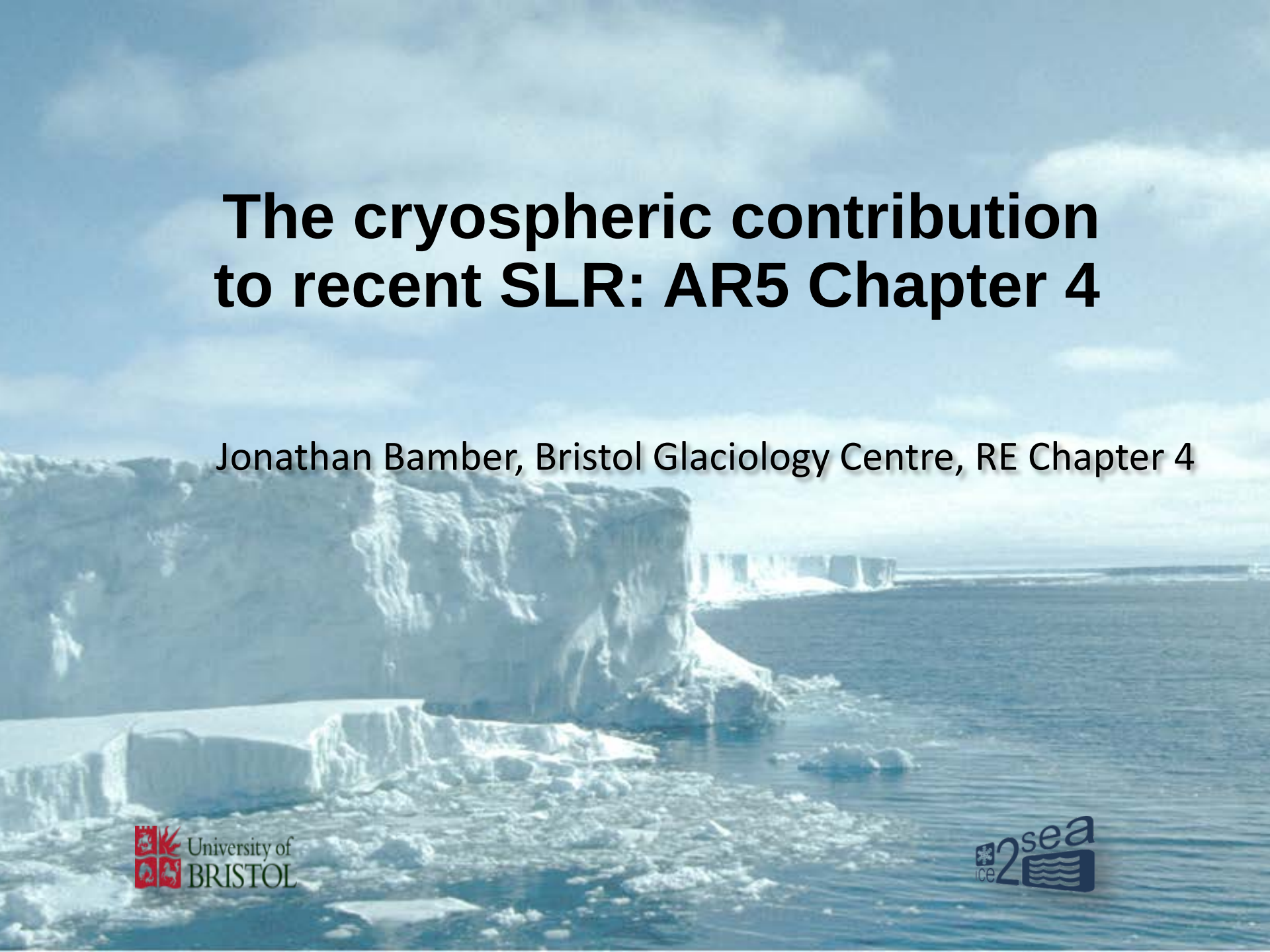
# The cryospheric contribution to recent SLR: AR5 Chapter 4

