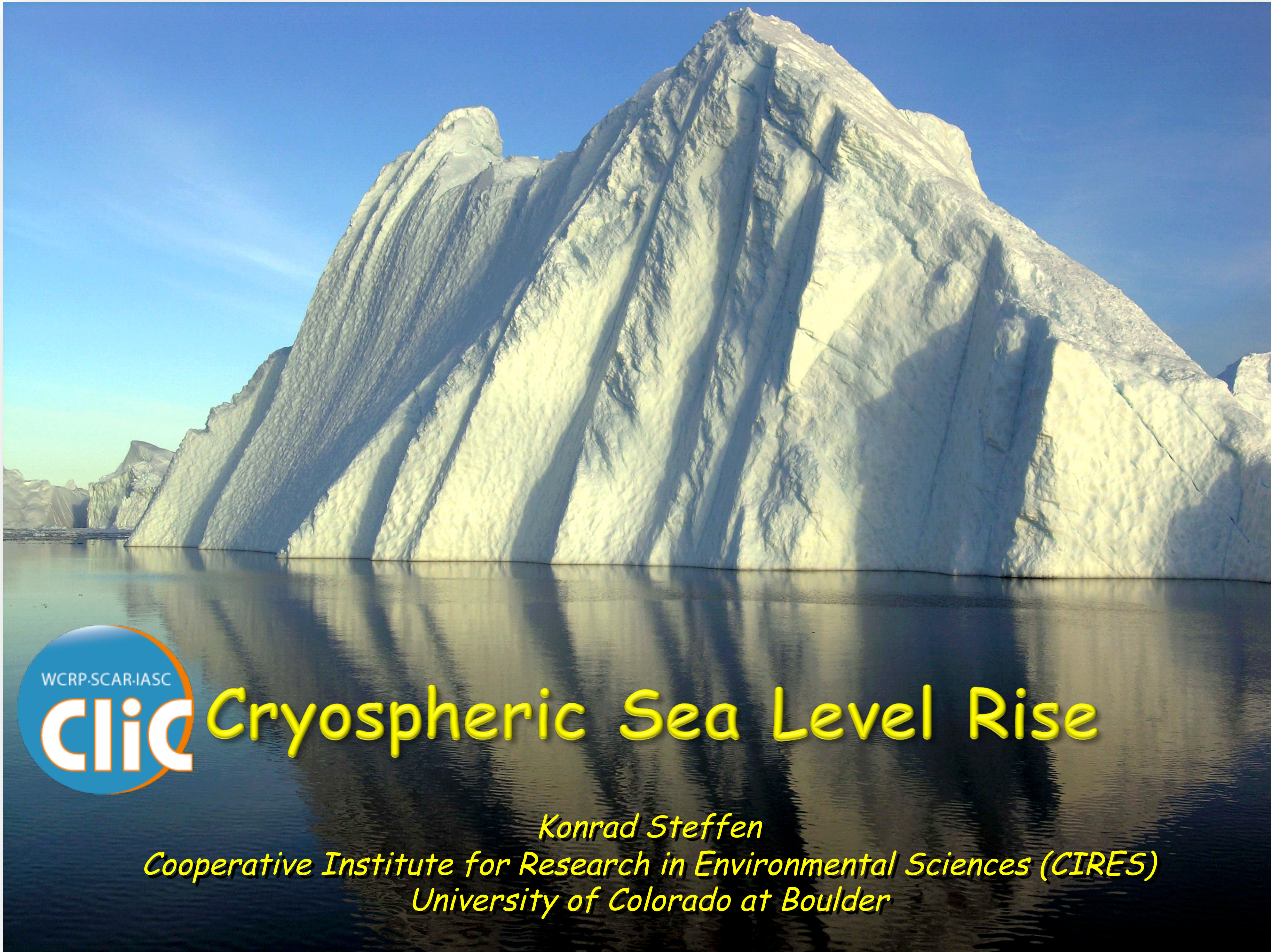
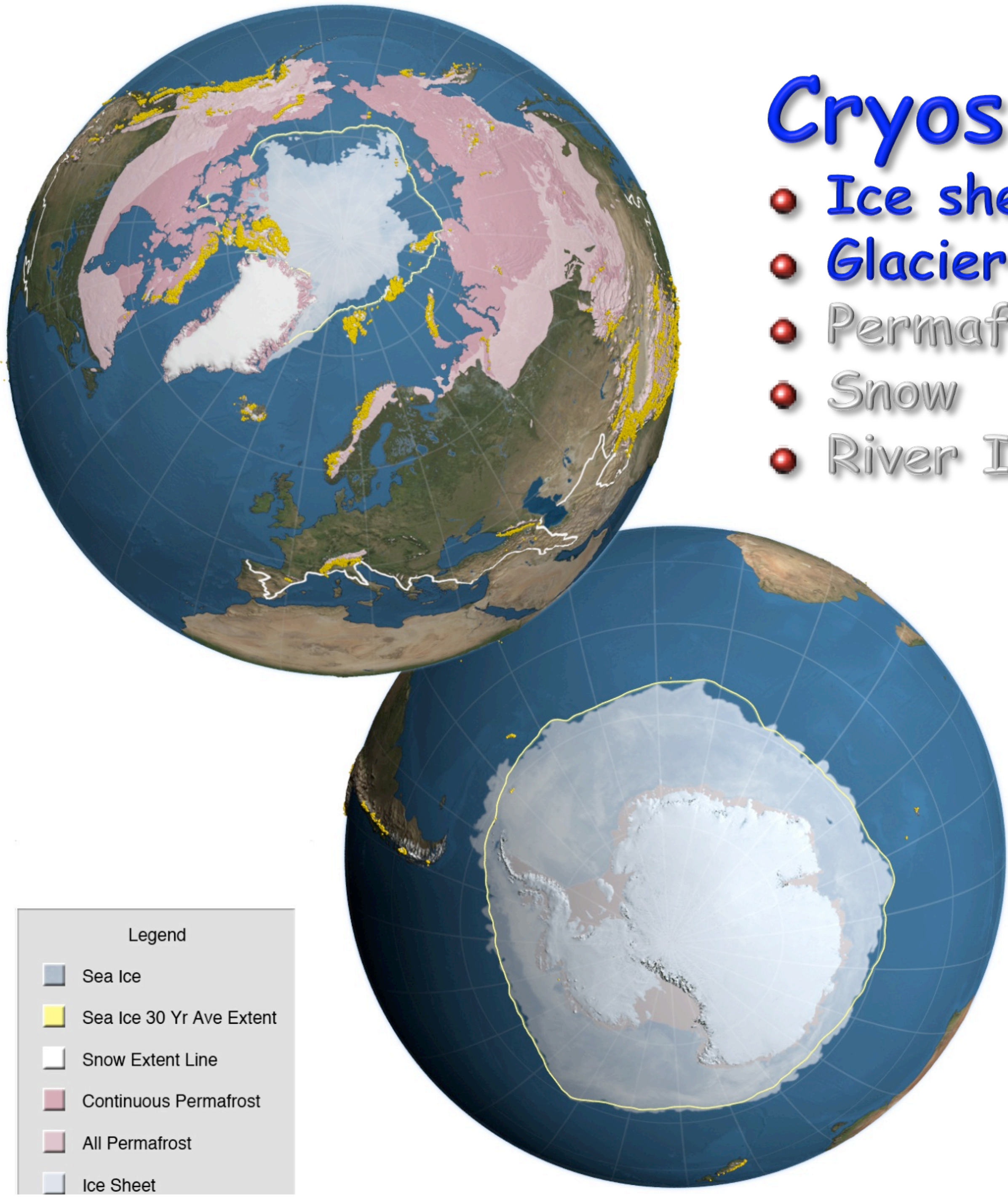


Cryospheric Sea Level Rise

Konrad Steffen
Cooperative Institute for Research in Environmental Sciences (CIRES)
University of Colorado at Boulder

