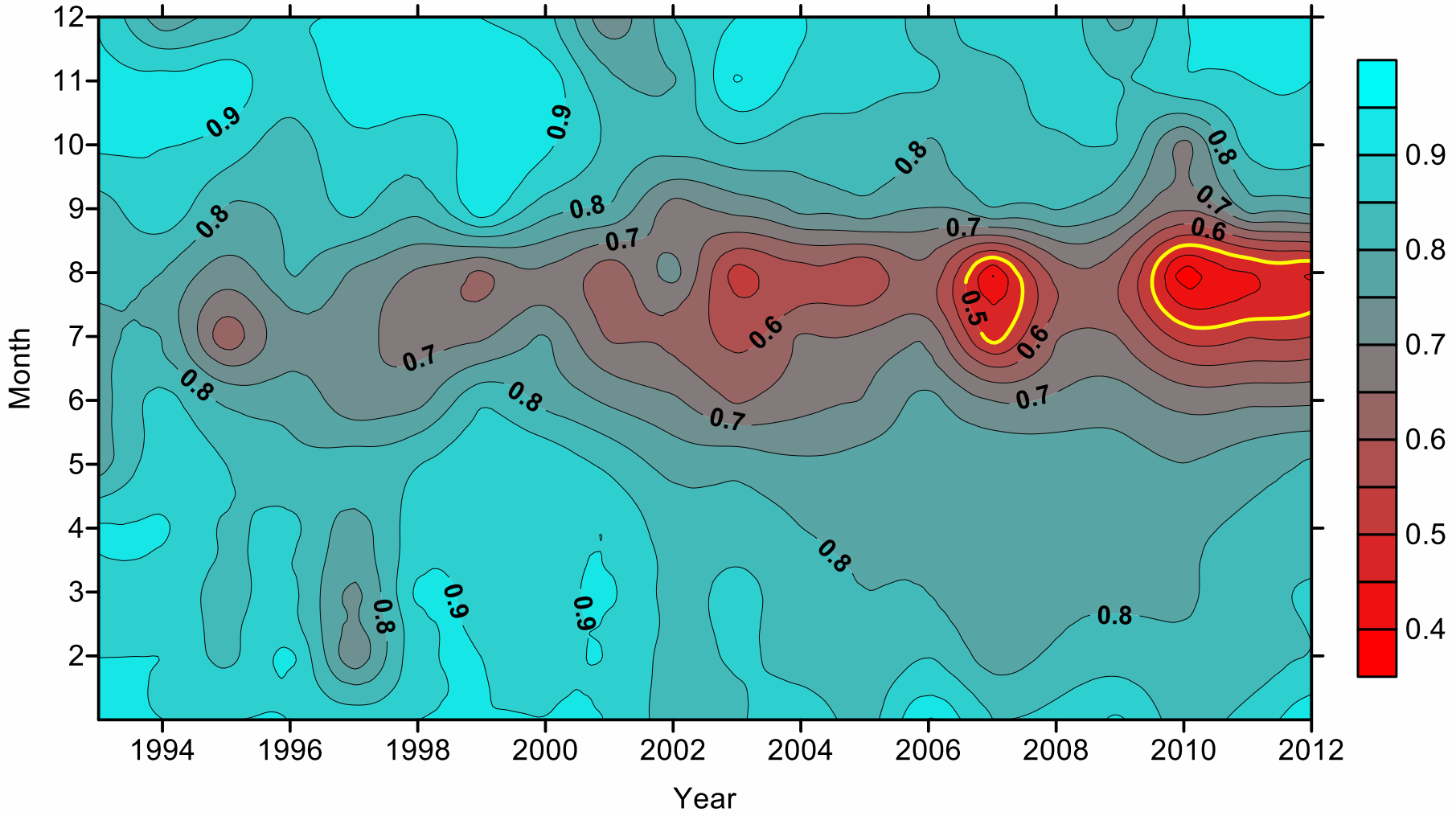
Swiss Camp 1991-2012



Mean annual air temperature increased by 4.5 °C since 1991 (~2 °C/decade)