Jonathan Bamber, Bristol Glaciology Centre, RE Chapter 4

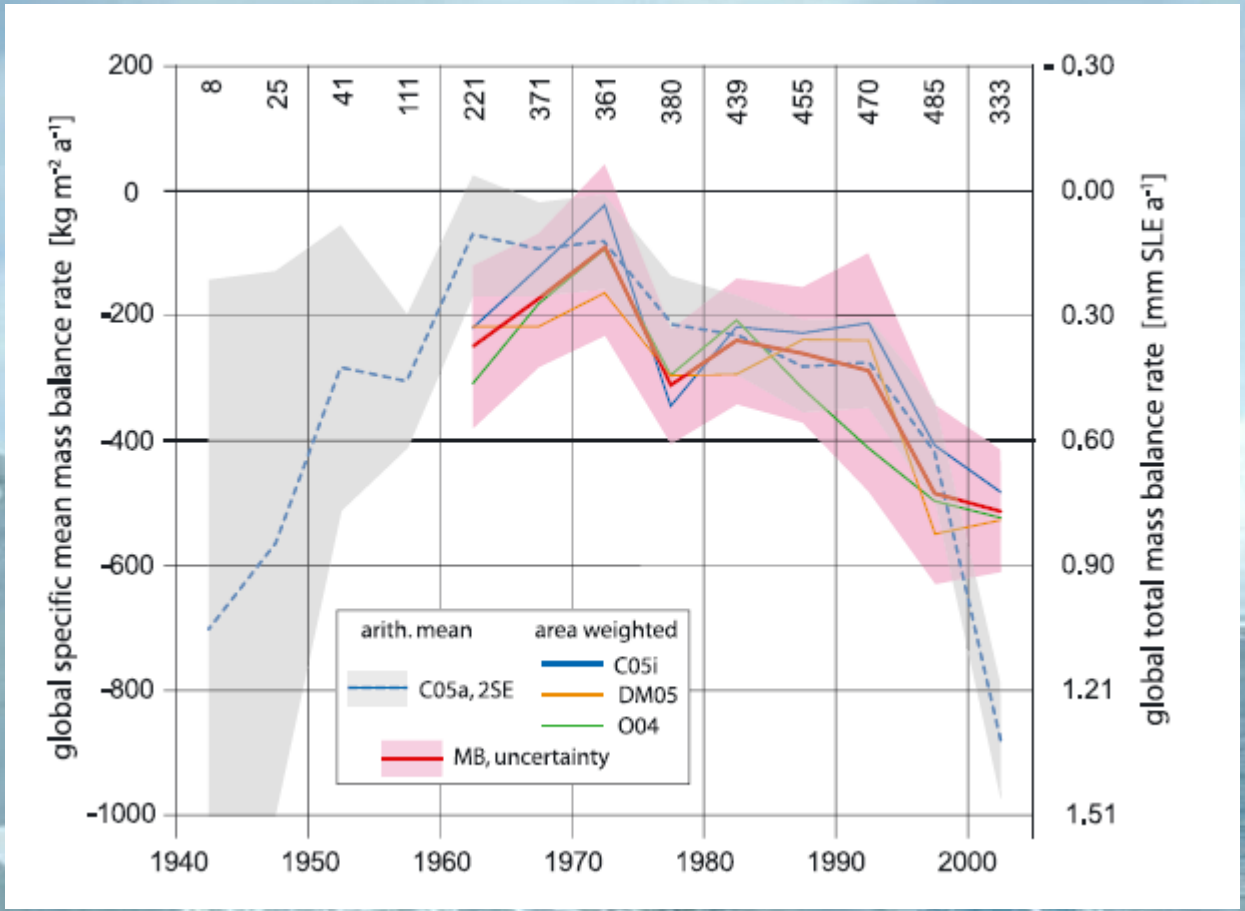


# Context and Concepts:

- “Modern era” began in 1992: launch of ERS-1
- Quantum advance with launch of ICESat and GRACE circa 2002
- Two processes control ice sheet mass balance
  - Surface mass balance (SMB)
  - Ice Dynamics (D)

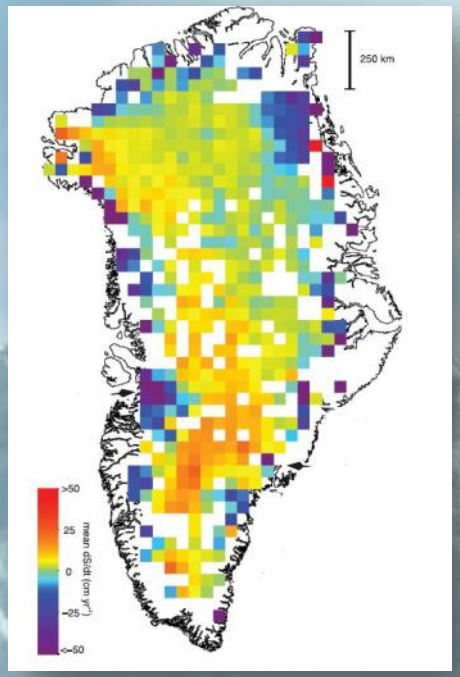
# Where were we: AR4

# G&IC:

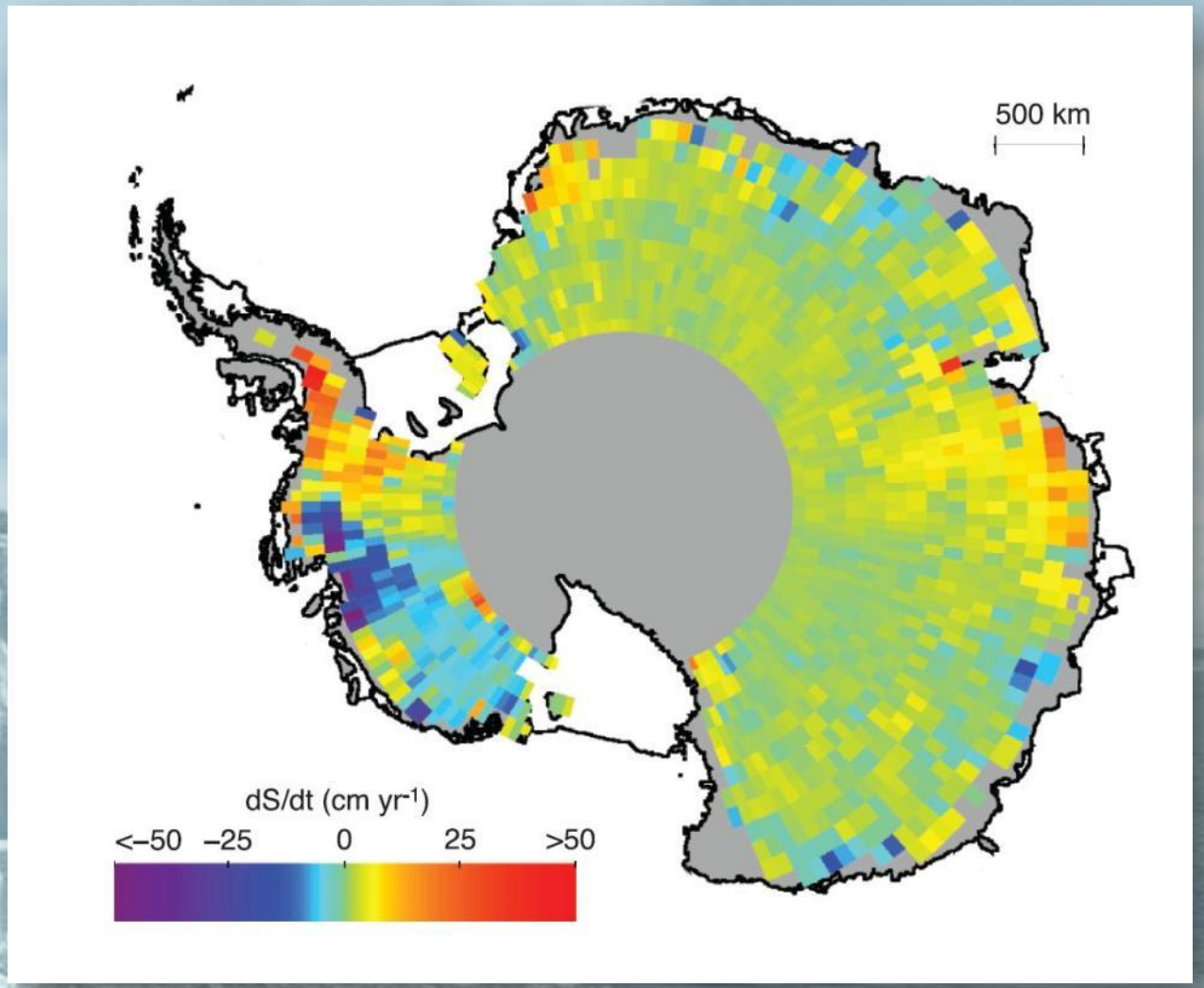



Kaser, G., J. G. Cogley, M. B. Dyurgerov, M. F. Meier, and A. Ohmura (2006), Mass balance of glaciers and ice caps: Consensus estimates for 1961-2004, *Geophys. Res. Lett., 33(19), L19501.*