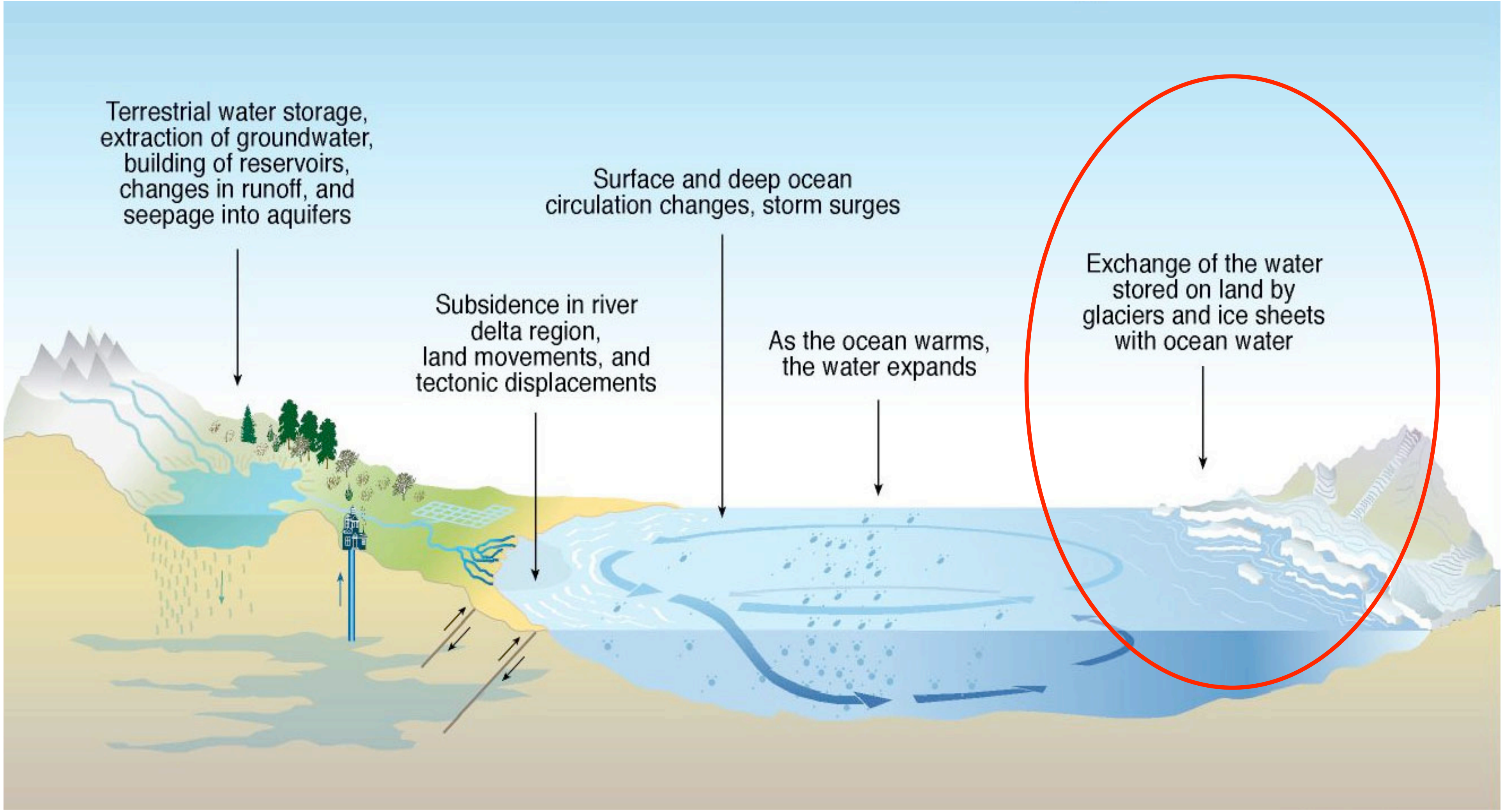
Cryosphere

- Ice sheets
- Glaciers & Ice Caps
- Permafrost
- Snow
- River Ice

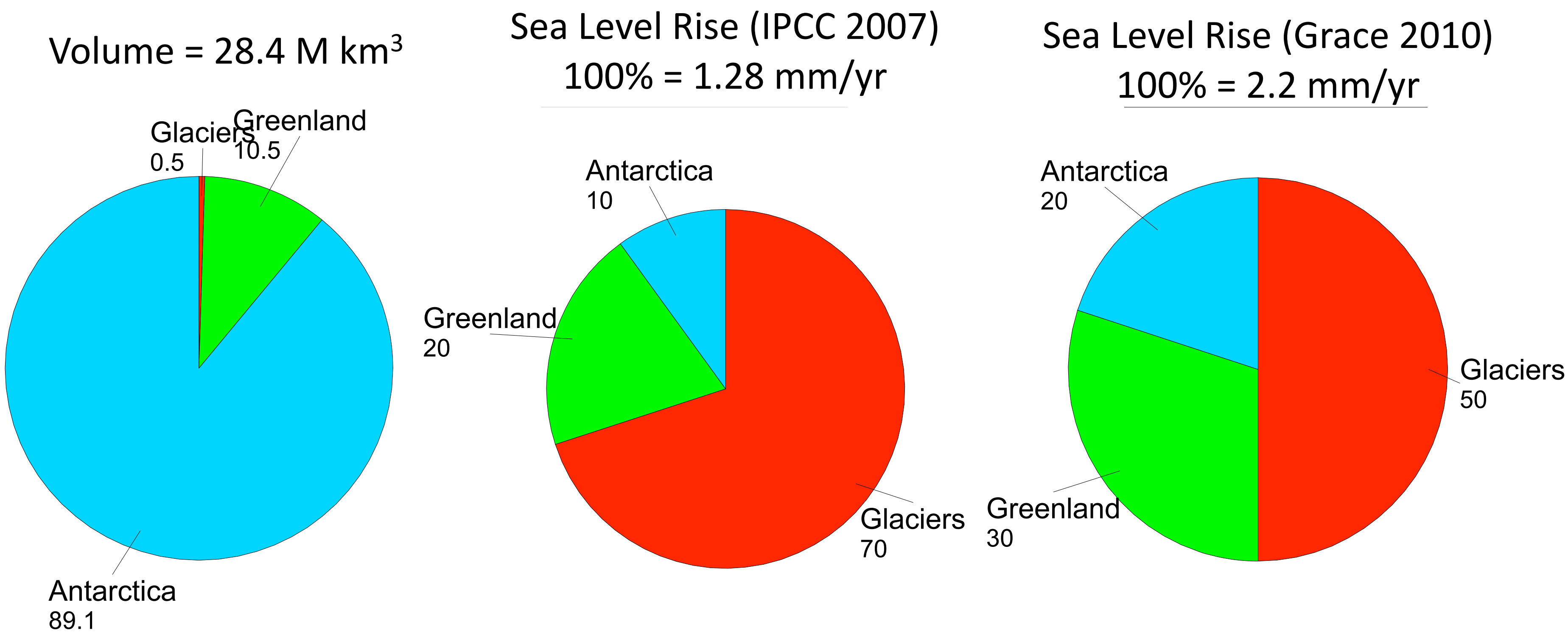


Joey Comiso, NSAS/GSFC

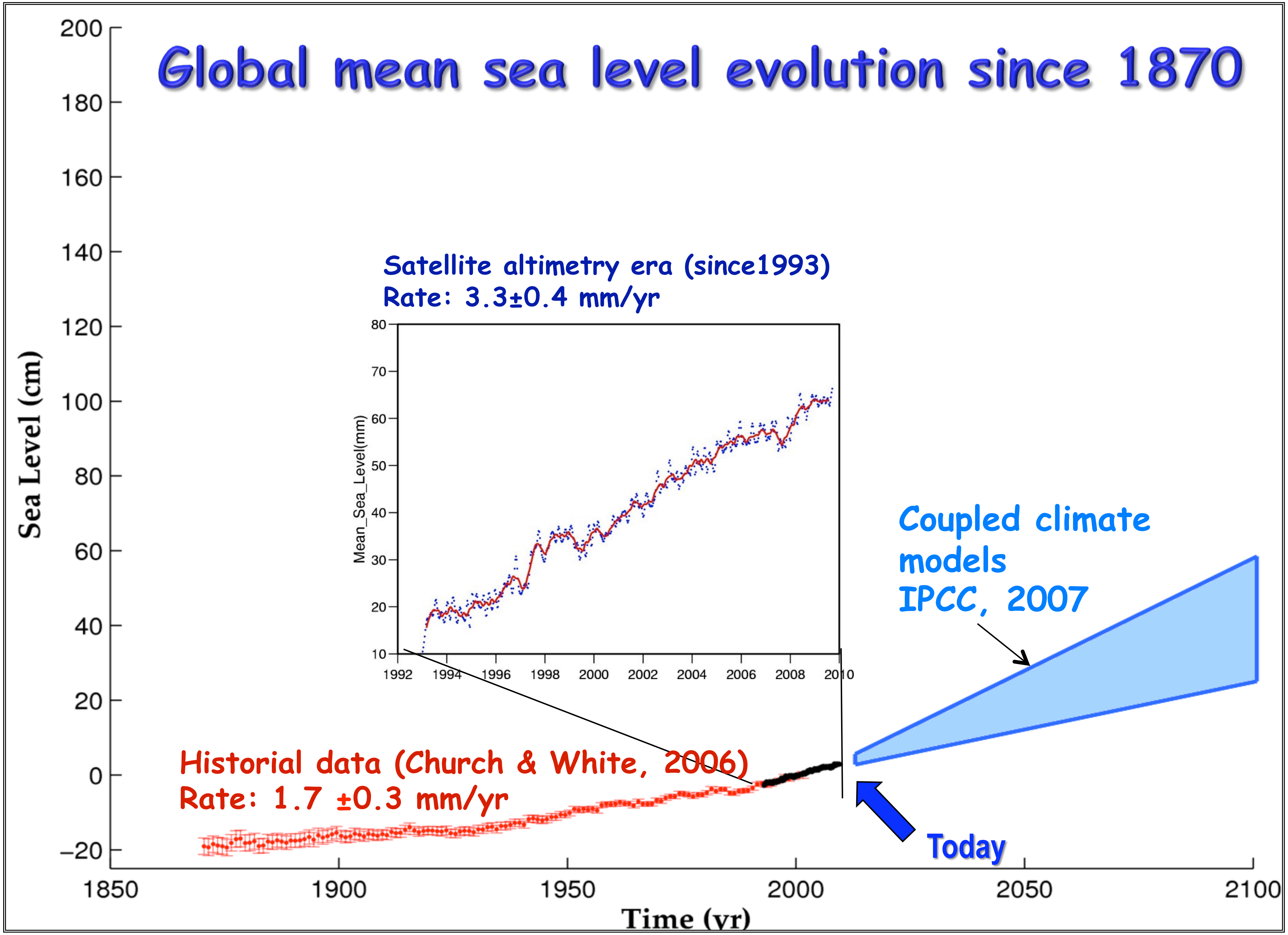
What Causes Sea Level to Change?

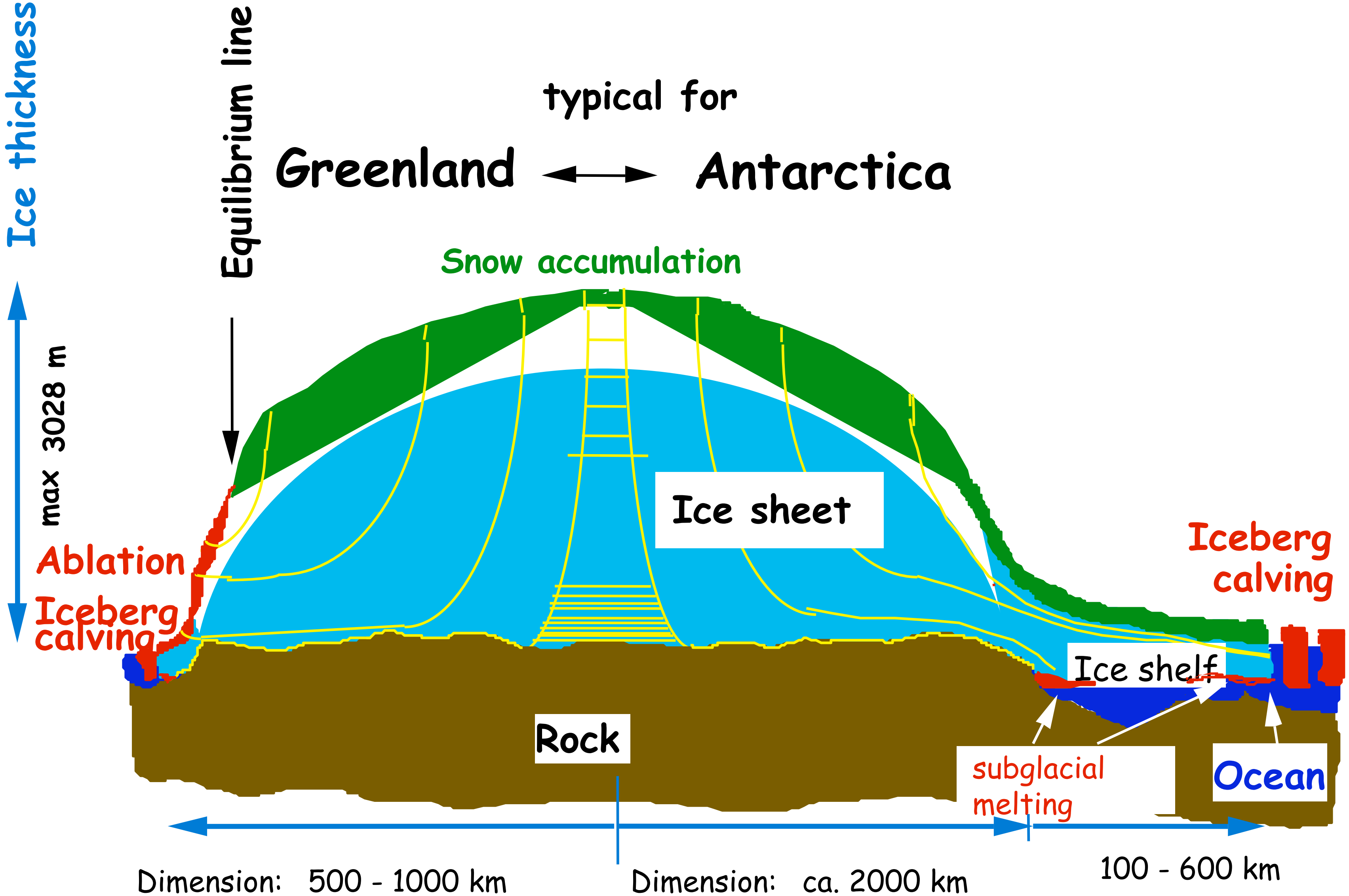


Cryospheric Sea Level Rise



Comparison of total volume (left), and total contribution to sea-level rise from glaciers & ice caps and the ice sheets in Greenland and Antarctica


Global mean sea level evolution since 1870
Satellite altimetry era (since1993)
Rate: 3.3±0.4 mm/yr
Mean_Sea_Level(mm)
Coupled climate models
IPCC, 2007
Historial data (Church & White, 2006)
Rate: 1.7 ±0.3 mm/yr
Today
Sea Level (cm)
Time (yr)