Albedo Variability

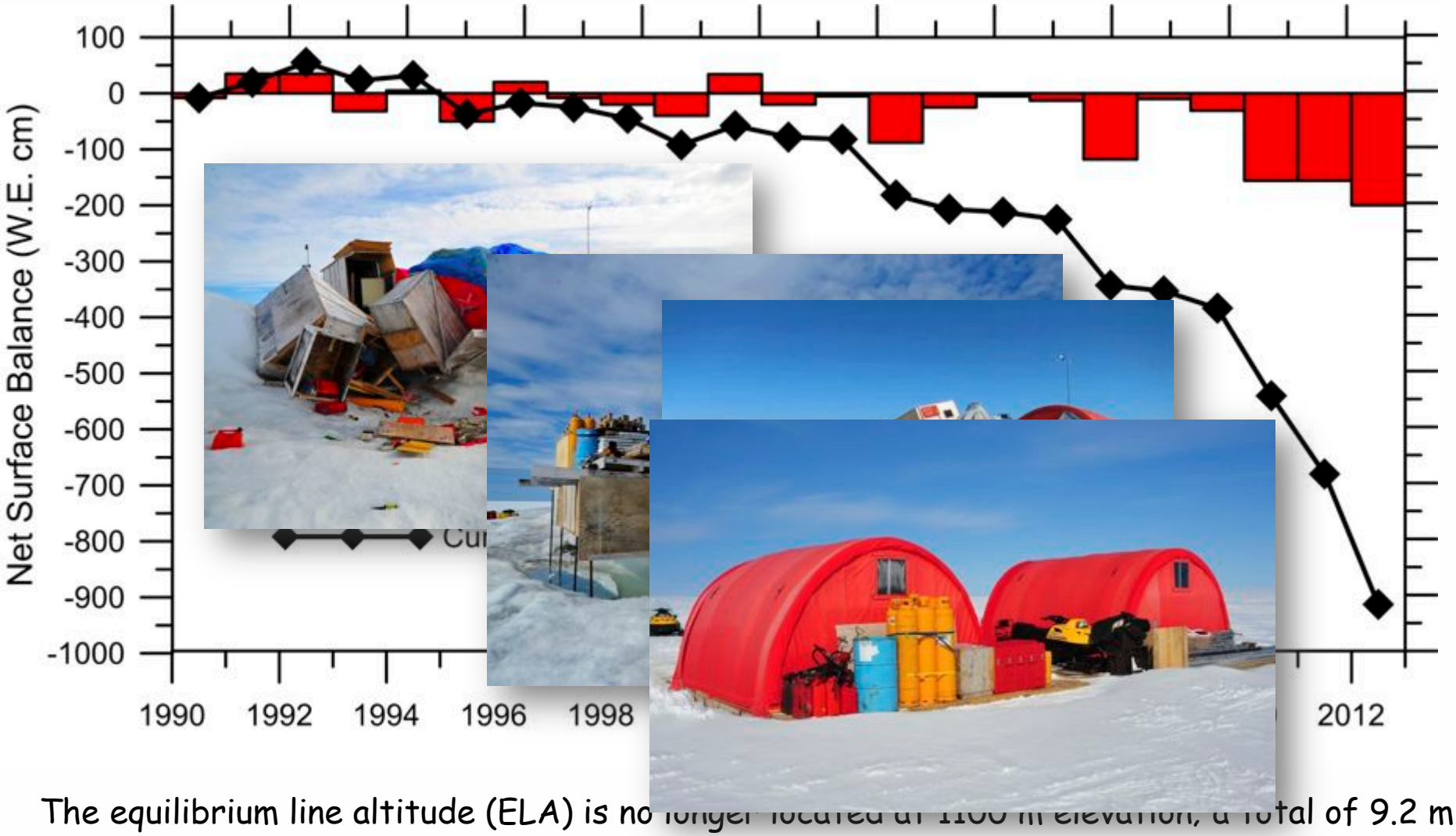
Swiss Camp 1993-2012



Surface mass balance is negative since 1996

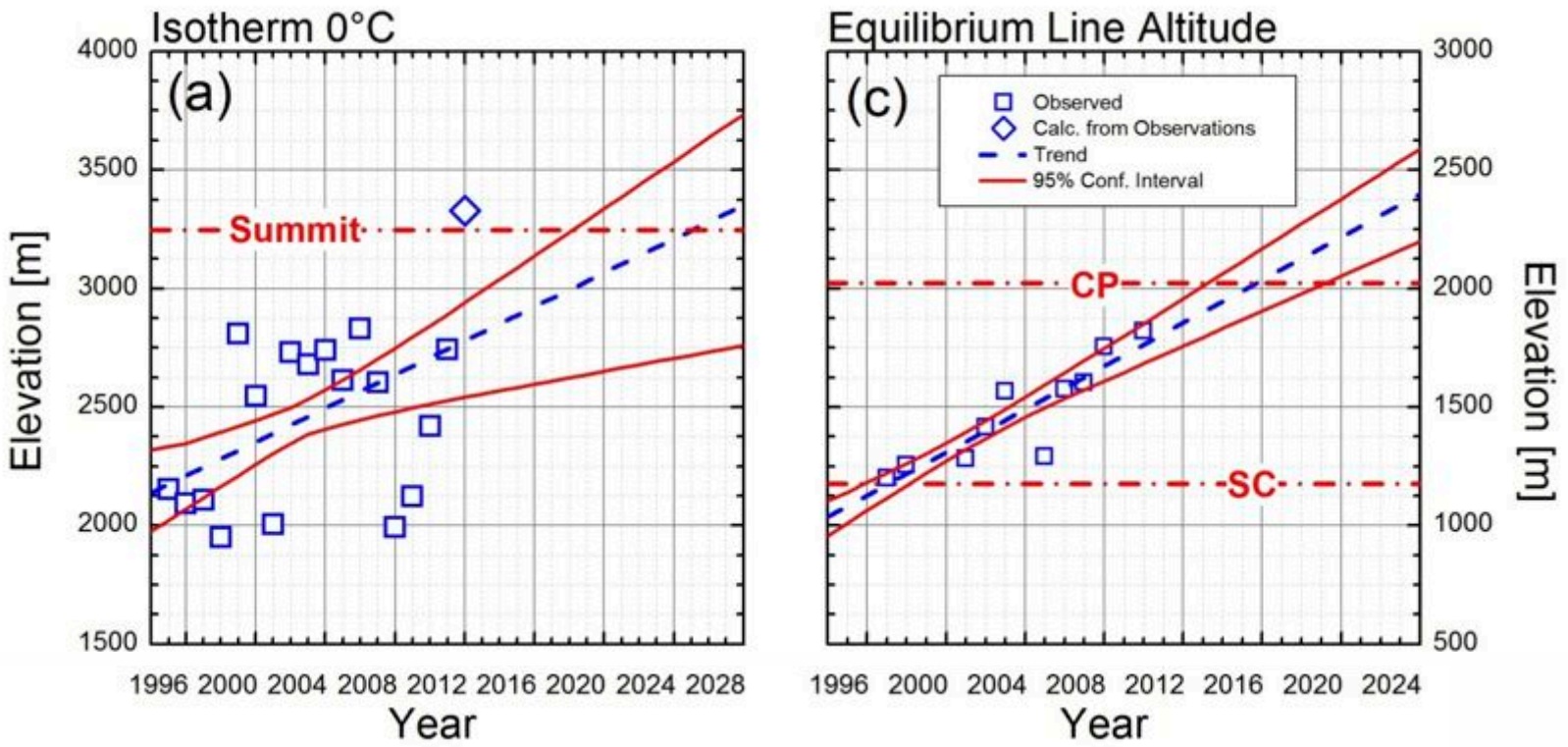
Interannual Variability of Net Surface Balance

Swiss Camp 1990 through 2012



The equilibrium line altitude (ELA) is no longer located at 1100 m elevation, a total of 9.2 m ice has been lost at Swiss Camp, in particular during the past 10 years.

Migration of ELA: 1996-2012

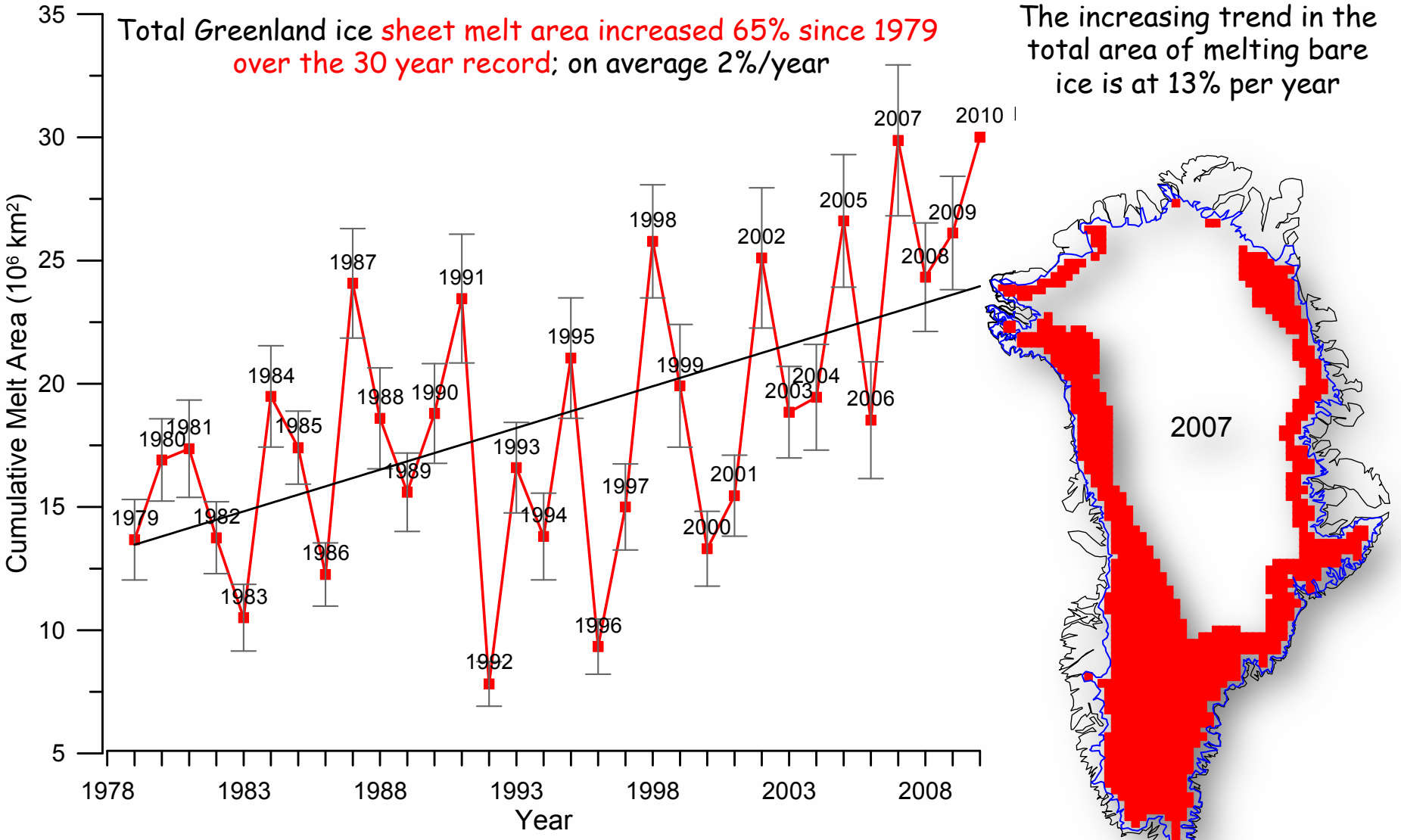