# IPCC AR4 (2007) on ice sheets




IPCC AR4 (2007)



# Where are we now: AR5

# Glaciers and ice caps:

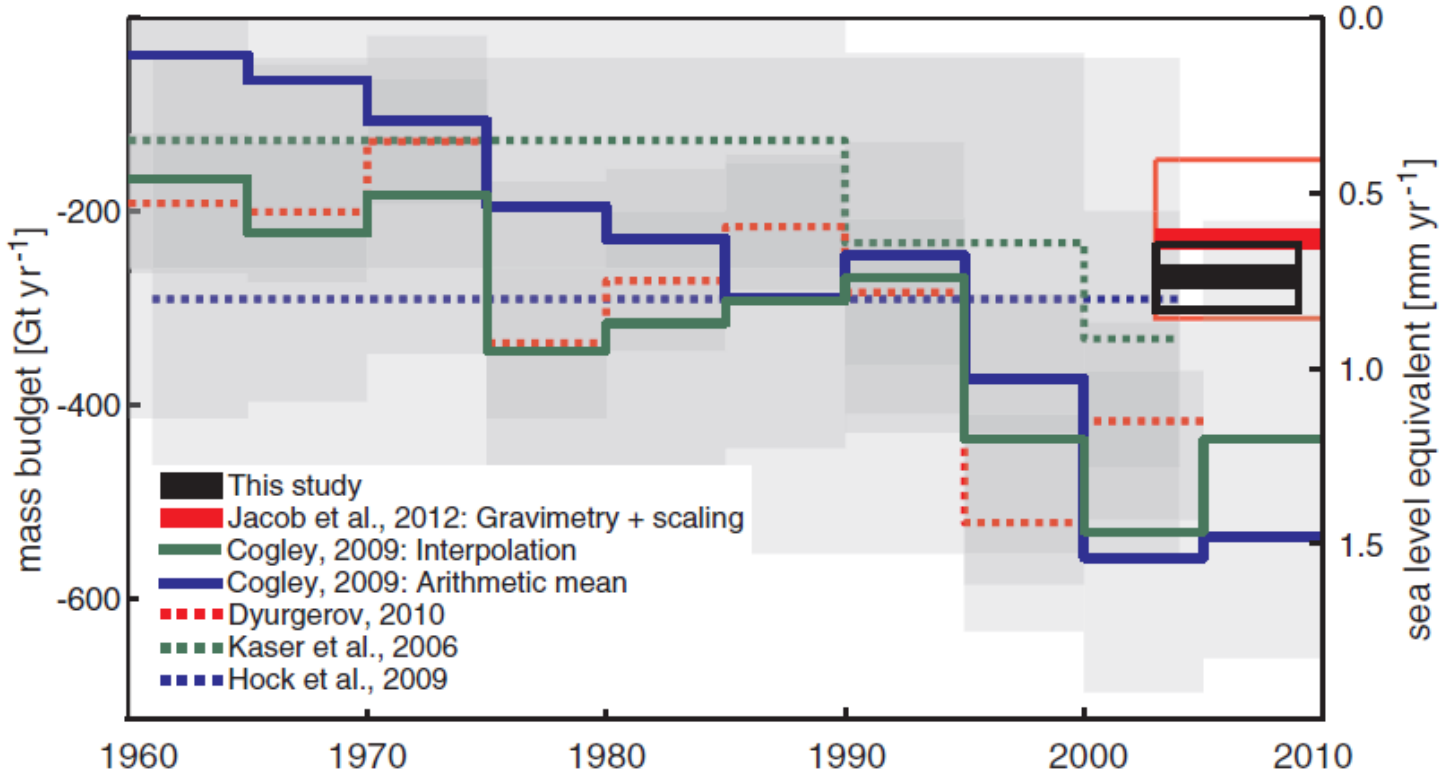
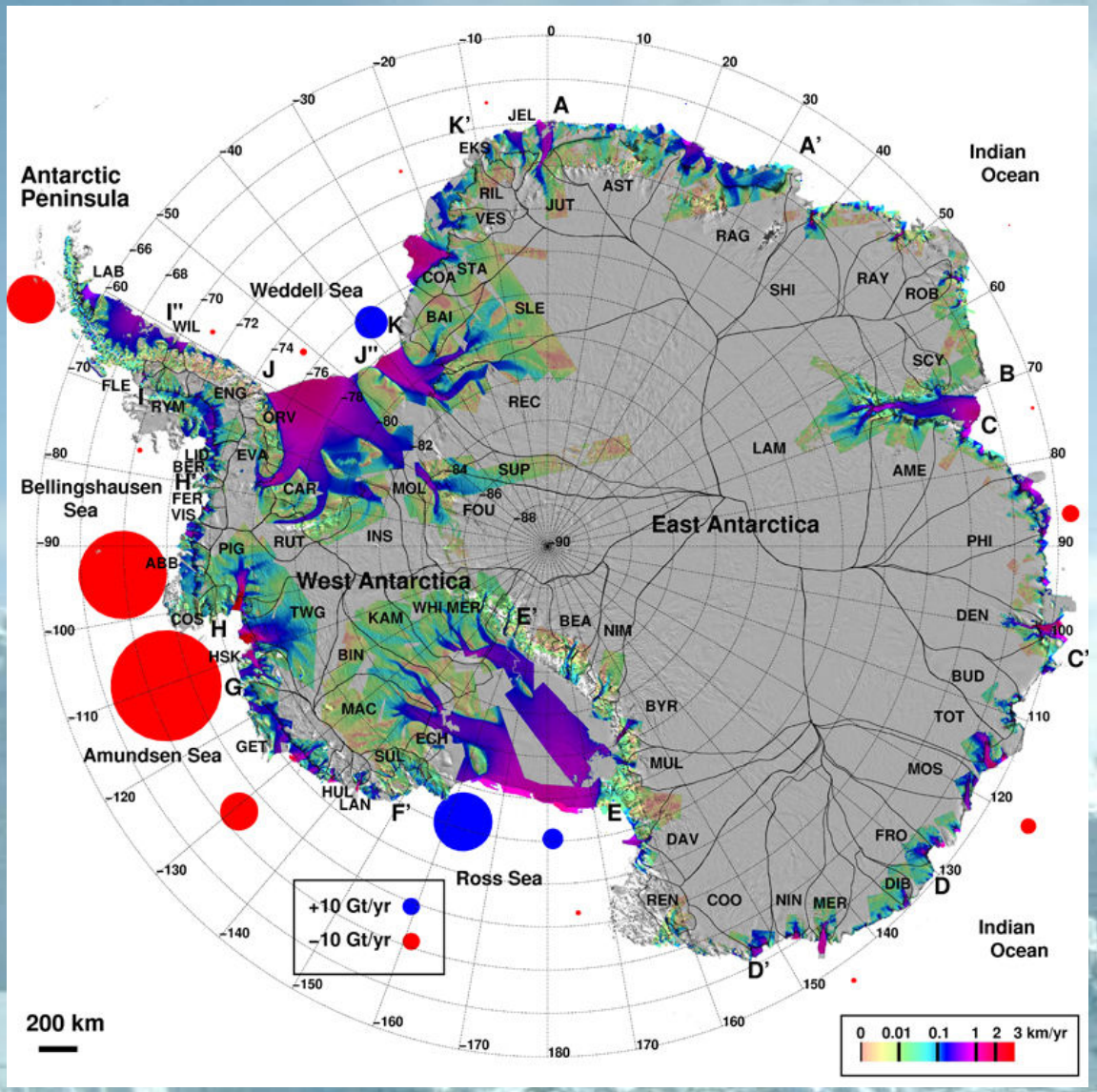