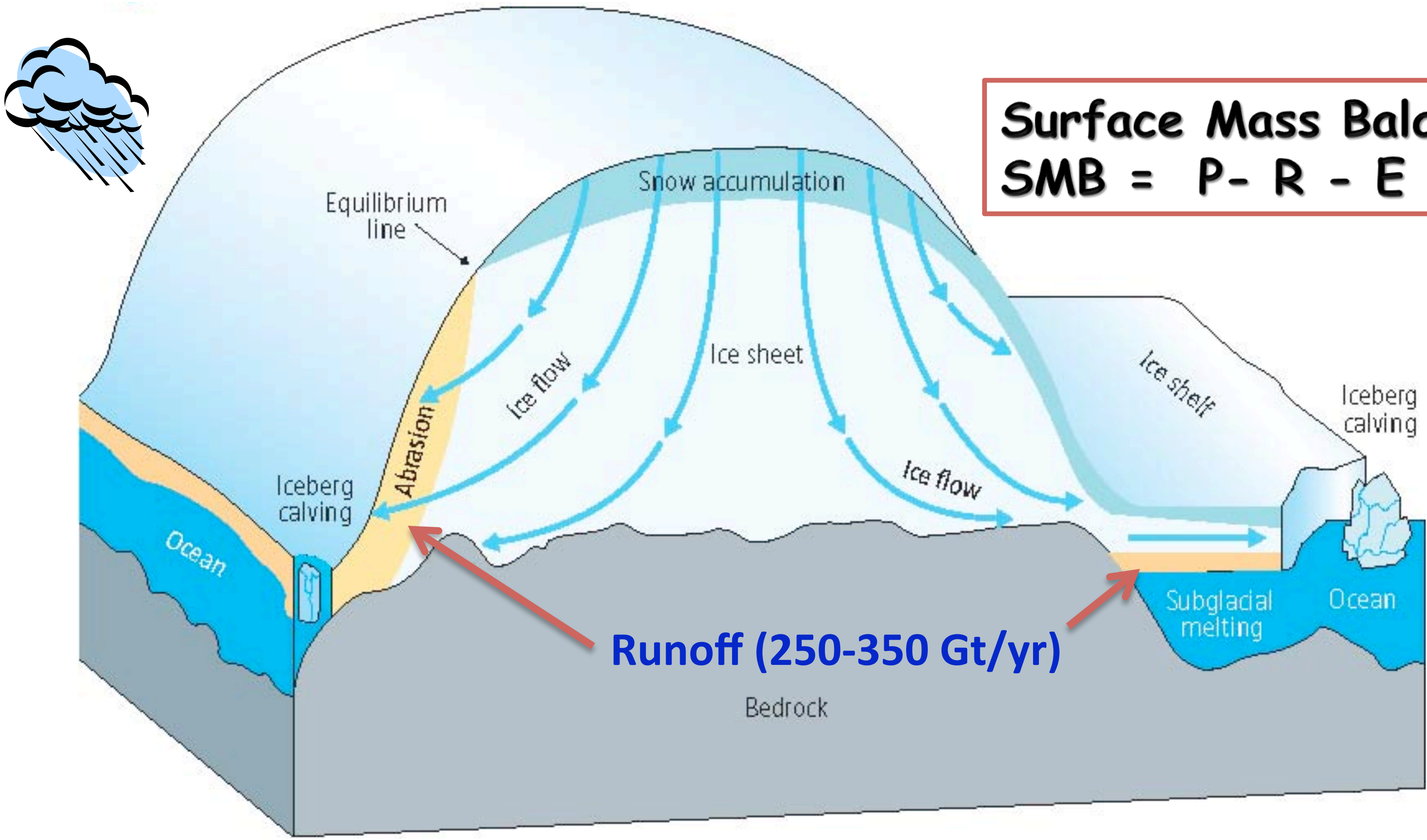
Dimension:	500 - 1000 km	Dimension:	ca. 2000 km
Area:	1.7 M km^2	Area:	12.3 M km^2
Volume:	2.9 M km^3, 7.3 m SLE	Volume:	24.7 M km^3, 56.6 m SLE
Total Acc.:	500 Gt a^{-1}, 1.4 mm SLE	Total Acc.:	1850 Gt a^{-1}, 5.1 mm SLE

Greenland Mass Balance

1995-2005

Precipitation (550-640 Gt/yr)

Evaporation (5-63 Gt/yr)

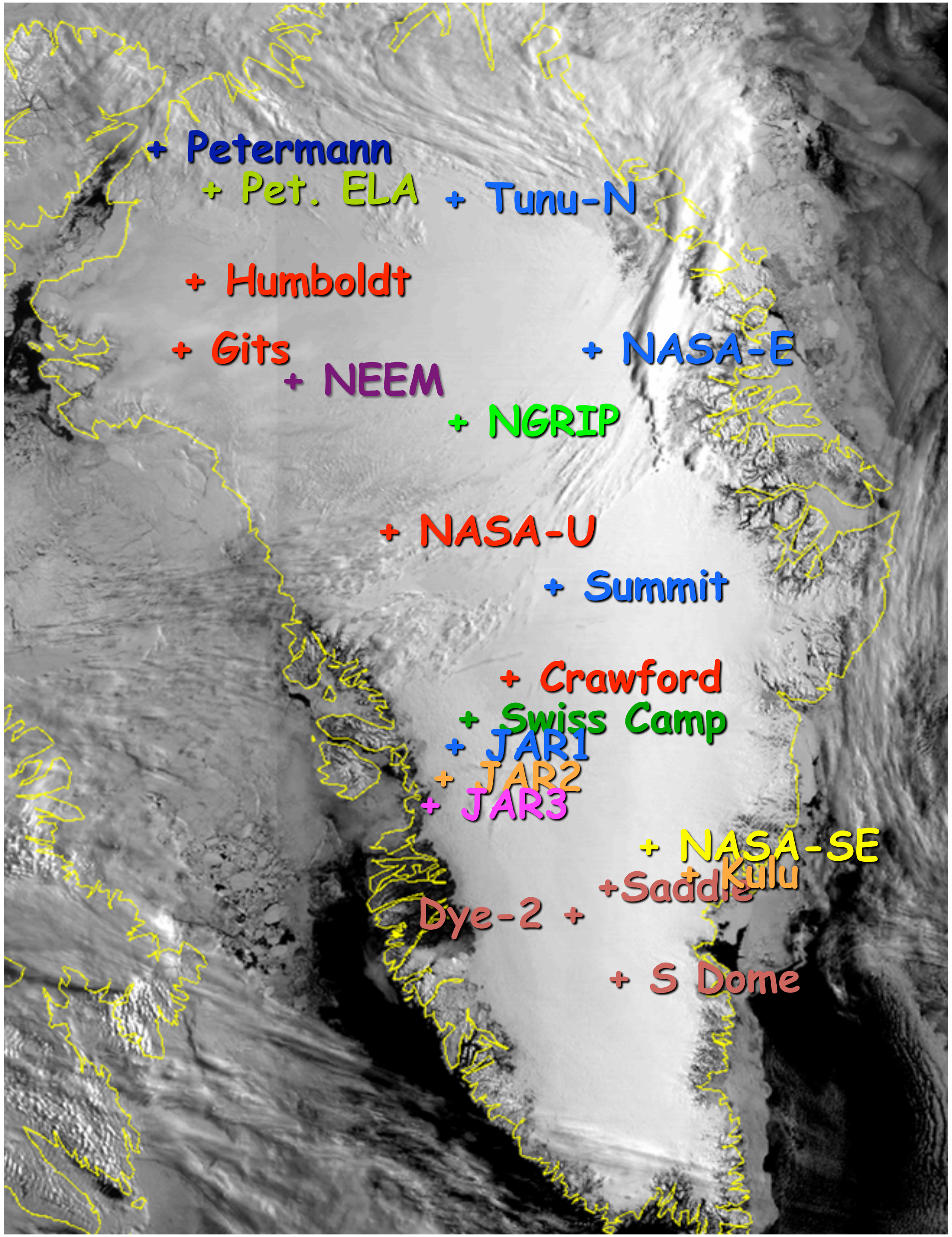


Surface Mass Balance
SMB = P- R - E

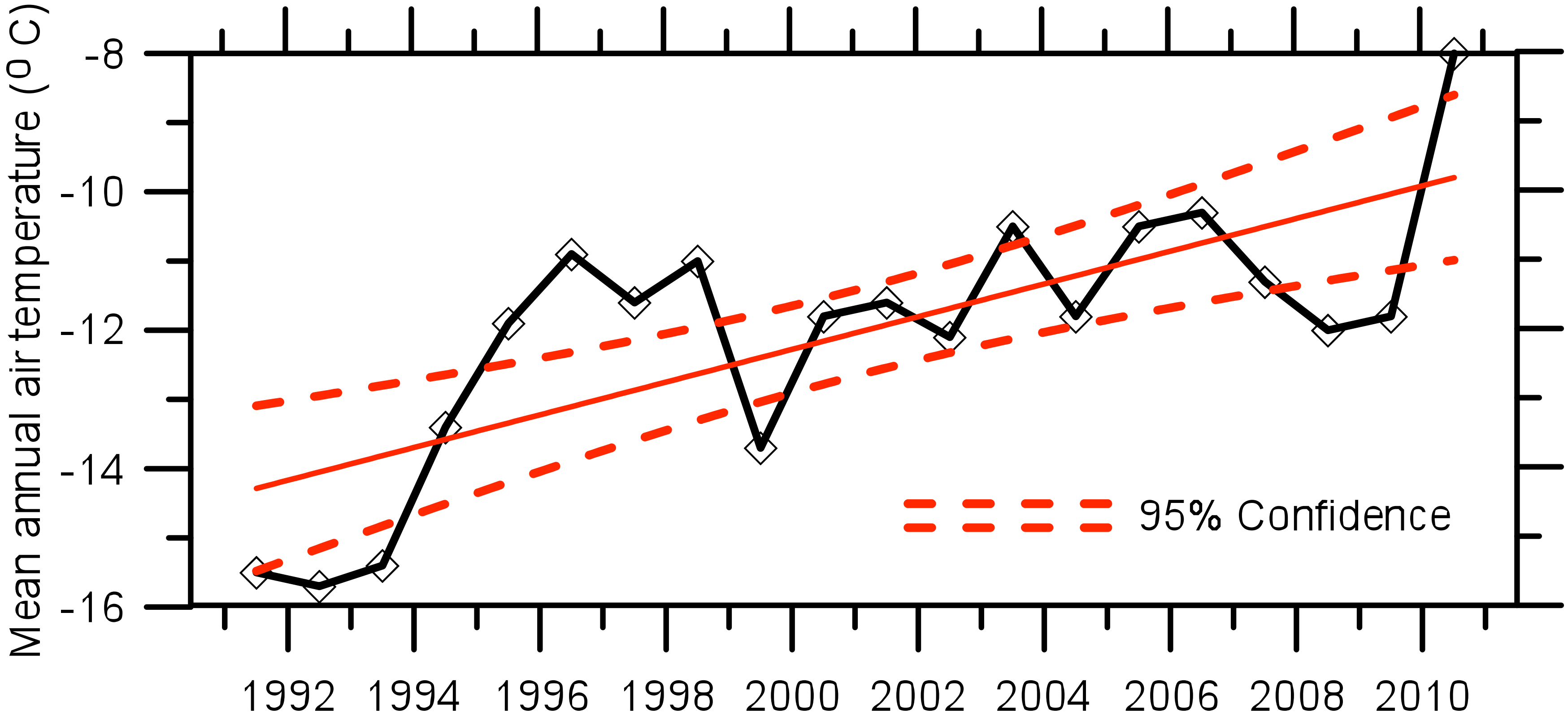
Ice Discharge (320-420 Gt/yr)

Im-Balance (50-200 Gt/yr)