McGrath, D., W. Colgan, N. Bayou, A. Muto, K. Steffen **Recent warming at Summit, Greenland: Global Context and Implications**, GRL, in Press, 2013.

Greenland Total Melt Area: 1979-2010

Total Greenland ice sheet melt area increased 65% since 1979 over the 30 year record; on average 2%/year

The increasing trend in the total area of melting bare ice is at 13% per year



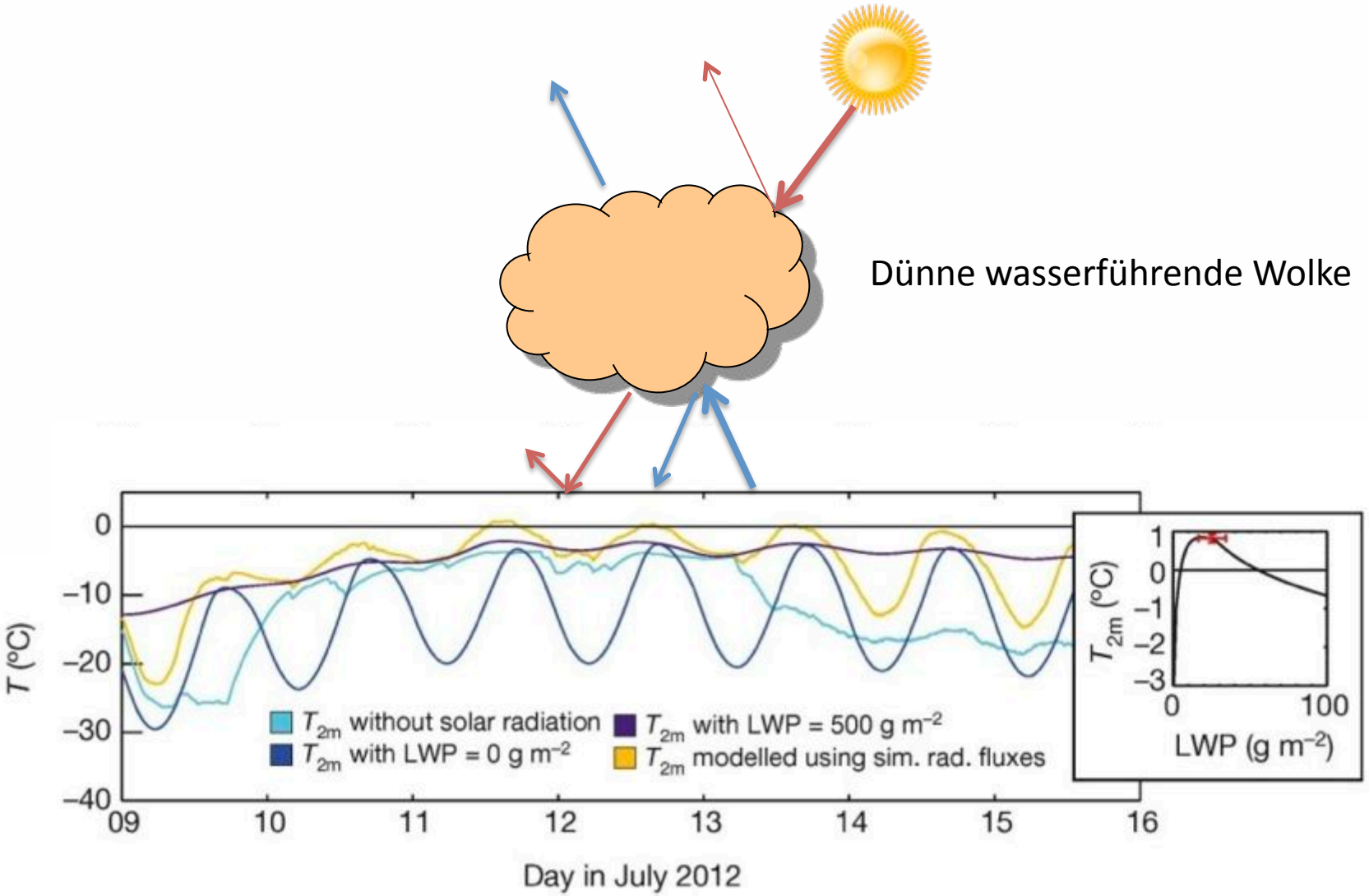
Grönlands Schmelze im Juli 2012

Surface Baseline Radiation Network (BSRN)