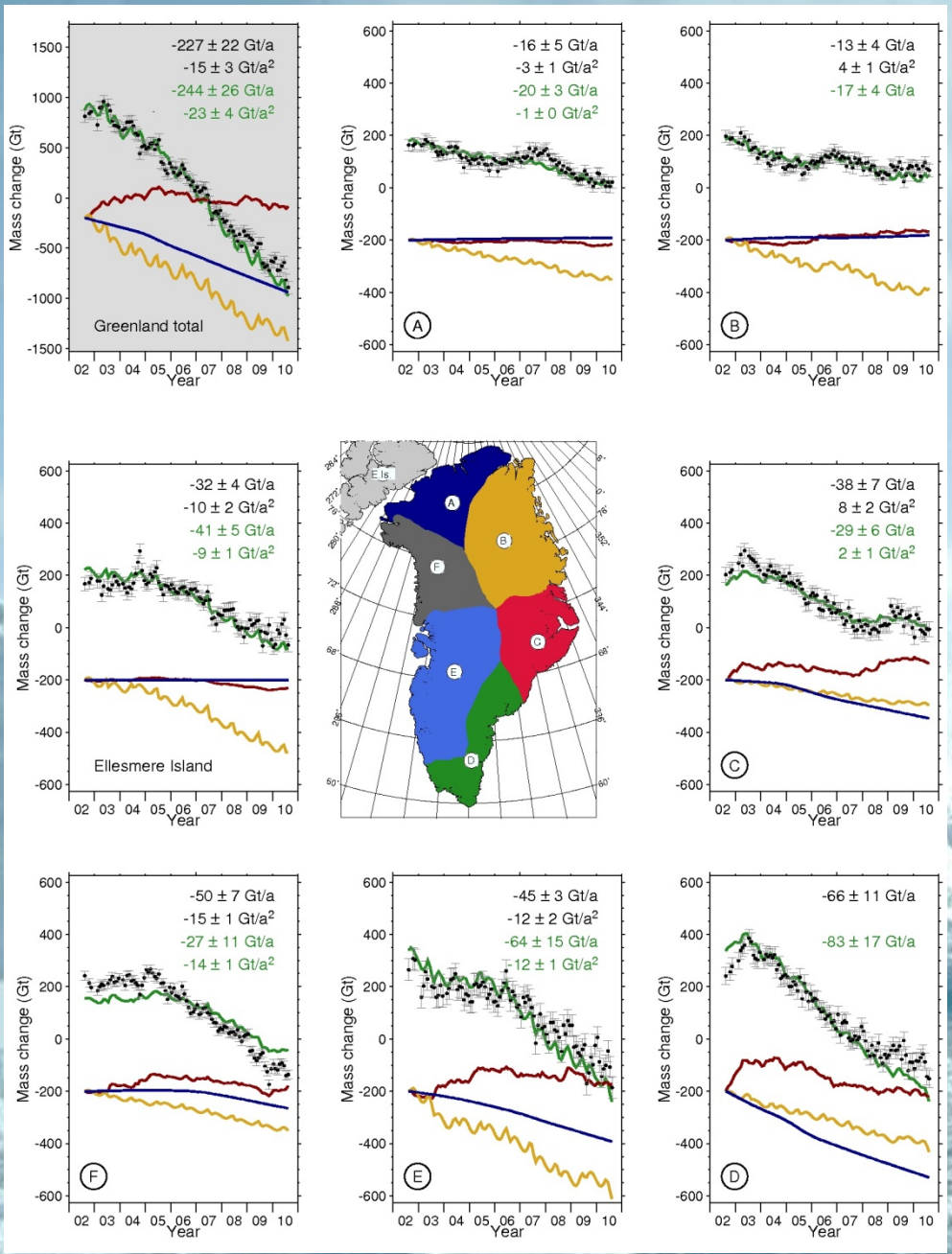

**Fig. 6. Global estimates of glacier mass change.** All estimates have been multiplied by the ratio of the total glacier area used in this study, 729,400 km$^2$, to that used in each source. 95% CIs are shown for all estimates except the arithmetic averages of C09 (*2*), which have formal errors in the range from 410 to 1520 Gt year$^{-1}$. The two C09 estimates are determined from an updated set of glaciological records using the methods of Cogley (*2*).