GC-Net Greenland Climate Network

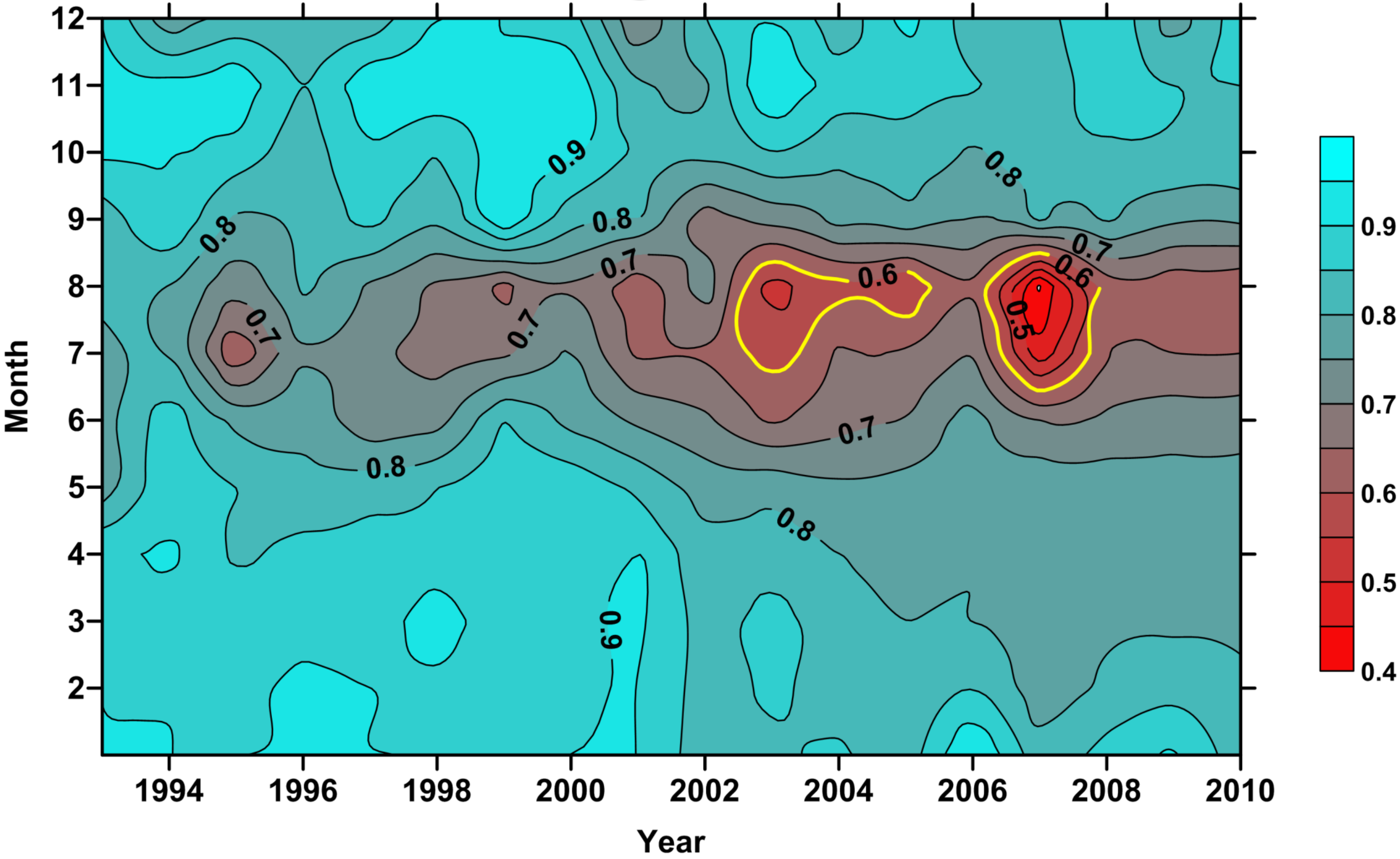


Air Temperatures at ETH/CU Camp 1991-2010



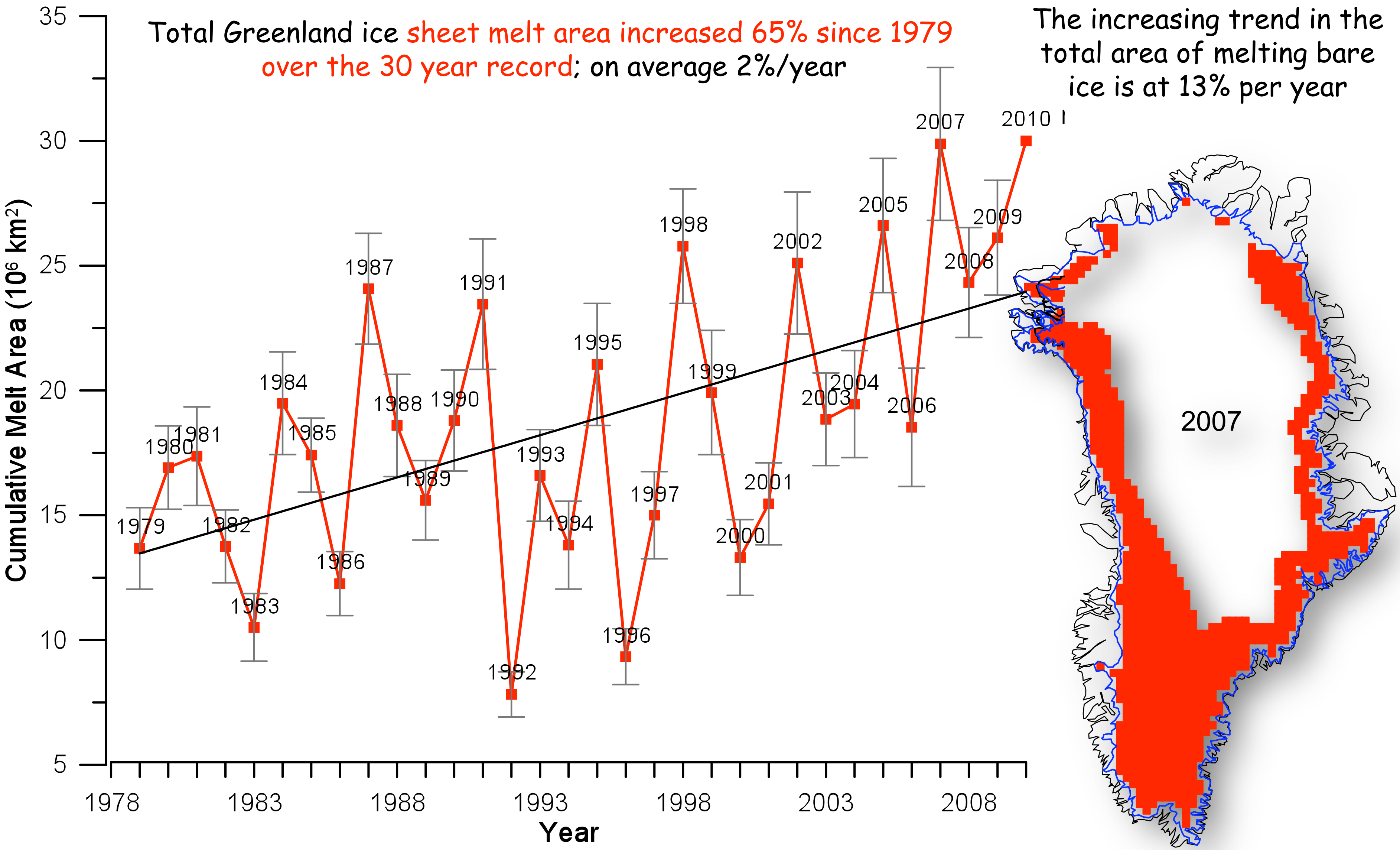
Mean annual air temperature increased by 4 °C since 1991 (~2 °C/decade)

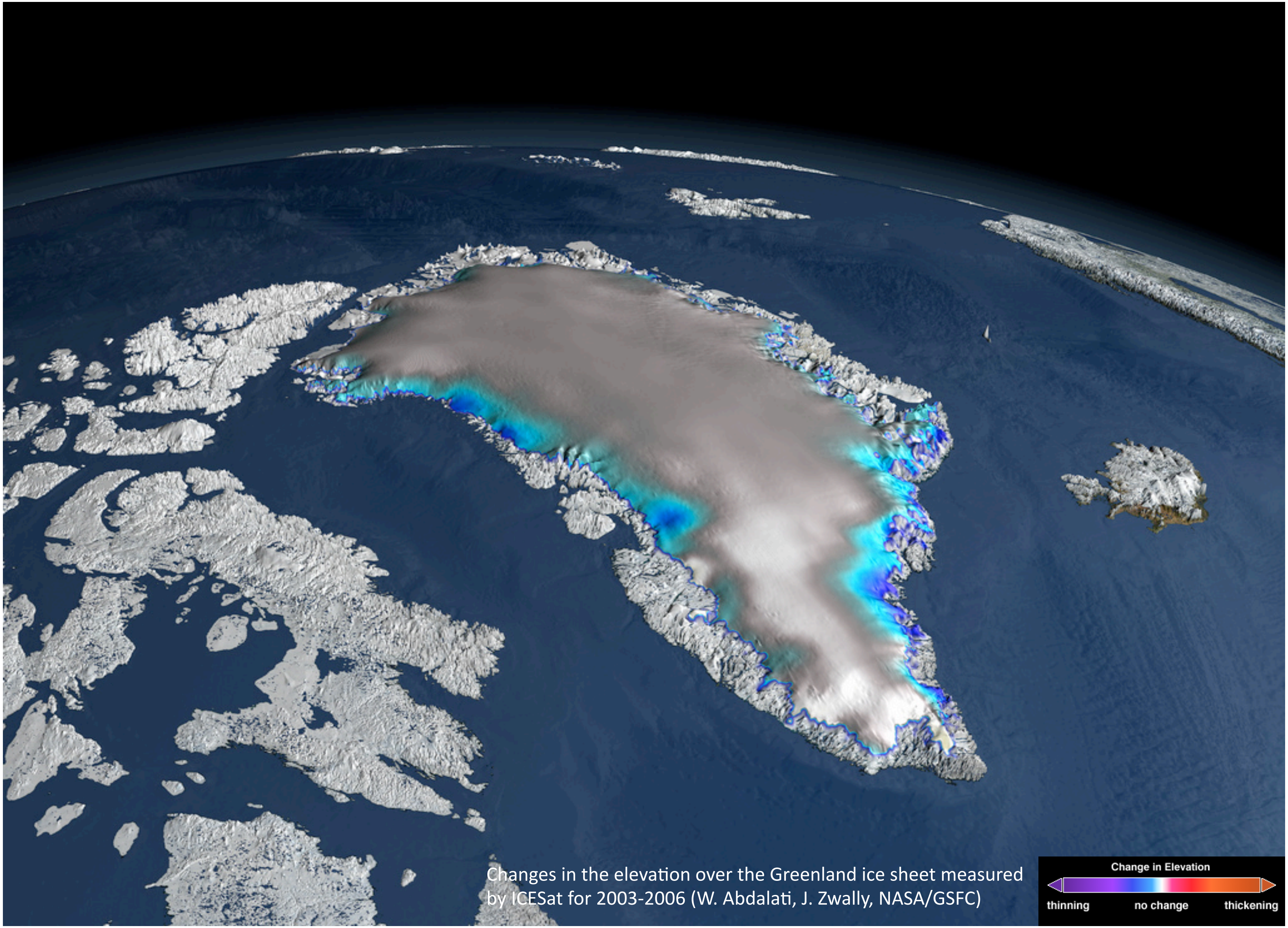
Albedo Variability
Swiss Camp 1991-2009



Surface mass balance is negative since 1996

Greenland Total Melt Area: 1979-2010

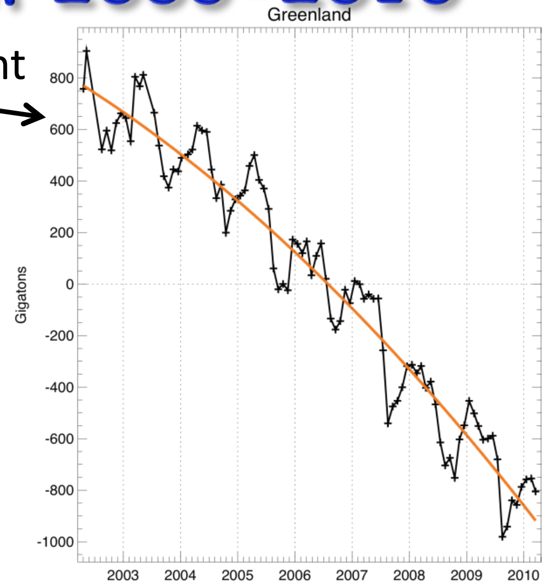


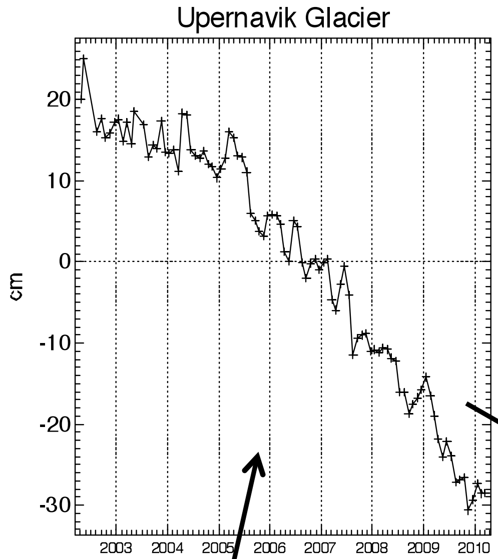


Changes in the elevation over the Greenland ice sheet measured by ICESat for 2003-2006 (W. Abdalati, J. Zwally, NASA/GSFC)