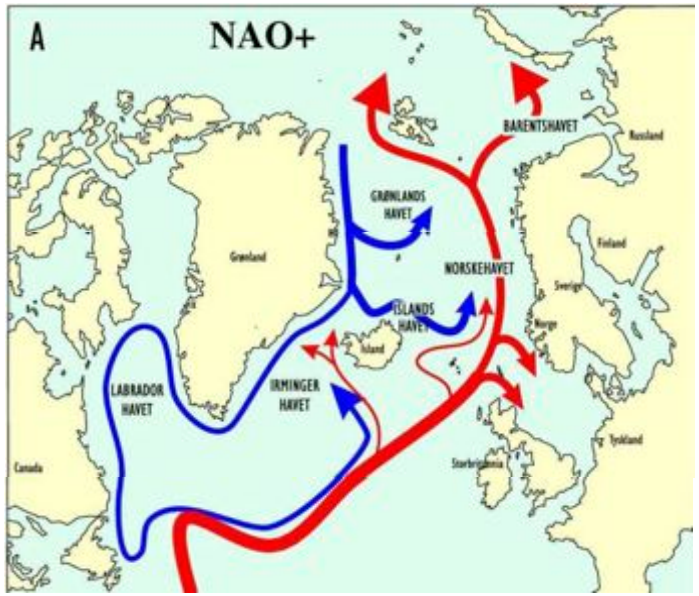
ETH Radiation monitoring at Summit Greenland since 1991

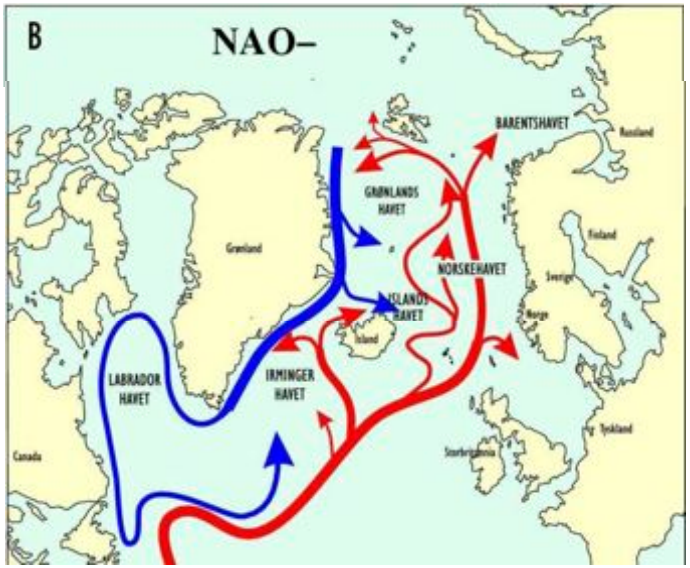
R. Bennartz, M. D. Shupe, D. D. Turner, V. P. Walden, K. Steffen, C. J. Cox, M. S. Kulie, N. B. Miller & C. Pettersen
July 2012 Greenland melt extent enhanced by low-level liquid clouds, Nature, doi:10.1038/nature12002.

Greenland Juli 2012 Melt Event



R. Bennartz, M. D. Shupe, D. D. Turner, V. P. Walden, K. Steffen, C. J. Cox, M. S. Kulie, N. B. Miller & C. Pettersen
July 2012 Greenland melt extent enhanced by low-level liquid clouds, Nature, doi:10.1038/nature12002.

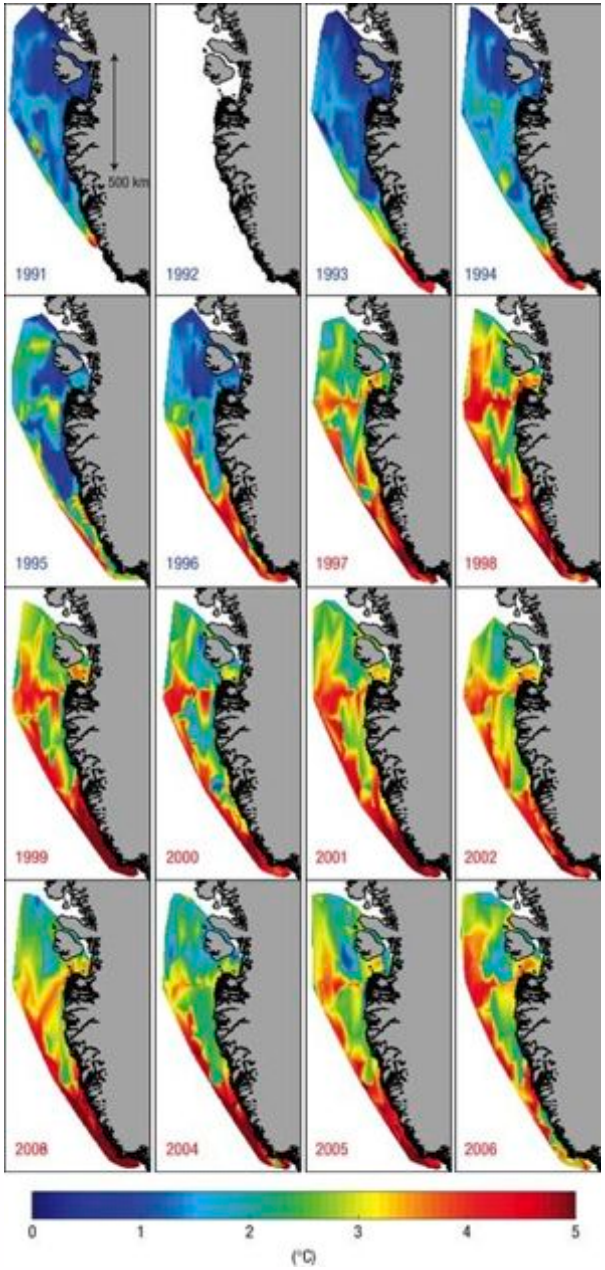




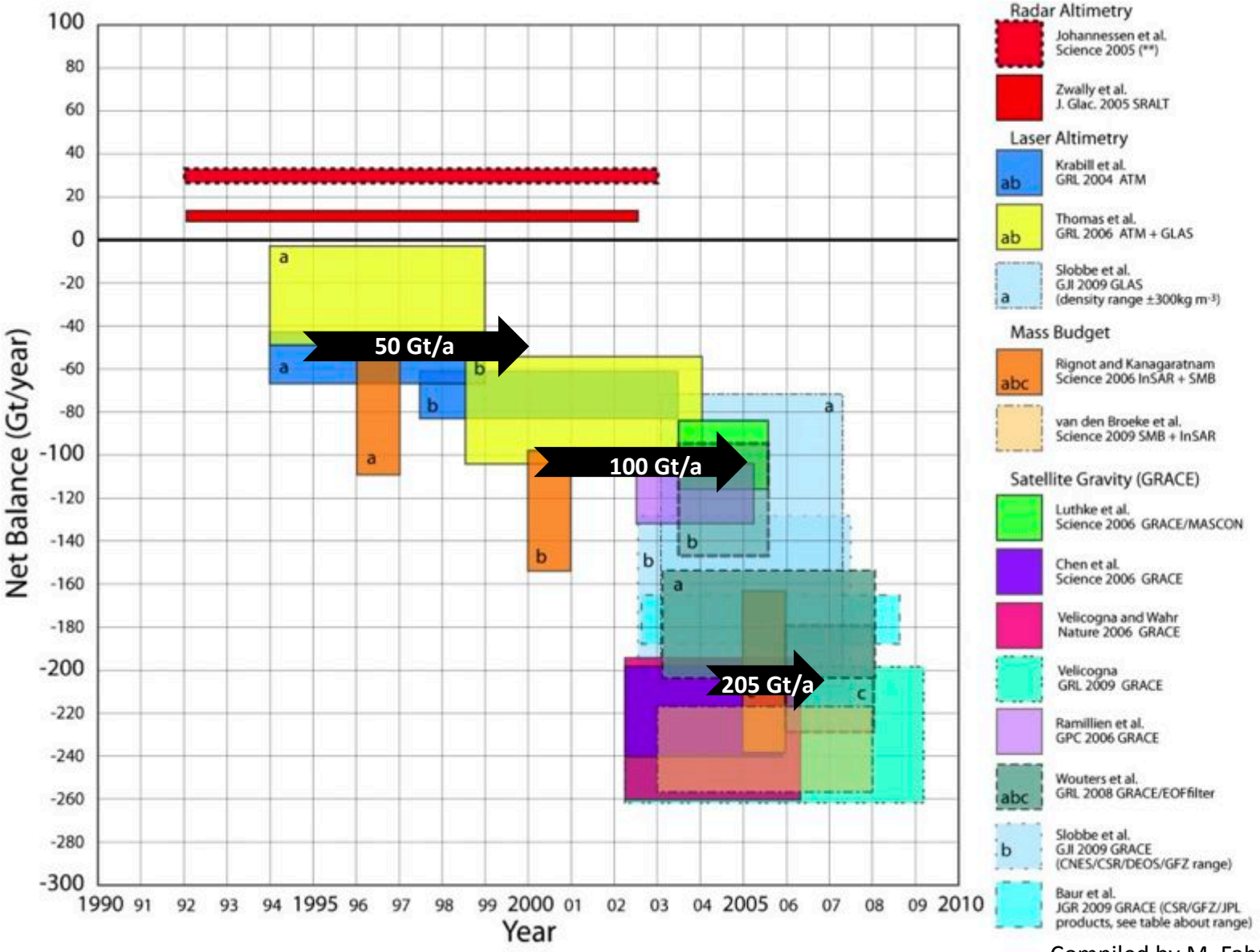
Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters

David Holland, Robert Thomas, Brad de Young, Mads Ribergaard, and Bjarne Lyberth

Warm Water Intrusion

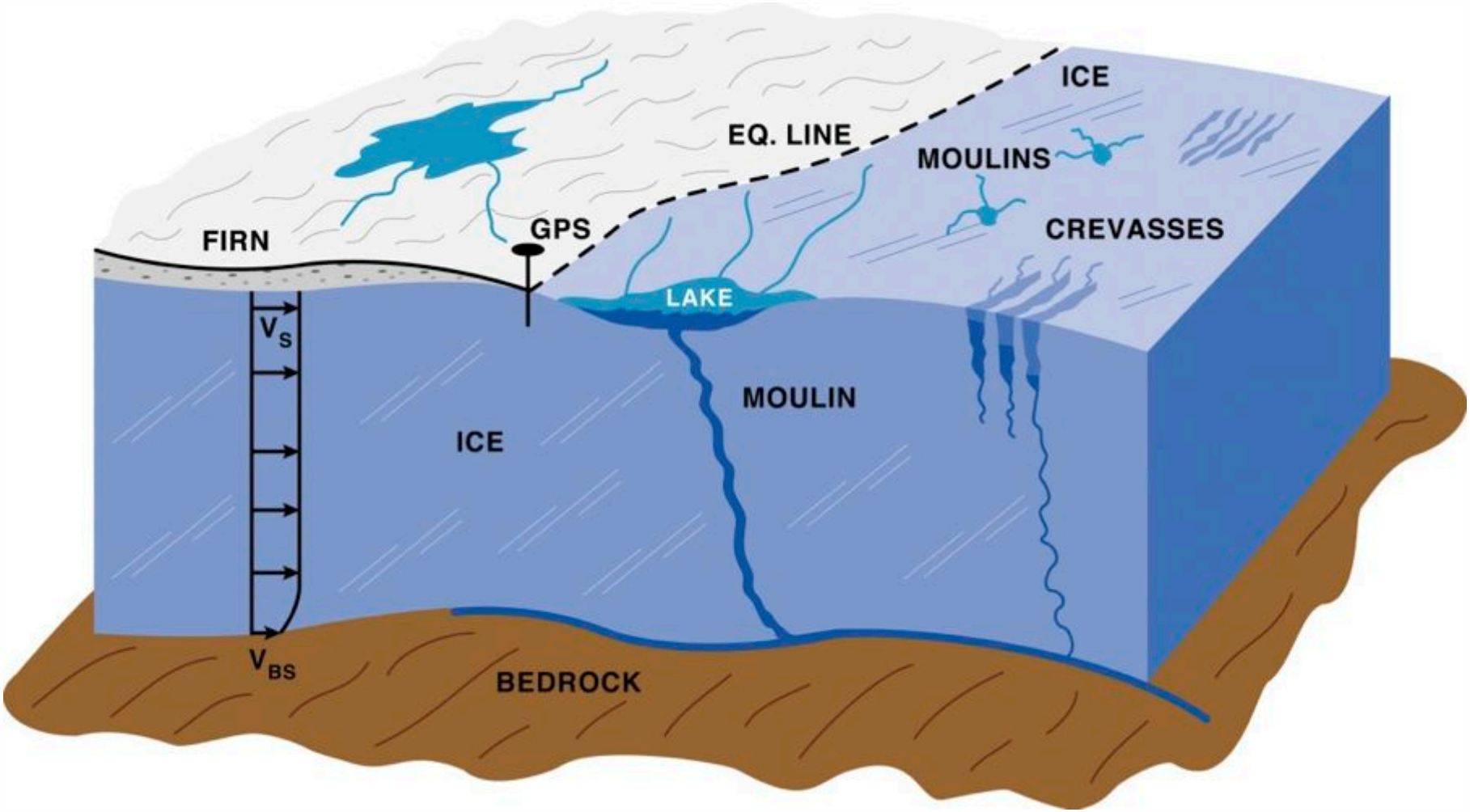


Greenland Ice Sheet Mass Balance

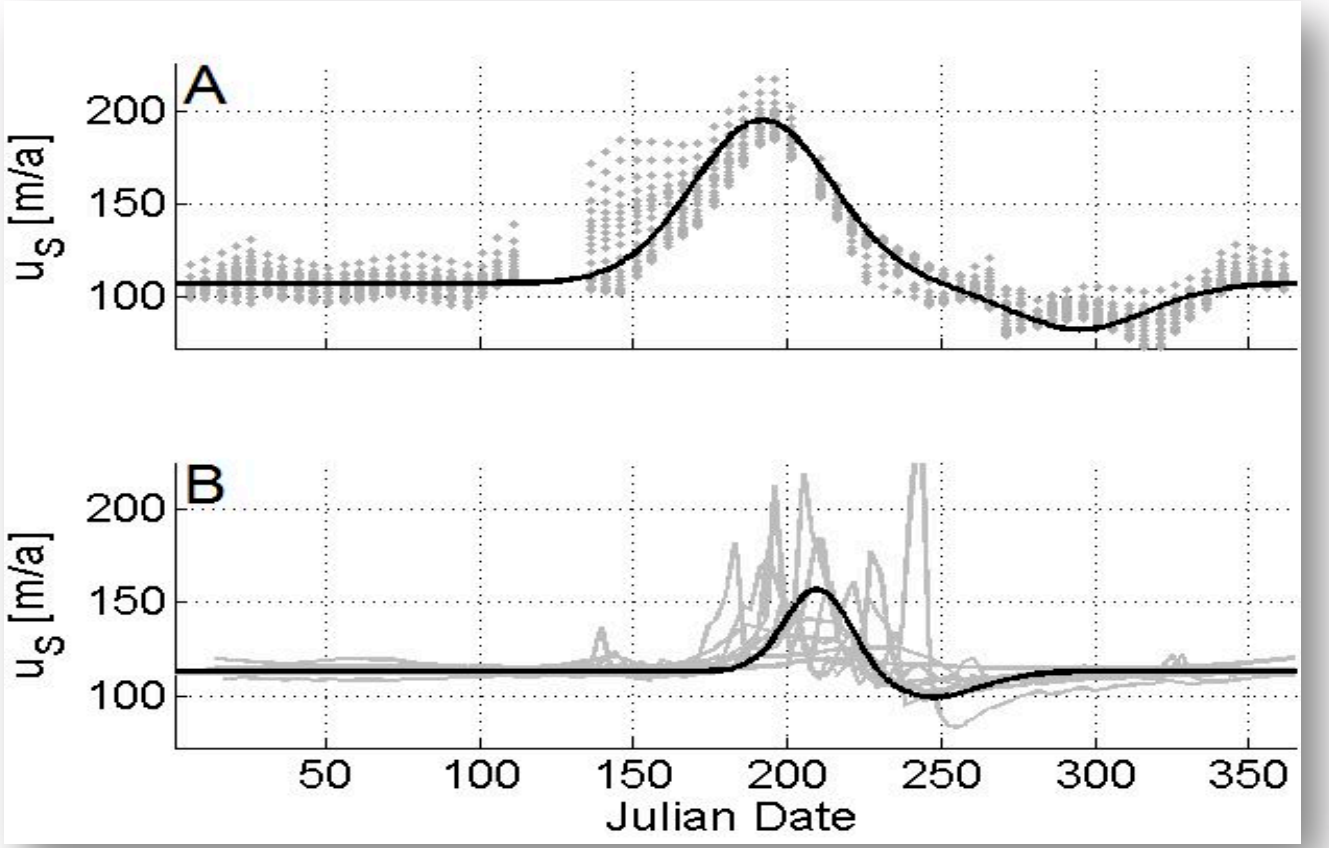


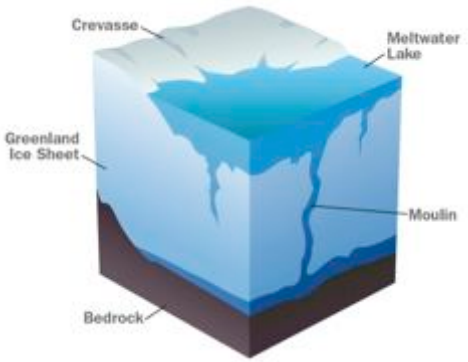
Compiled by M. Fahnestock for AMAP

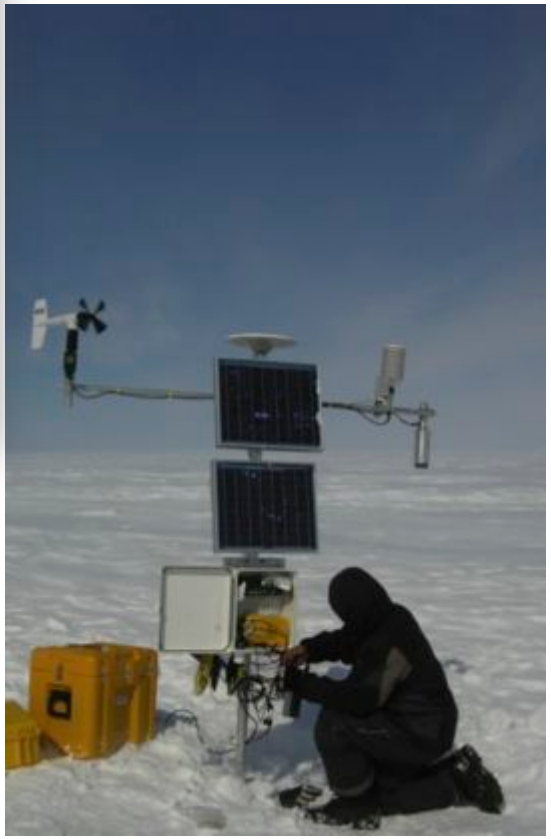
Surface Melt-Induced Acceleration of Greenland Ice-Sheet Flow