Gardner, A. S., et al. (2013), A Reconciled Estimate of Glacier Contributions to Sea Level Rise: 2003 to 2009, *Science, 340(6134), 852-857.*

# Antarctic trends 1996-2006




Rignot, E., J. L. Bamber, M. R. van den Broeke, C. Davis, Y. Li, W. J. van de Berg, and E. van Meijgaard (2008), Recent Antarctic ice mass loss from radar interferometry and regional climate modelling, *Nature Geosci, 1(2), 106-110.*

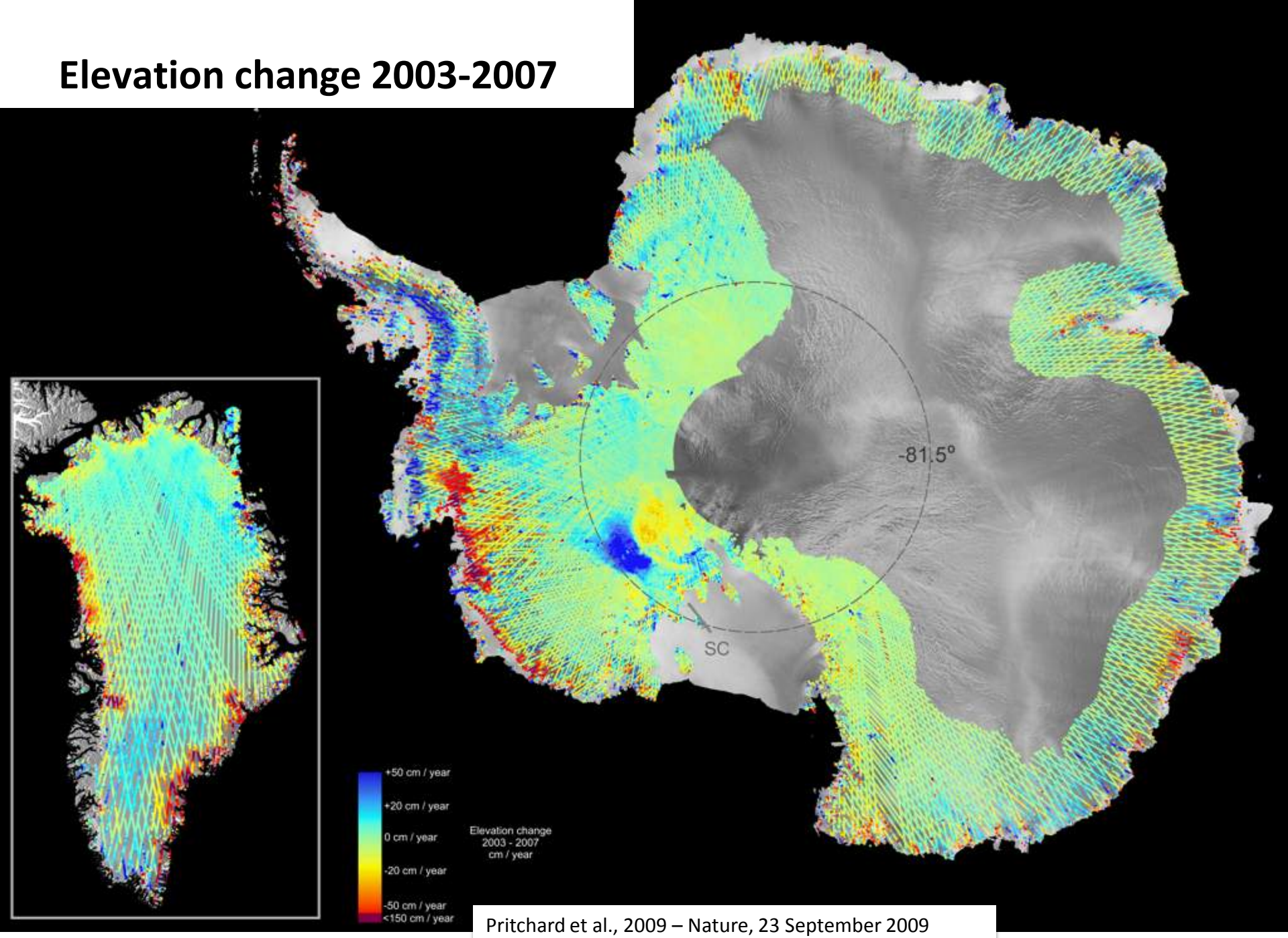



# Greenland trends:

blue line= ice dynamics
red line = precip
yellow= runoff
green = sum of above
black = GRACE

Sasgen, I., M. van den Broeke, J. L. Bamber, E. Rignot, L. S. Sorensen, B. Wouters, Z. Martinec, I. Velicogna, and S. B. Simonsen (2012), Timing and origin of recent regional ice-mass loss in Greenland, *Earth and Planetary Science Letters, 333, 293-303.*