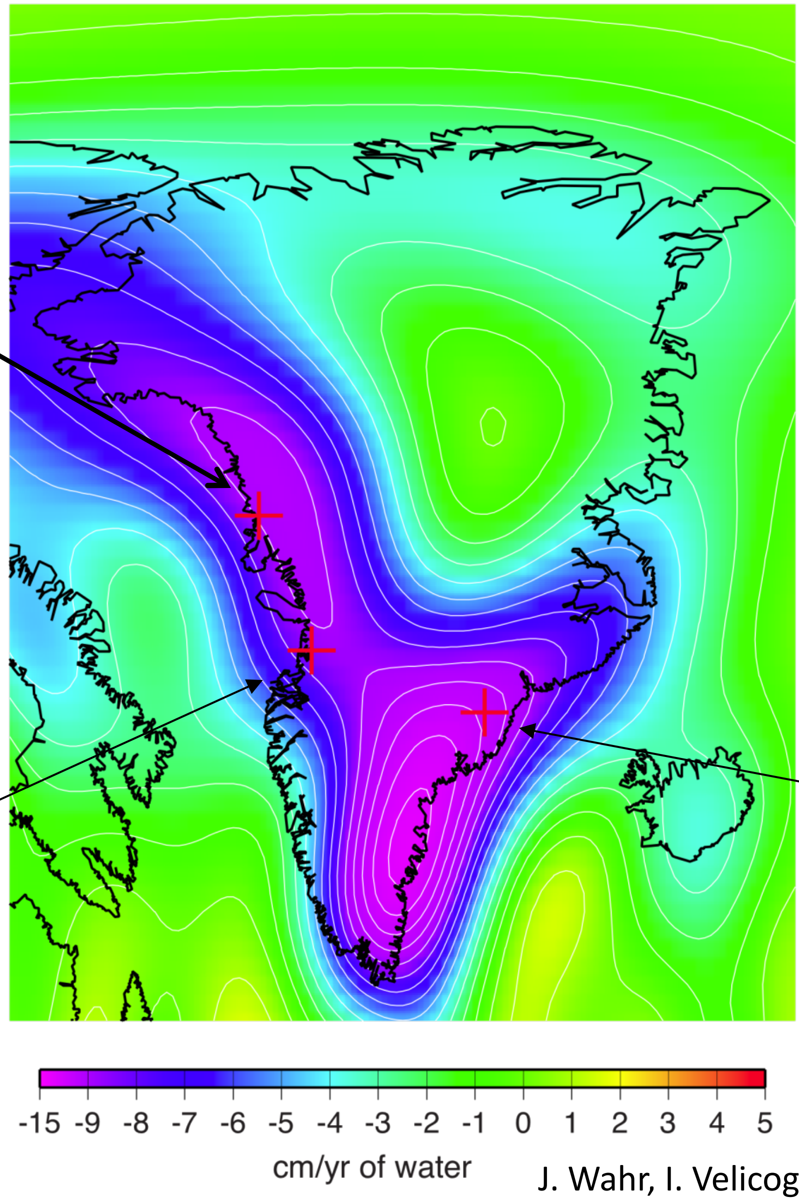
GRACE: Rate of Mass Loss between 2003-2010

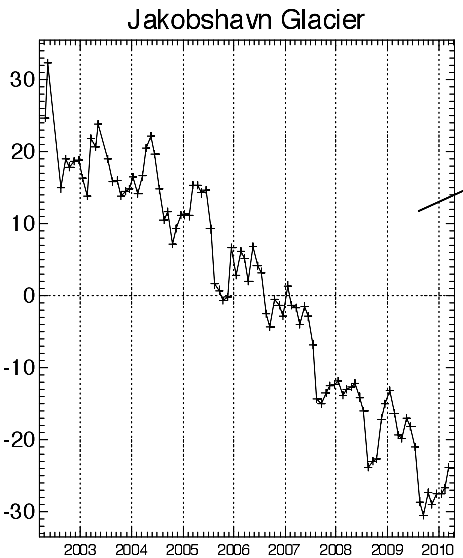
Rate of total mass loss: 240 Gt/a, equivalent to 0.66 mm/yr sea level rise.

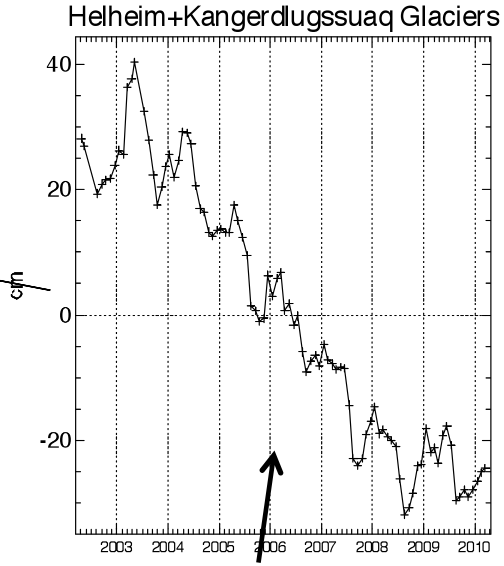




Mass loss increased in 05.



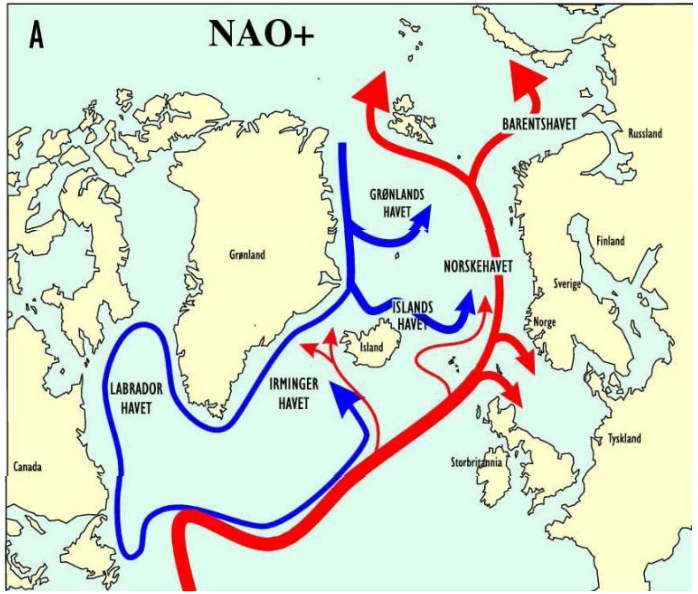


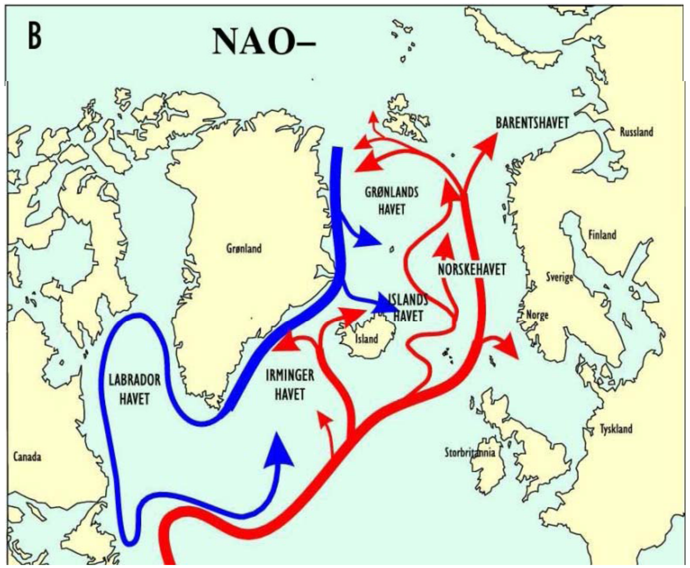


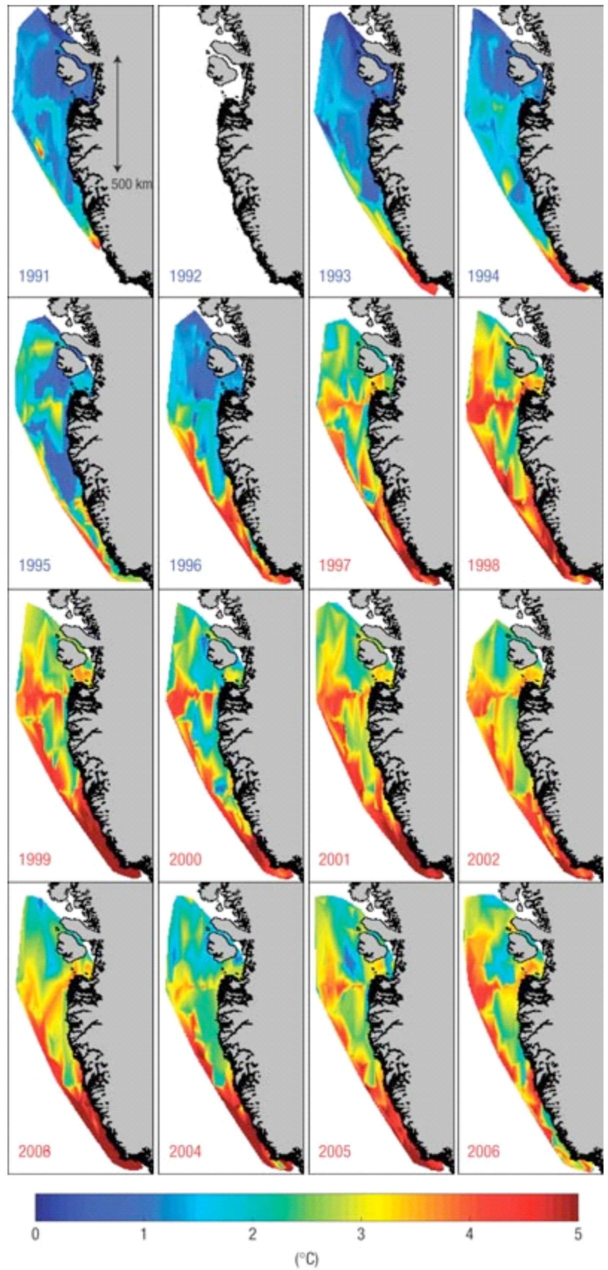
Mass loss increased in 04/05.
Decreased in 07/08.