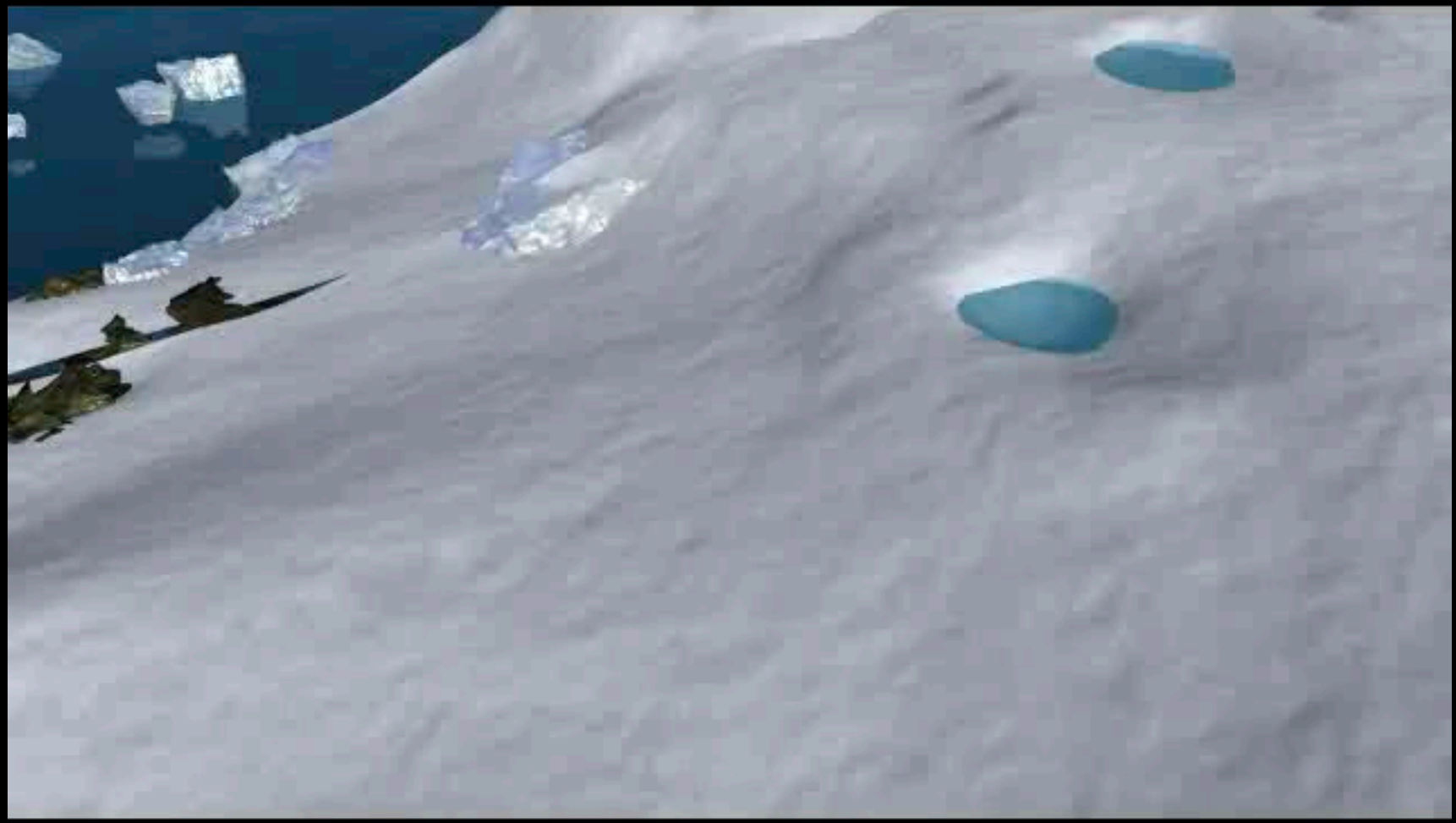


H. Jay Zwally, Waleed Abdalati, Tom Herring, Kristine Larson, Jack Saba, and Konrad Steffen, Science 297, 2002.

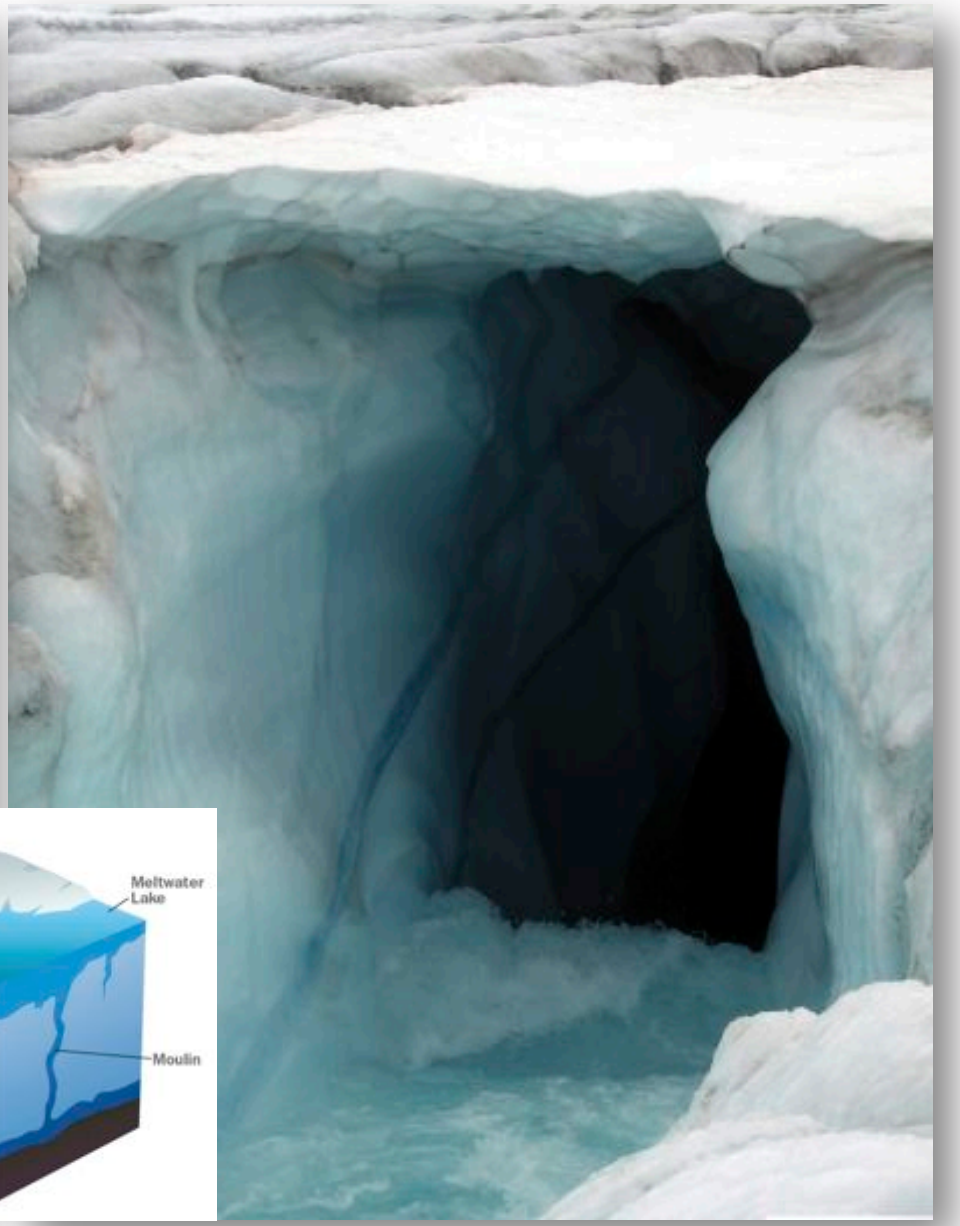

A
B
200
150
100
u_S [m/a]
50
100
150
200
250
300
350
Julian Date

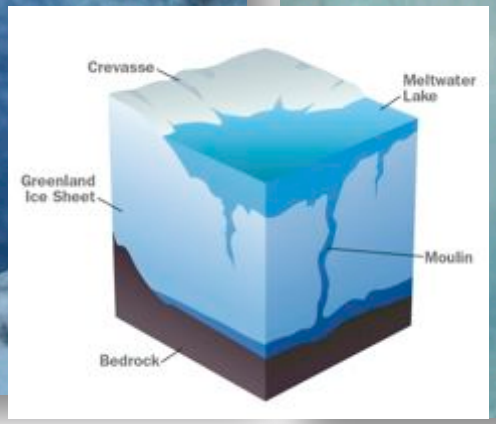

Crevasse
Meltwater Lake
Greenland Ice Sheet
Moulin
Bedrock



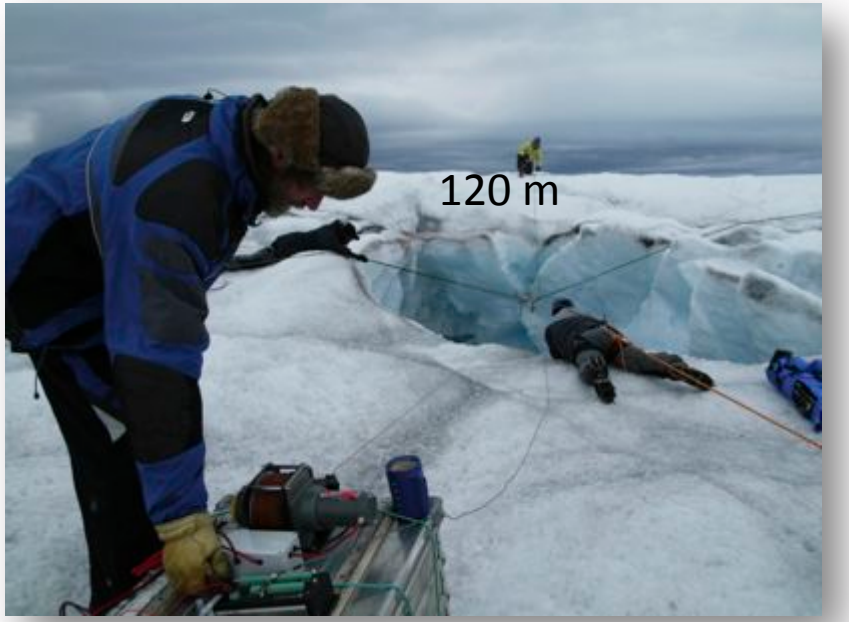


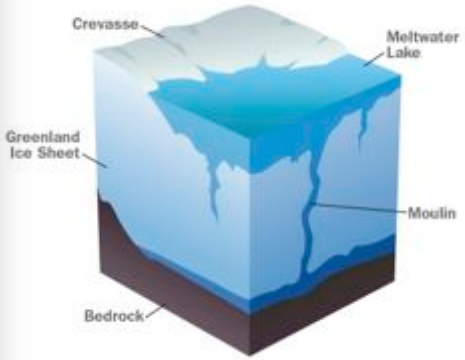
Melt Induced Ice Flow and Moulins





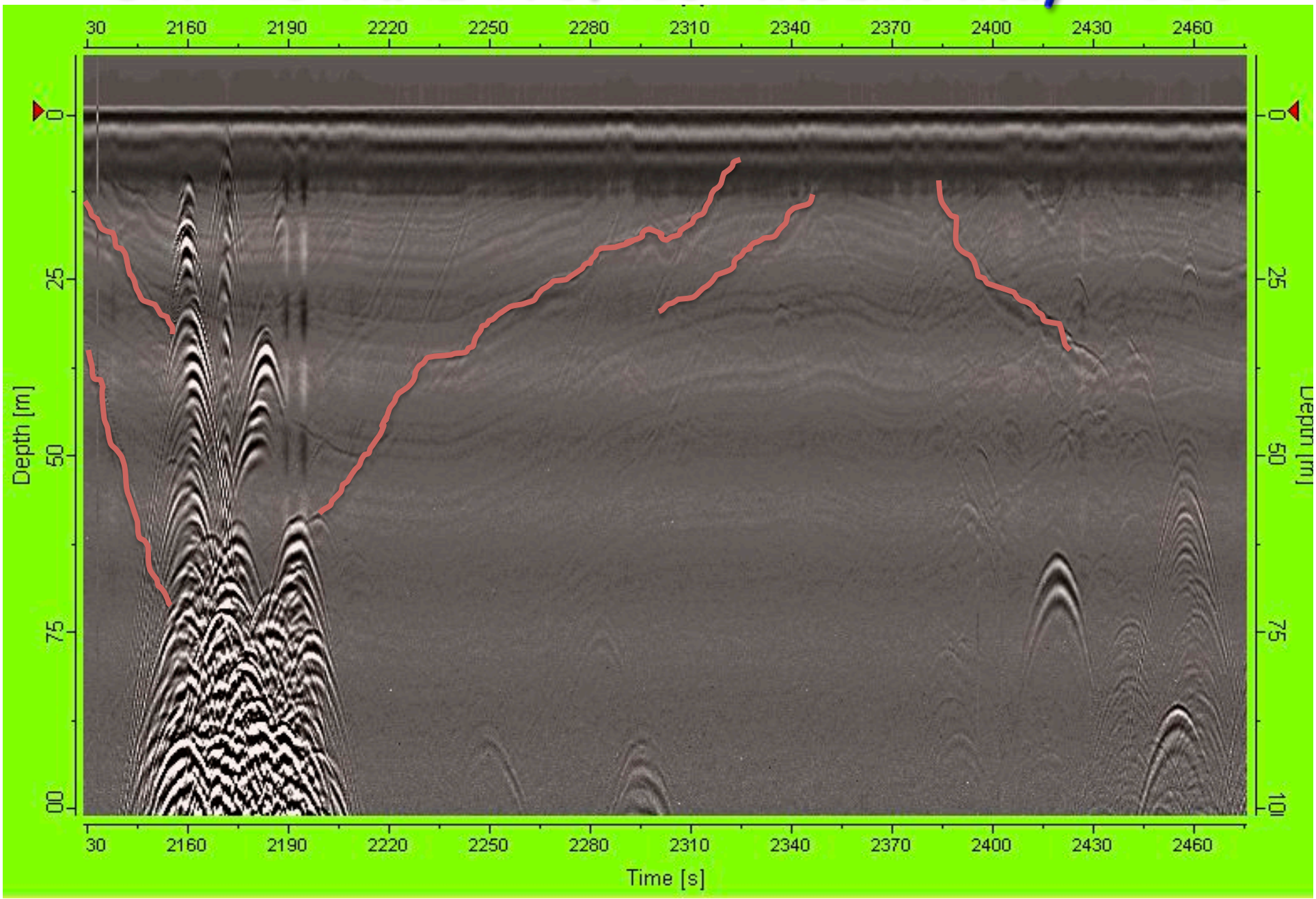
Moulin Experiment August 2007, 2008, 2009