# Elevation change 2003-2007



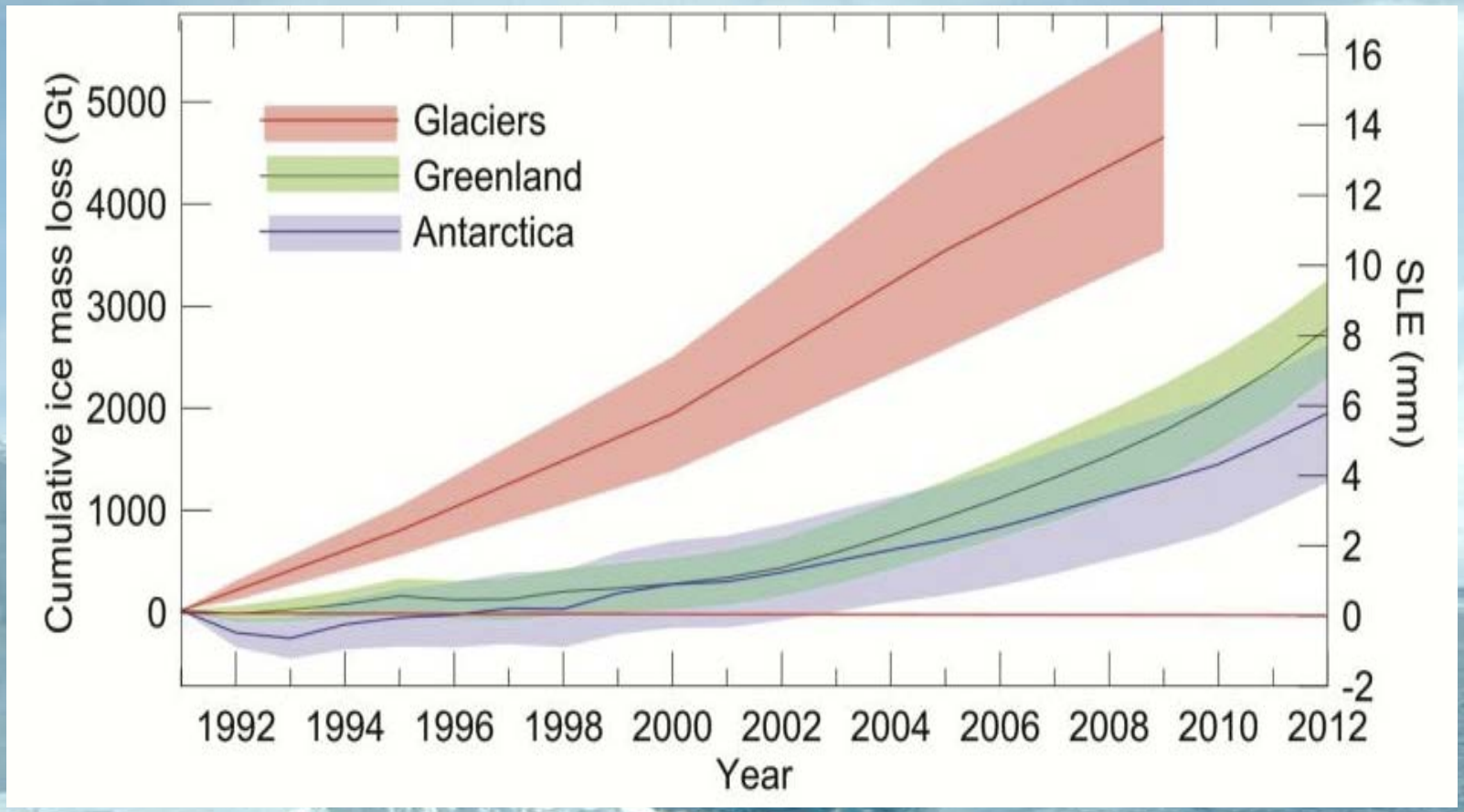

Pritchard et al., 2009 – Nature, 23 September 2009

# IPCC WGI AR5 Summary for Policymakers – Key statements

- **B.Observed Changes in the Climate System**
  - B.3 Cryosphere
    - The average rate of ice loss from the Greenland ice sheet has *very likely* increased from 34 [−6 to 74] Gt yr–1 over the period 1992–2001 to 215 [157 to 274] Gt yr–1 over the period 2002–2011.
    - The average rate of ice loss from the Antarctic ice sheet has *likely* increased from 30 [−37 to 97] Gt $yr^{-1}$ 21 over the period 1992–2001 to 147 [72 to 221] Gt $yr^{-1}$ over the period 2002–2011.

    There is very *high confidence* that these losses are mainly from the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica.