J. Wahr, I. Velicogna

Warm Water Intrusion

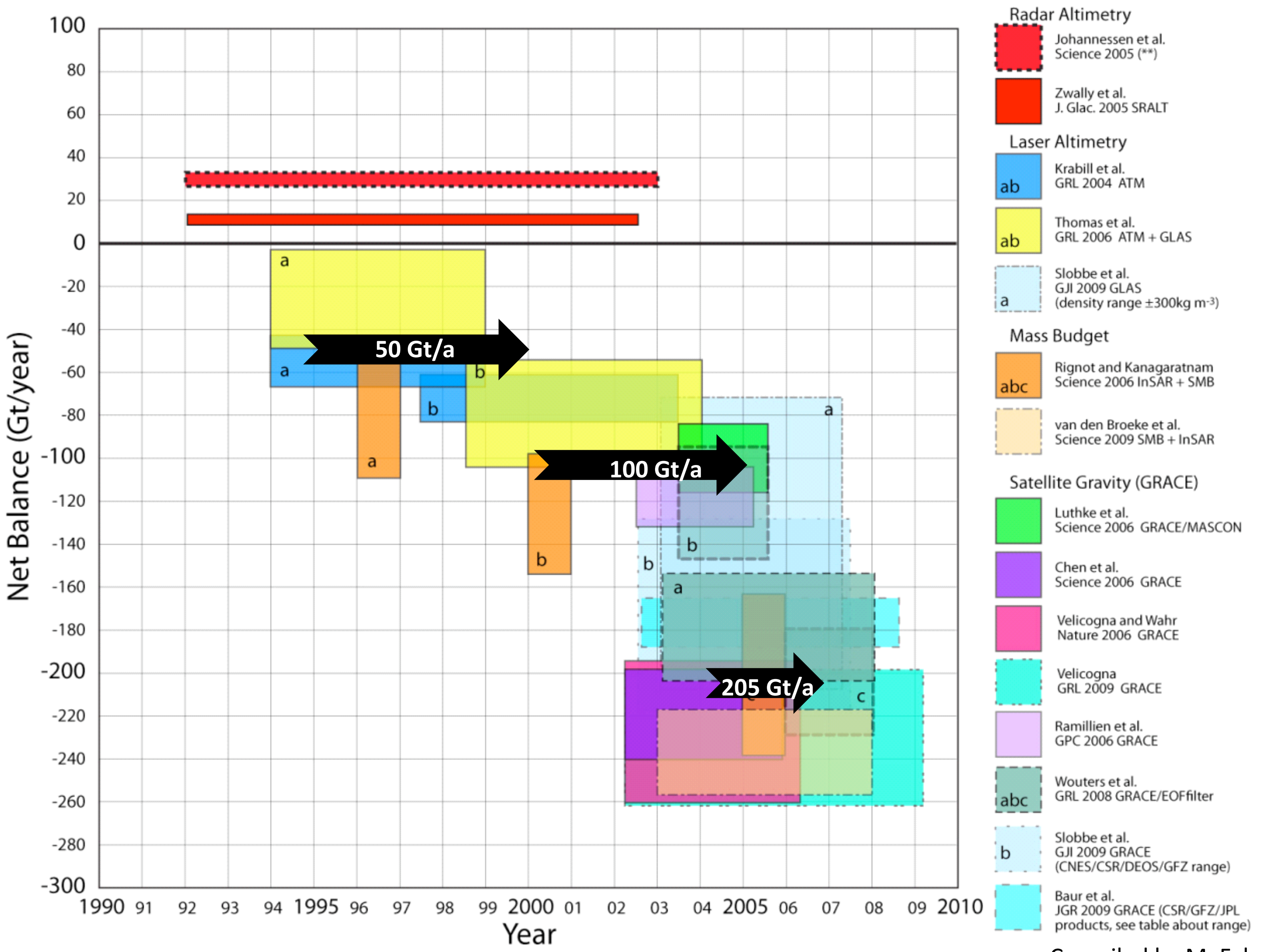






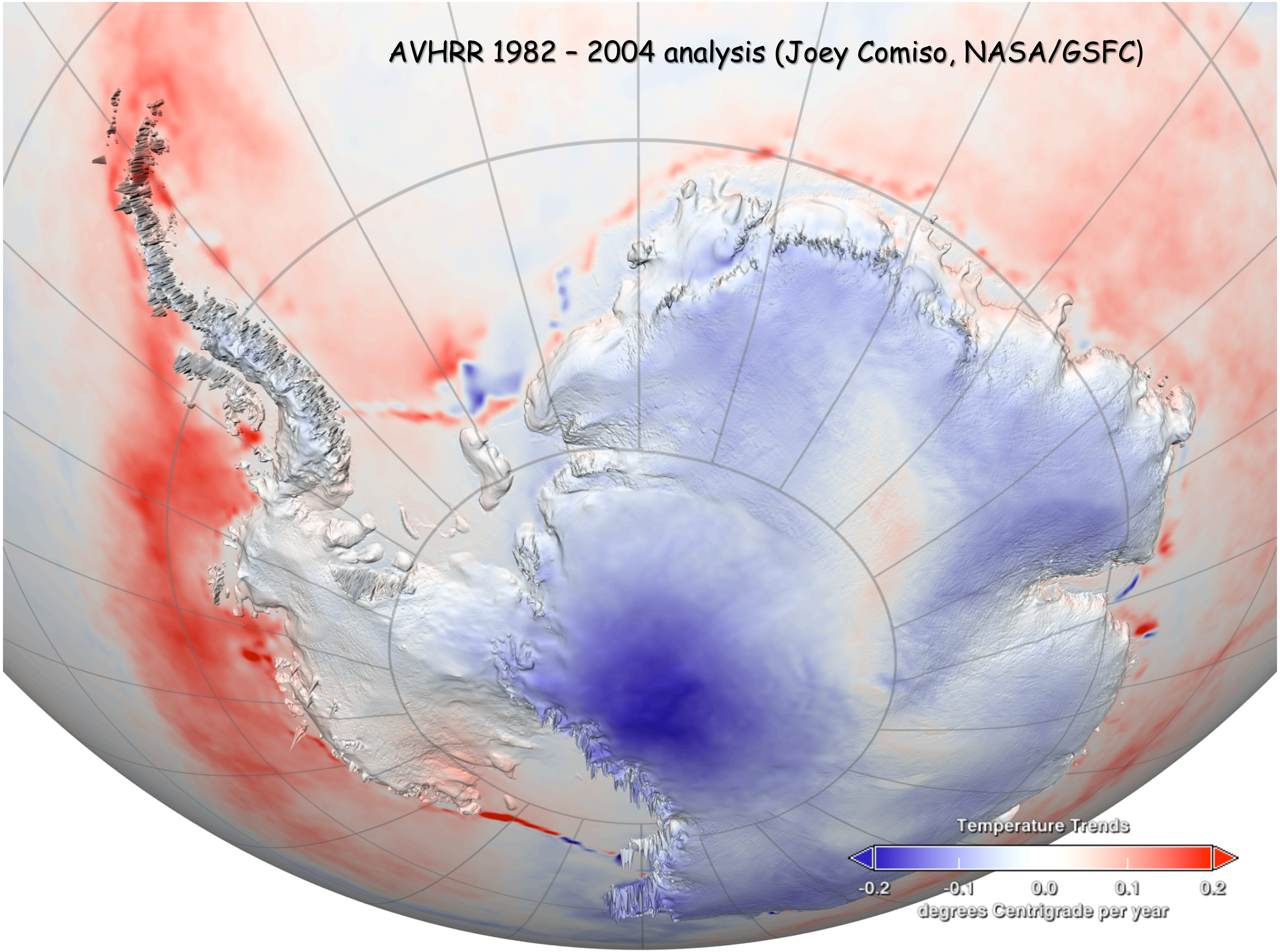
Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters
David Holland, Robert Thomas, Brad de Young, Mads Ribergaard, and Bjarne Lyberth

Greenland Ice Sheet Mass Balance

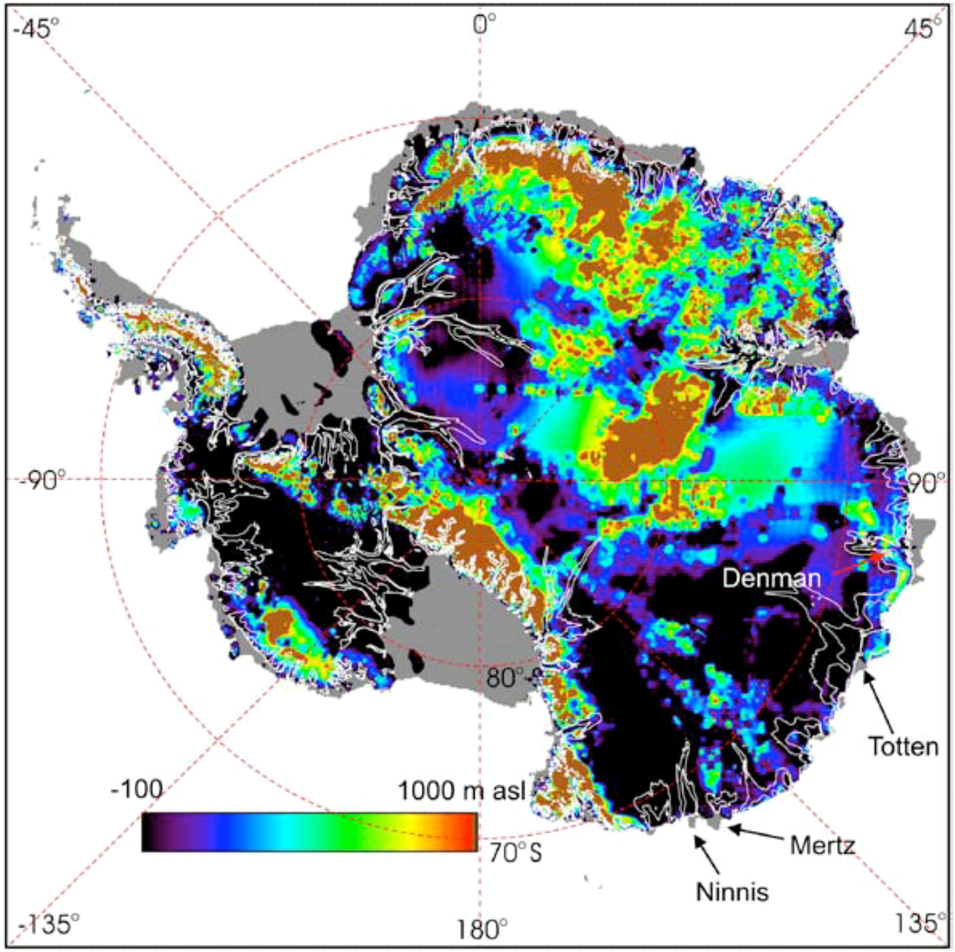


Compiled by M. Fahnestock for AMAP

AVHRR 1982 – 2004 analysis (Joey Comiso, NASA/GSFC)



Bedrock Topography of Antarctica

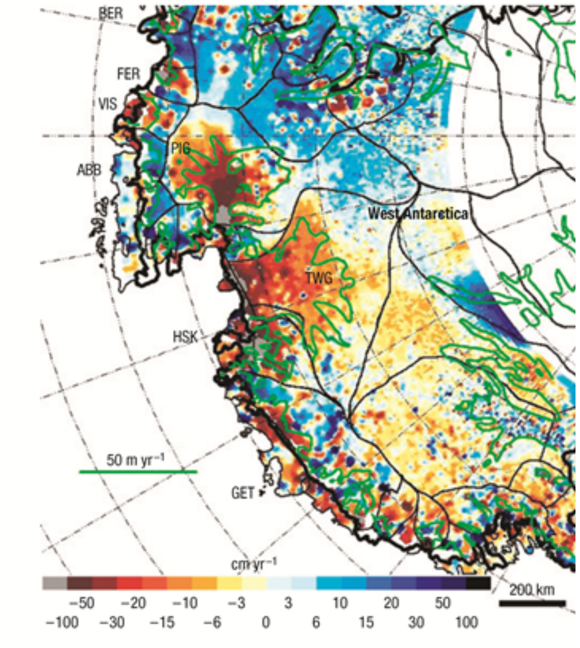


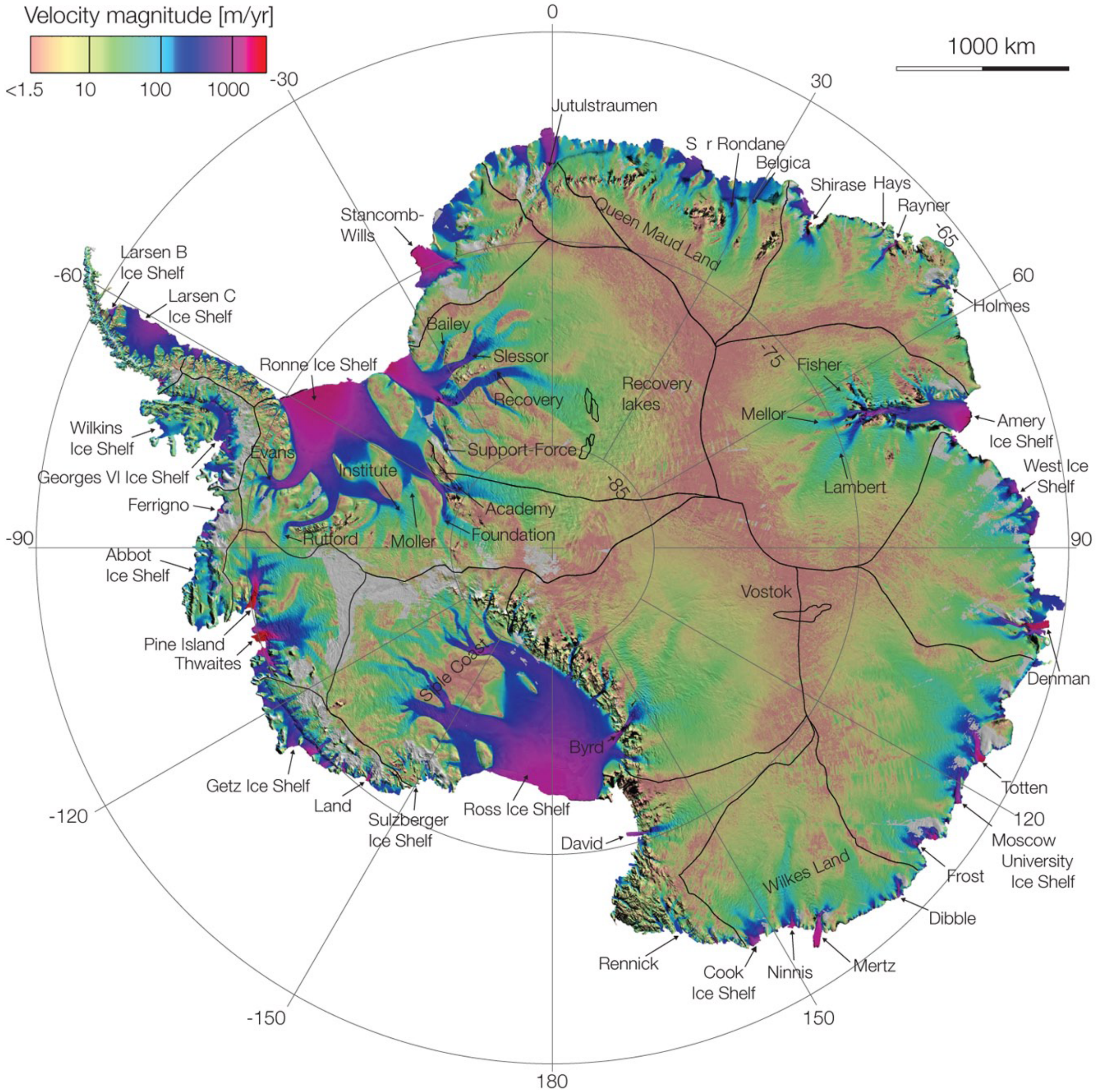
Bedrock topography for Antarctica highlighting areas below sea level (in black), fringing ice shelves (in dark grey) and areas above sea level (in rainbow colors).From *Bamber et al.* (2007)

Changes in ocean circulation and ocean temperatures will produce changes in basal melting, but the magnitude of these changes is currently not modeled or predicted.