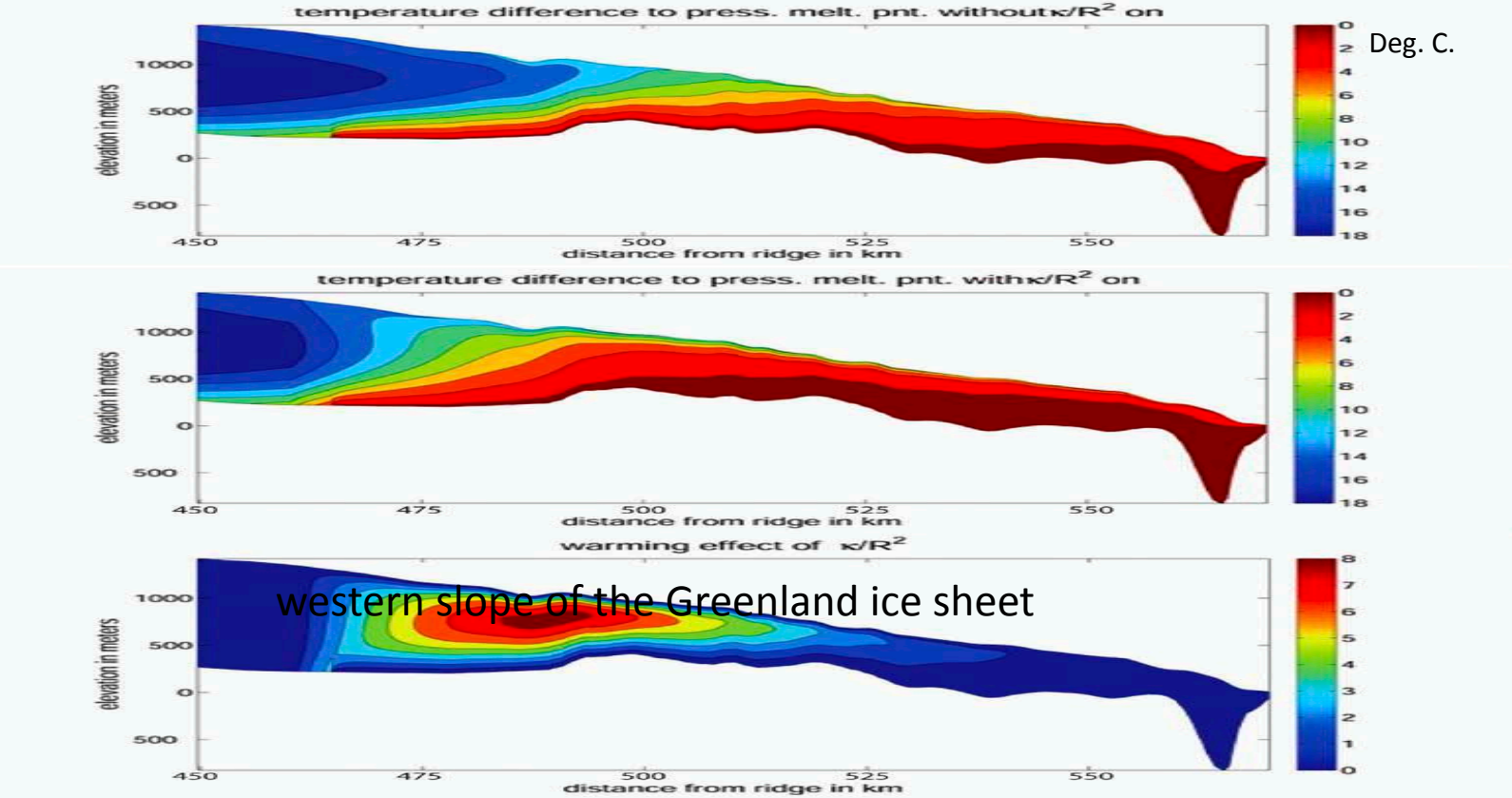



Discovery
HD

GPR 25 MHz Profiles: Moulin May 2008

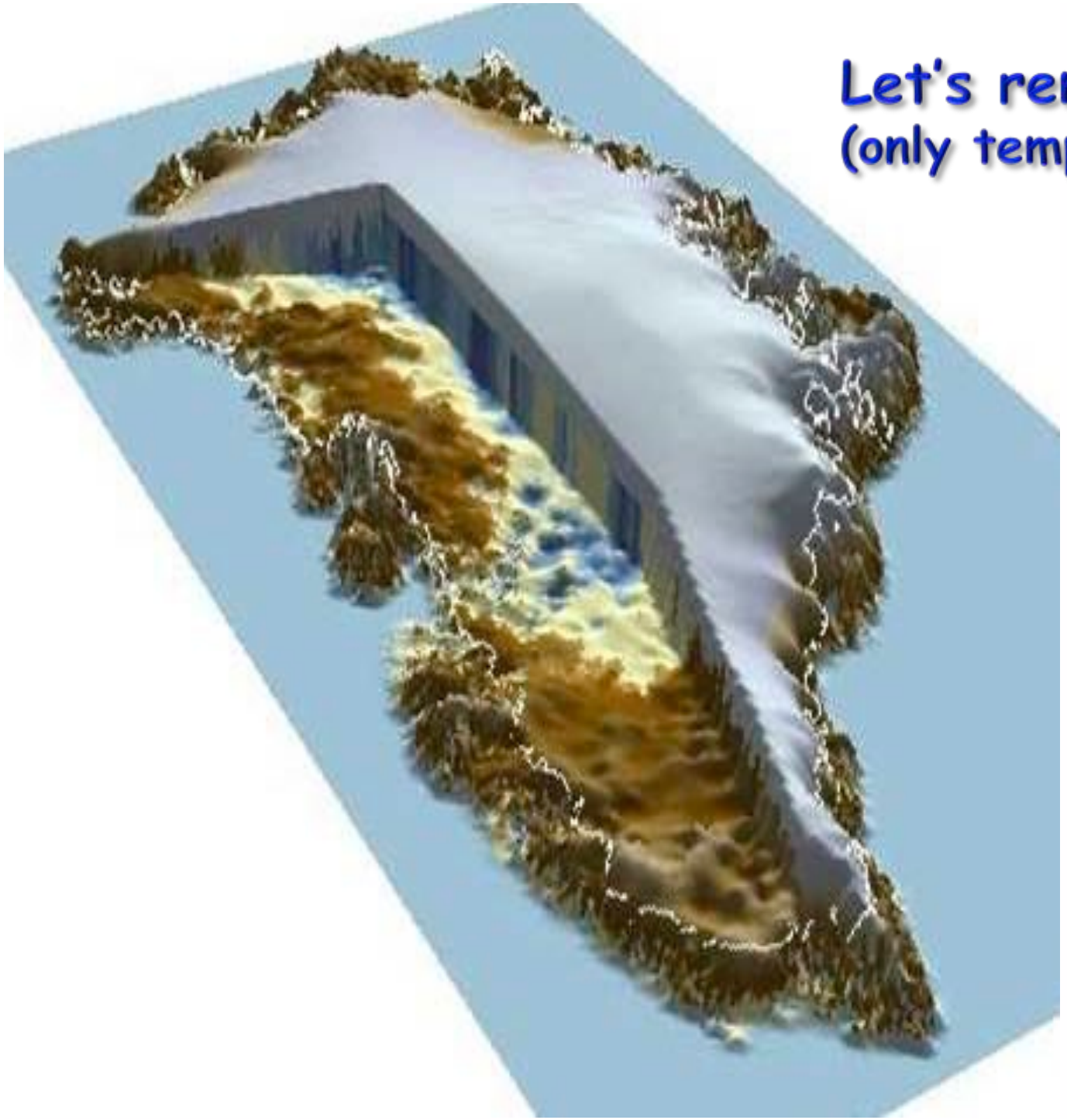


Cryo-Hydrologic Warming
(englacial temperature increase)



- influence of en-glacial melt water network on ice temperatures with and without including a cryo-hydrologic term in ice model.

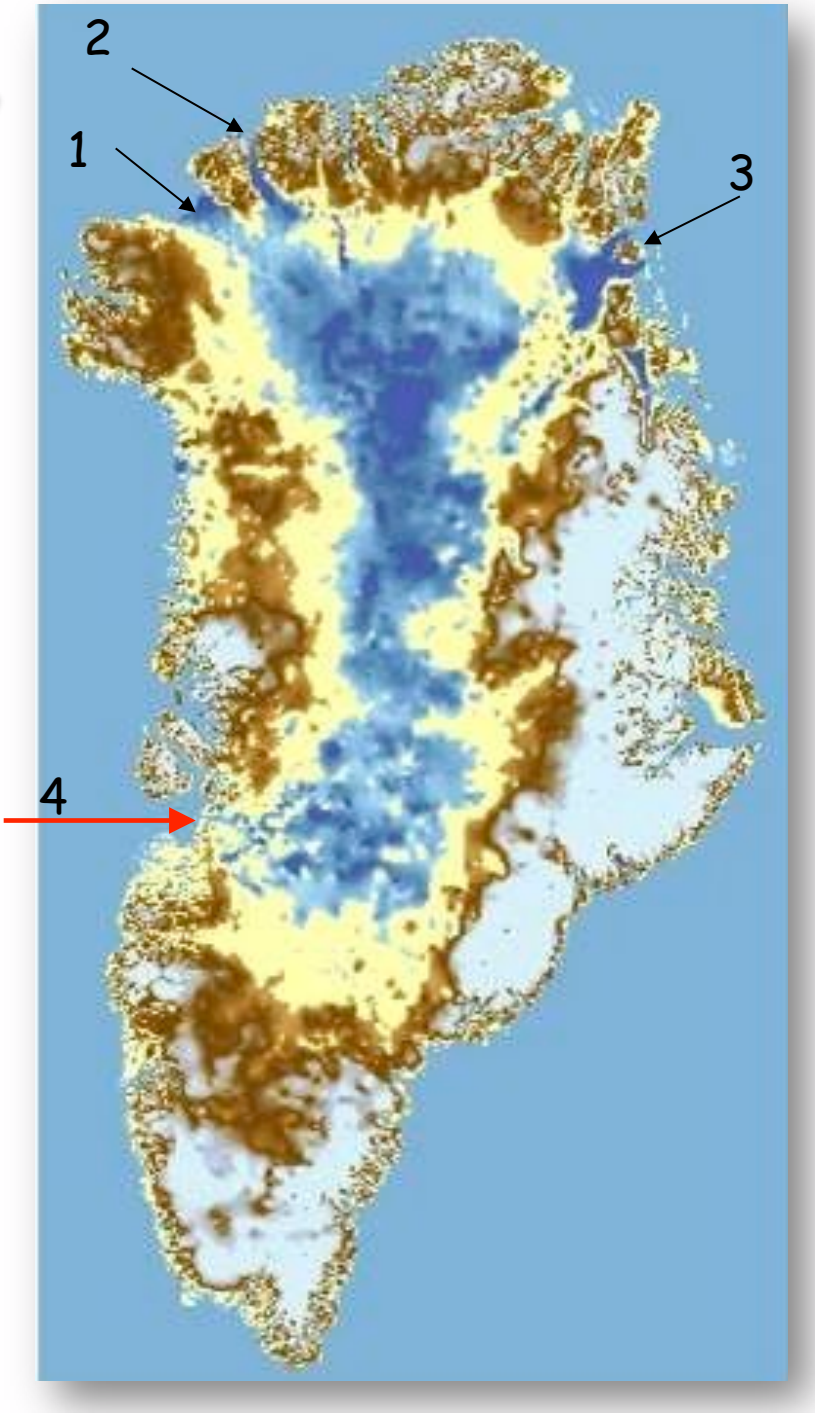
Phillips, Rajaram, and Steffen: Cryo-hydrologic warming: A potential mechanism for rapid thermal response of ice sheet (GRL, 2010)