# Ice-loss from glaciers and ice sheets

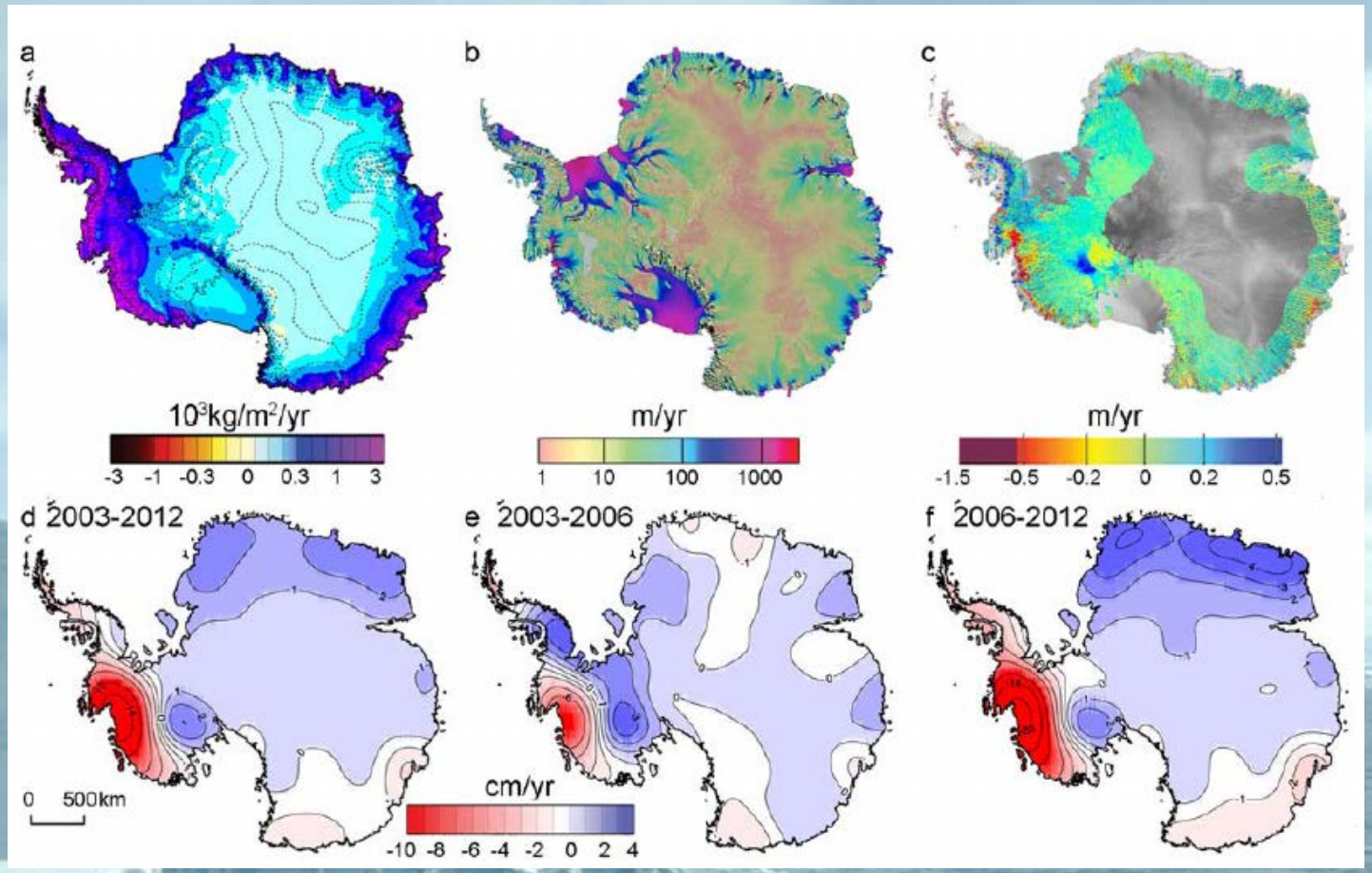



2005–2010 (6-year) 1.04 ±0.37
1993–2010 (18-year) 0.60 ±0.18

IPCC WGI Fig 4.25
AR5 Final Draft September 2013

# Antarctic ice sheet change

- Substantial improvement on AR4
- Assessment of geographical and temporal pattern of ice-loss
- Agreement between techniques
- Assessment of contribution to GMSL uses published values for two periods:




2005–2010 (6-year) 0.41 ±0.20 mm GMSL
1993–2010 (18-year) 0.27 ±0.11 mm GMSL

IPCC WGI Fig 4.14
AR5 Final Draft September 2013

# Greenland ice sheet change

- Substantial improvement on AR4
- Assessment of geographical and temporal pattern of ice-loss
- Agreement between techniques
- Assessment of contribution to GMSL uses published values for two periods:

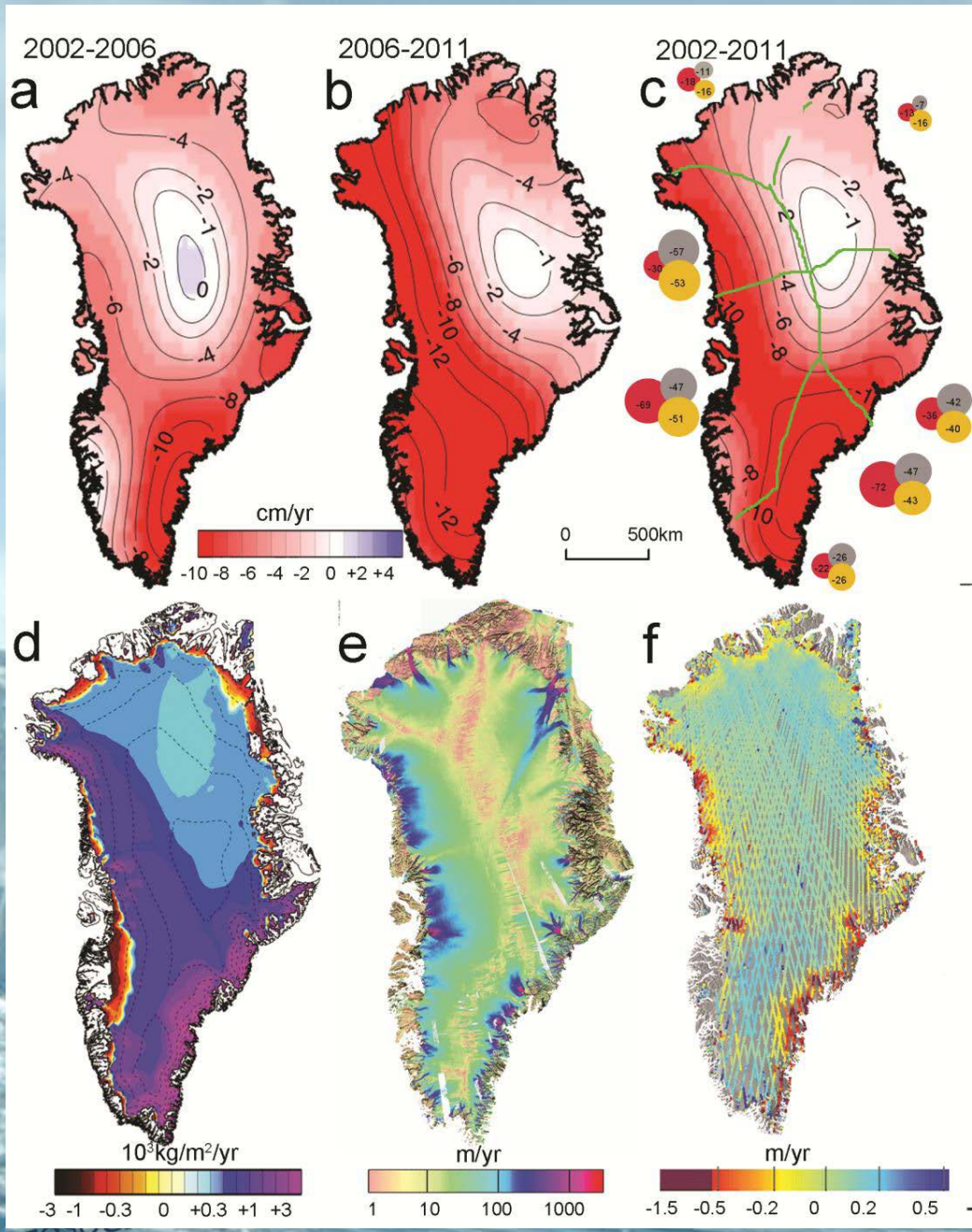
2005–2010 (6-year)