West Antarctic ice sheet (7 m SLE) grounded below sea level on marine sediment experiencing high geothermal heat flow.

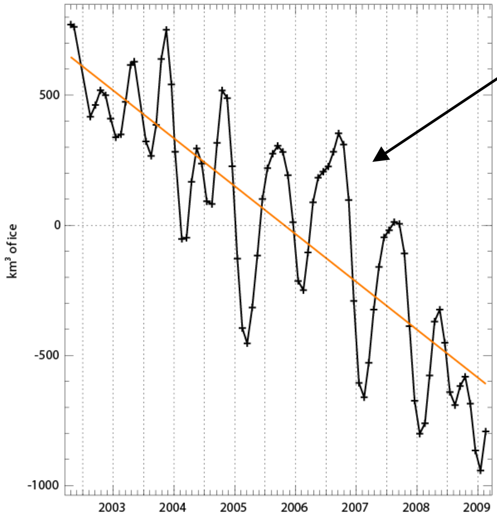
Antarctic Ice Velocity and Mass Loss





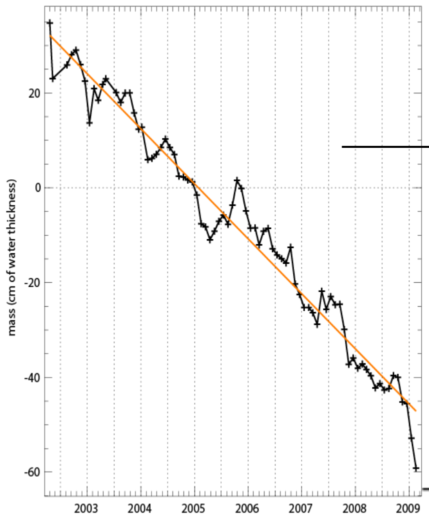
dh/dt (1995-2005)

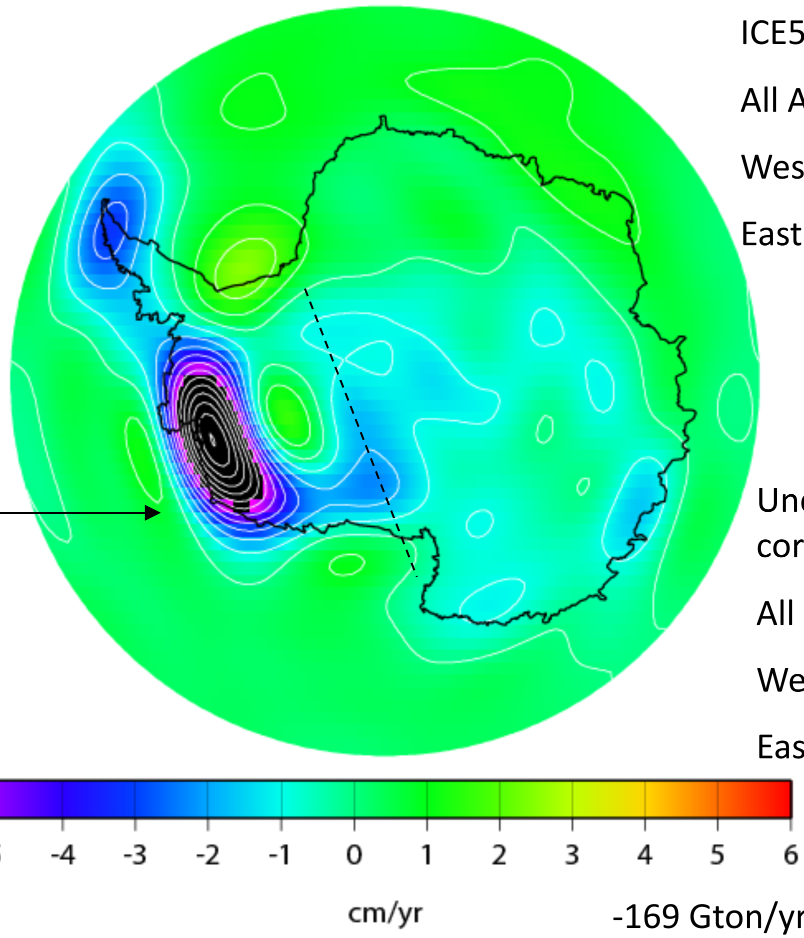
Rate of mass change during April 2002 - Feb 2009



Total Antarctic ice volume.

Amundsen Sea glaciers





Rate of mass change after removing ICE5G rebound model:

All Antarctica: -169 Gt/yr

West Antarctica: -128 Gt/yr

East Antarctica: -36 Gt/yr

Uncertainty of post-glacial rebound correction:

All Antarctica: ± 75 km^3/yr

West Antarctica: ± 20 km^3/yr

East Antarctica: ± 50 km^3/yr

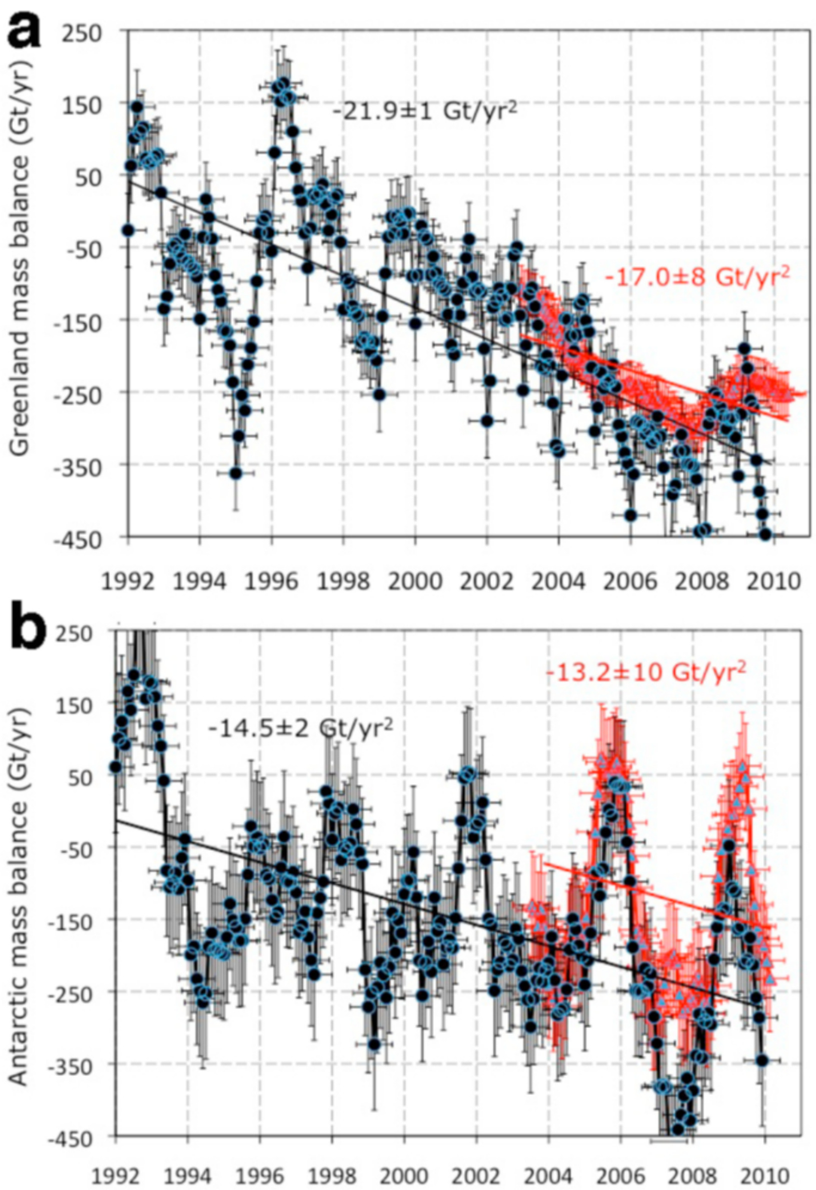
-169 Gton/yr = 0.47 mm/yr sea level rise

The results depend critically on which rebound model is removed.

After removing ICE-5G rebound prediction	After removing Ivins&James rebound prediction
All Antarctica: -169 Gton/yr	All Antarctica: -122 Gton/yr

John Wahr, Univ. Colorado

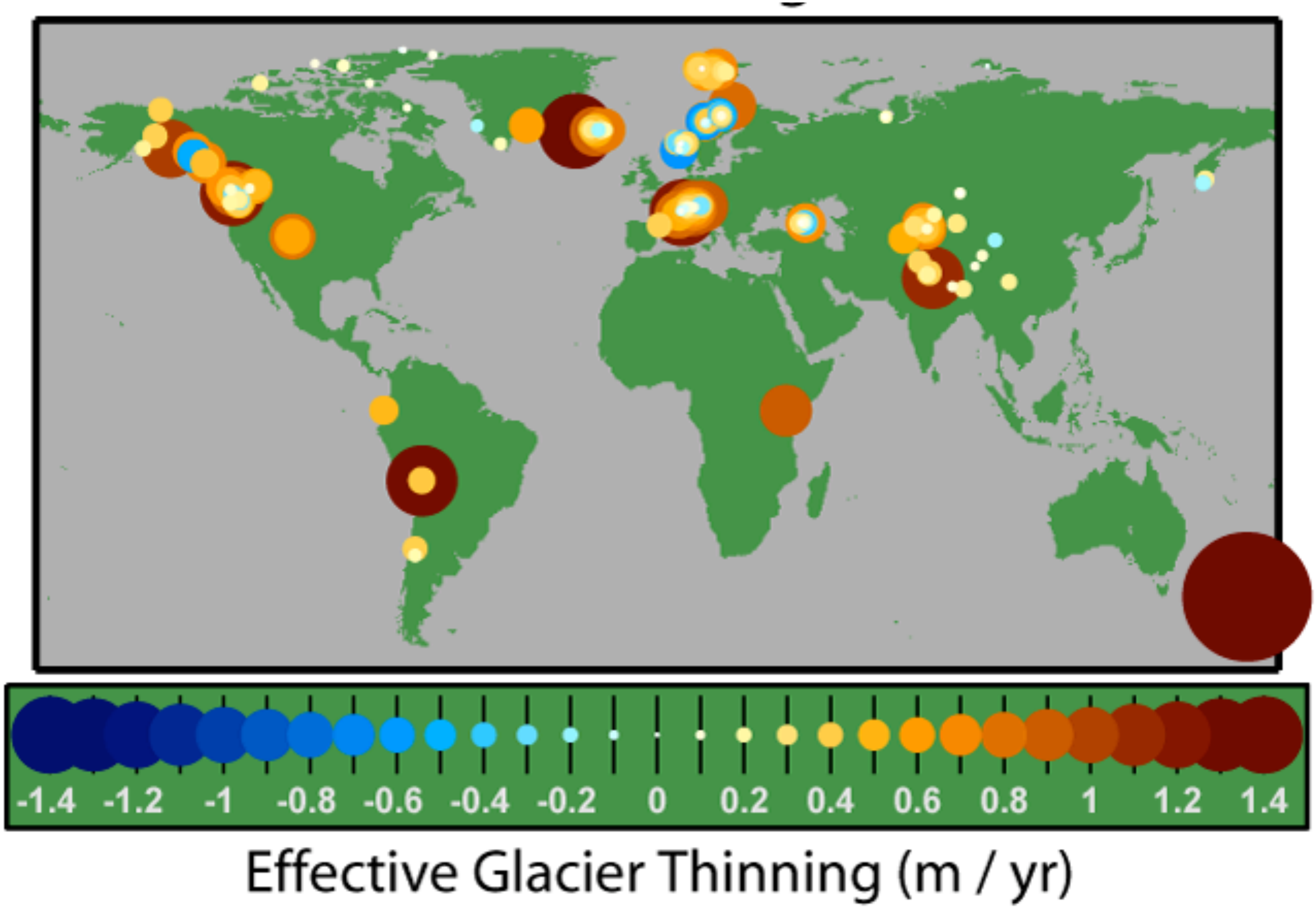
Ice Sheet Mass Change Acceleration 1992-2010