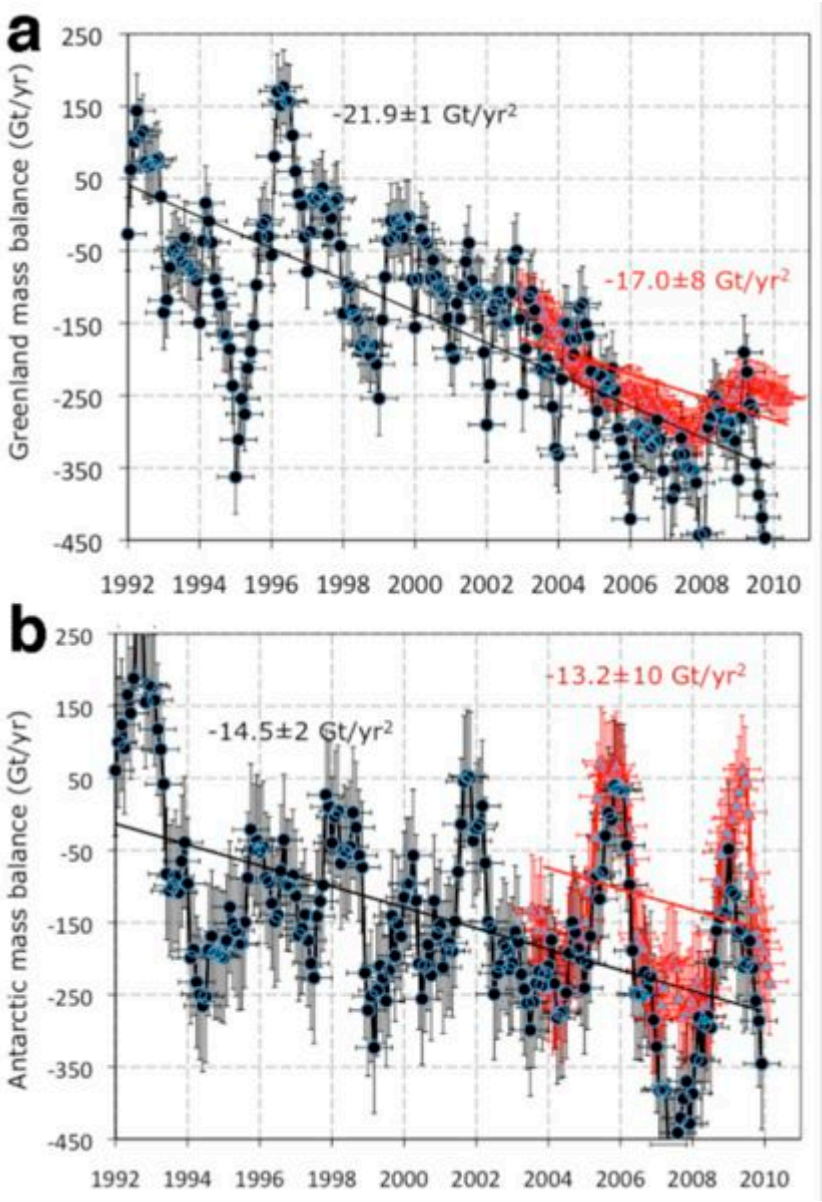
Let's remove the ice
(only temporarily)

Bedrock Topography of Greenland

- (1) Humboldt, (2) Petermann, (3) 79 North and (4) Jakobshavn glaciers are the *"plugs in the bathtub"*
- If the grounding line of these glaciers retreat further, increase in ice flux is possible.
- This possible scenario has now been observed at Jakobshavn Isbrea → increase in velocity, surface lowering, and retreat of grounding line
- **No ice-sheet model is currently capable of capturing the glacier speedups in Greenland that have been observe over the last decade.**



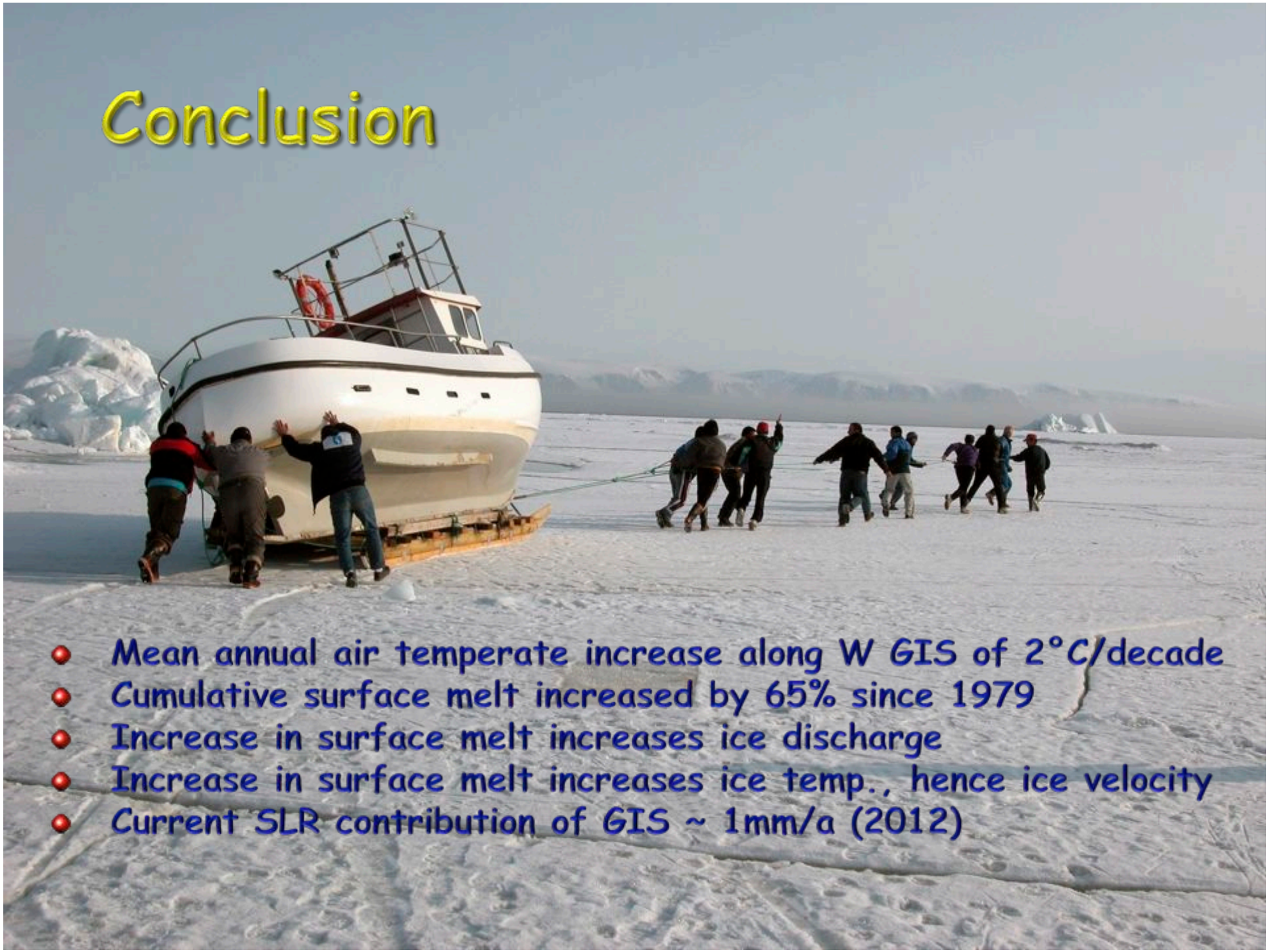
Ice Sheet Mass Change Acceleration 1992-2010



- In 2006, the Greenland and Antarctic ice sheets experienced a combined mass loss of 475 ± 158 Gt/yr, equivalent to **1.3 ± 0.4 mm/yr** sea level rise.
- Acceleration in ice sheet loss over the last 18 years was 21.9 ± 1 Gt/yr^2 for Greenland and 14.5 ± 2 Gt/yr^2 for Antarctica, for a combined total of **36.3 ± 2 Gt/yr^2**
- Acceleration is 3 times larger than for mountain glaciers and ice caps (12 ± 6 Gt/yr^2).

Rignot et al., 2011, GRL

Conclusion



- Mean annual air temperate increase along W GIS of 2°C/decade
- Cumulative surface melt increased by 65% since 1979
- Increase in surface melt increases ice discharge
- Increase in surface melt increases ice temp., hence ice velocity
- Current SLR contribution of GIS ~ 1mm/a (2012)


Thank you