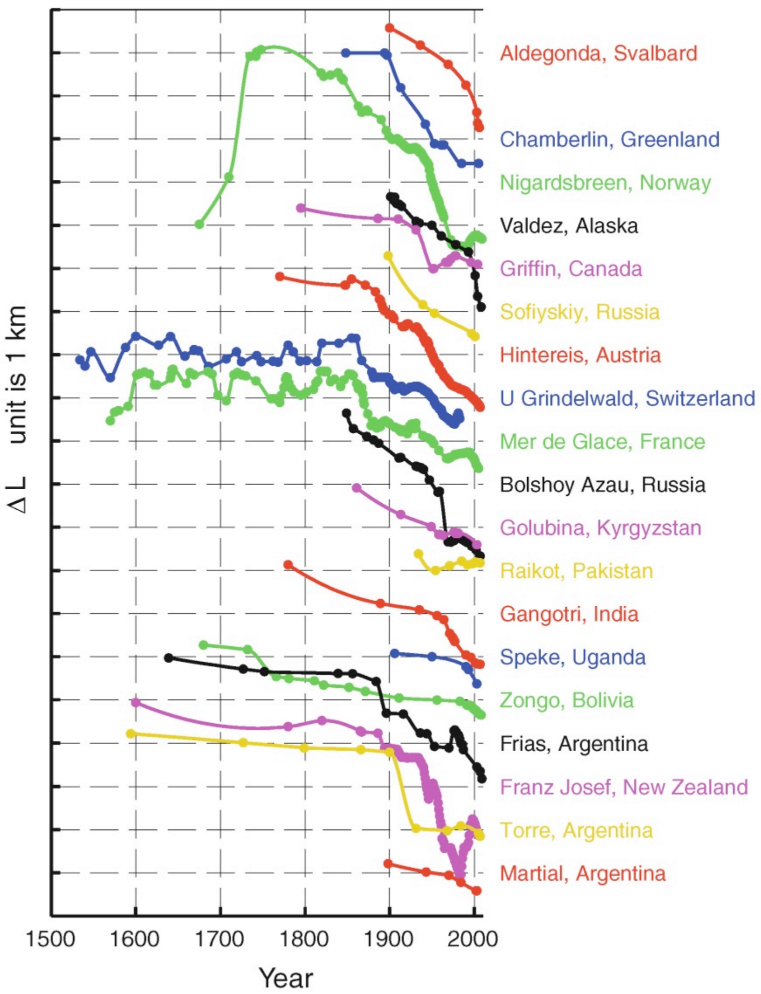
- In 2006, the Greenland and Antarctic ice sheets experienced a combined mass loss of 475 ± 158 Gt/yr, equivalent to **1.3 ± 0.4 mm/yr** sea level rise.
- Acceleration in ice sheet loss over the last 18 years was 21.9 ± 1 Gt/yr^2 for Greenland and 14.5 ± 2 Gt/yr^2 for Antarctica, for a combined total 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

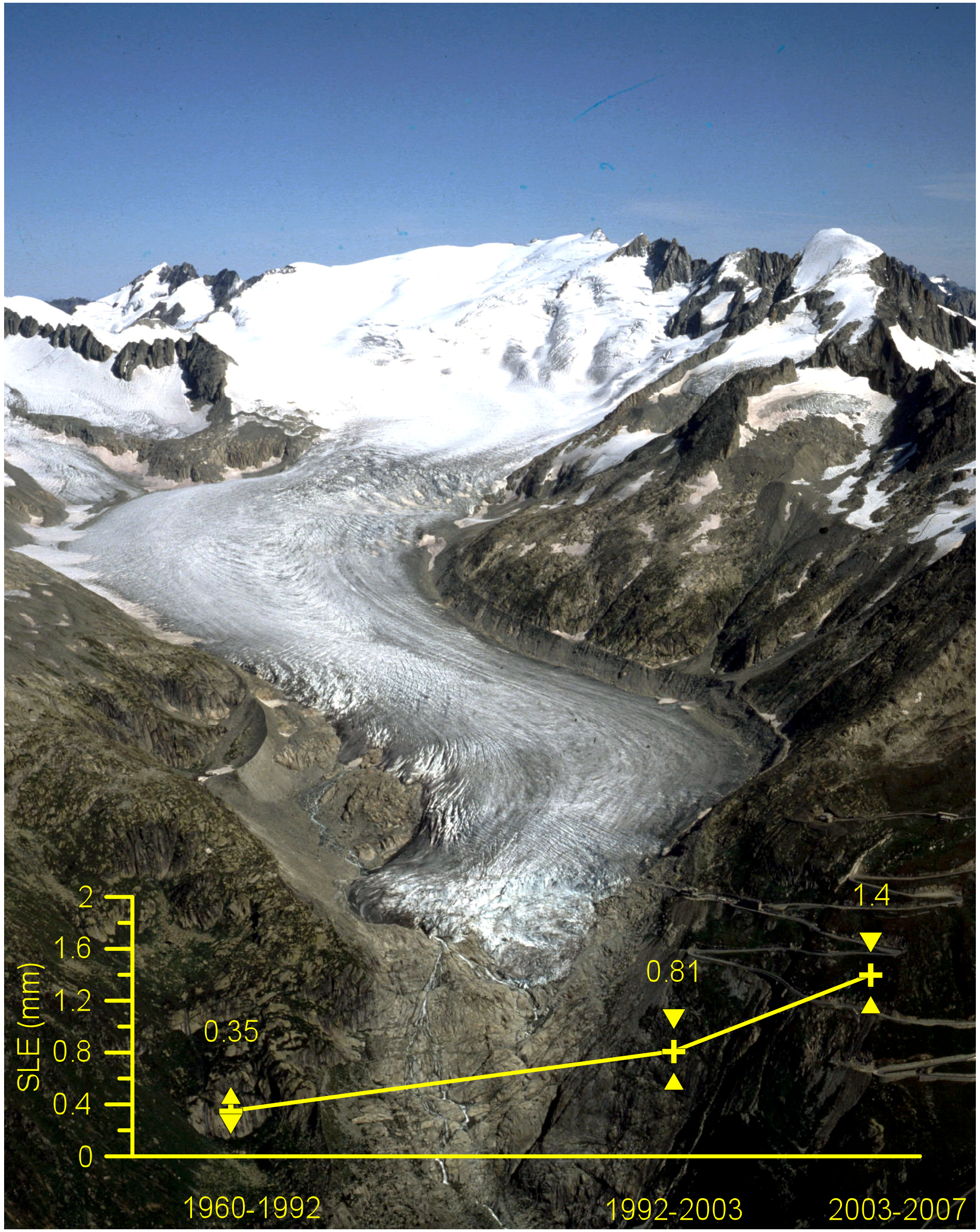
Glaciers and Ice Cap Changes since 1970



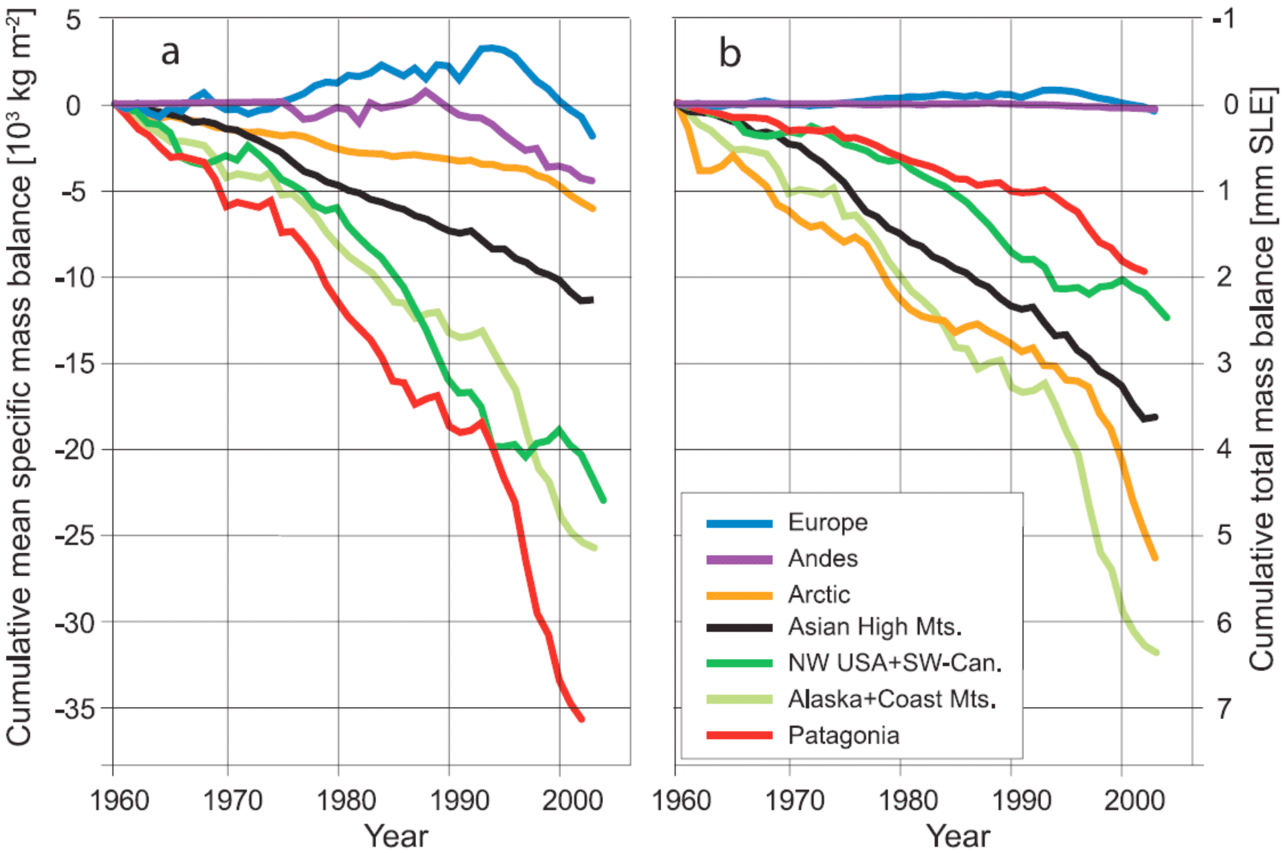
Glaciers and Ice Caps

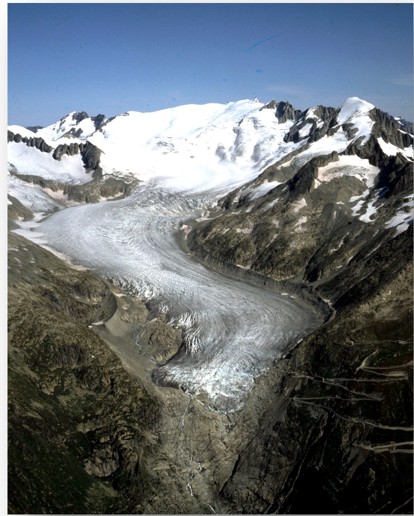


Leclercq et al., 2011, Surv.. Geophys.



Glaciers and Ice Caps





Currently, accumulation areas are too small, forcing glaciers to lose 27% of their volume to attain equilibrium with current climate, resulting at least 184 ± 33 mm SLR

Based on data from Dyurgerov and Meier (2005)

Rhone Glaciers 1856

Martin Funk, ETH Switzerland

Rhone Glaciers 1962

Martin Funk, ETH Switzerland

Rhone Glaciers 2050

Martin Funk, ETH Switzerland

Conclusion

- Mean SLR from Greenland and Antarctica ~ 1mm/yr (2000-2010)
- Mean SLR by glaciers and ice caps ~1.4 mm/yr (2000-2010)
- Total cryospheric SLR 2.4 mm/yr; increasing to 2.8 mm/yr (2010)
- Acceleration of ice loss from ice sheets 3 times larger than from glaciers and ice caps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CliC