<u>0.63 ±0.17 mm</u>

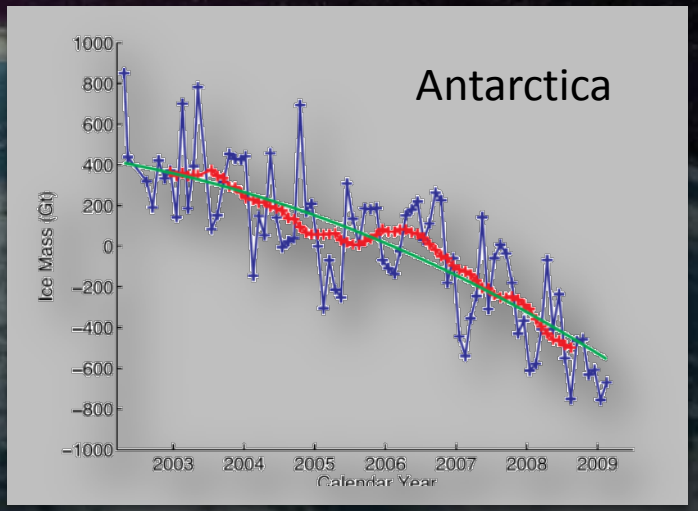
1993–2010 (18-year)

<u>0.33 ±0.08 mm</u>

IPCC WGI Fig 4.13
AR5 Final Draft September 2013

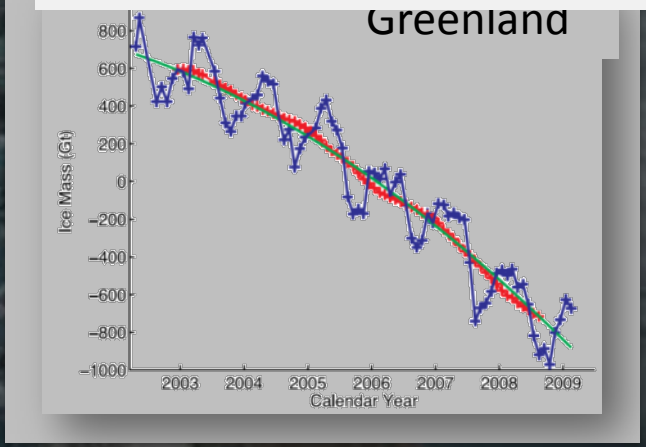


# Grace – satellite gravity

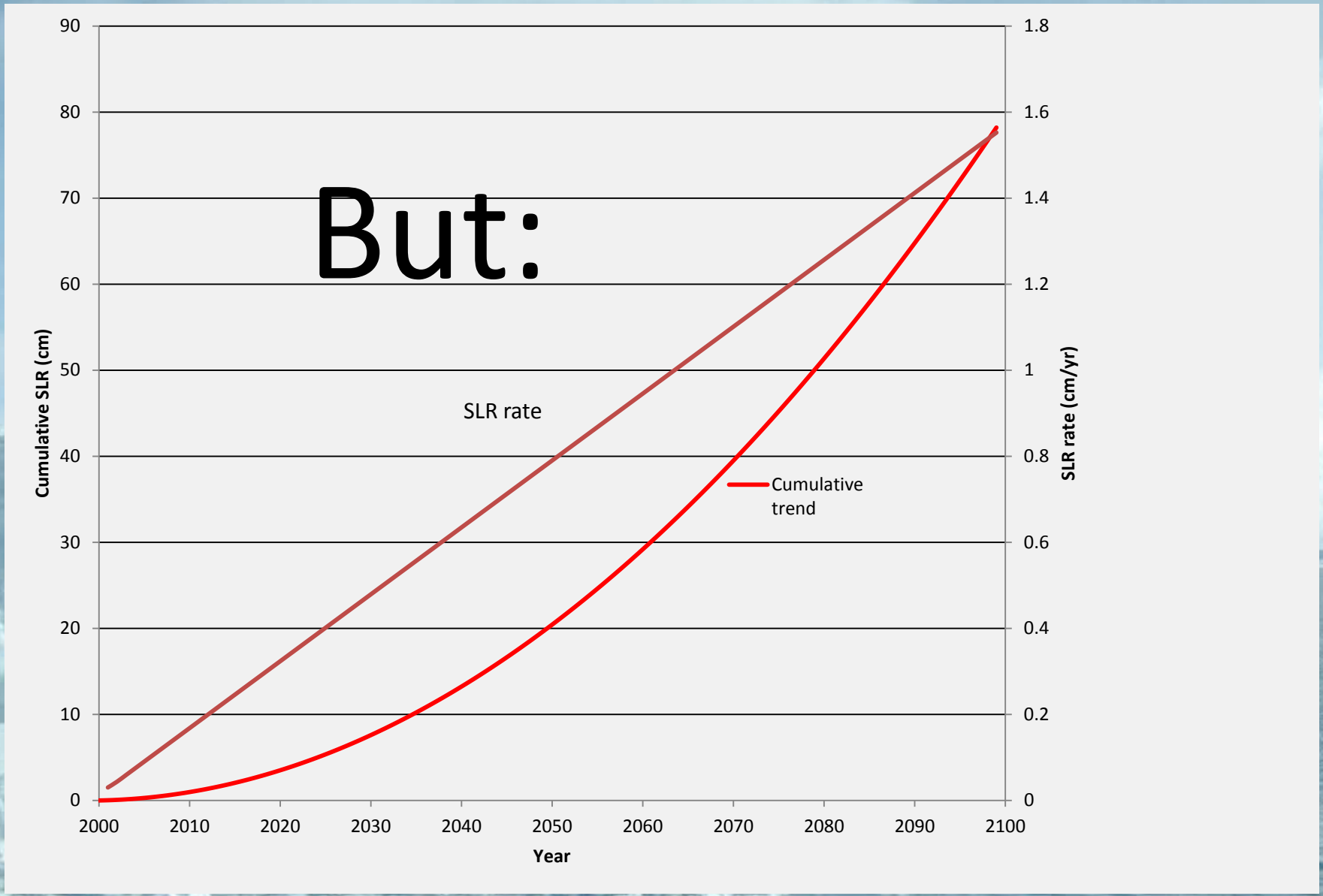



Updated to include mass budget back to 1992 in
Rignot, E., I. velicogna, M. van den Broeke, A. Monaghan, and J. Lenaerts (2011), Acceleration of the contribution of the Greenland and Antarctic Ice Sheets to sea level rise, *Geophys. Res. Lett.*

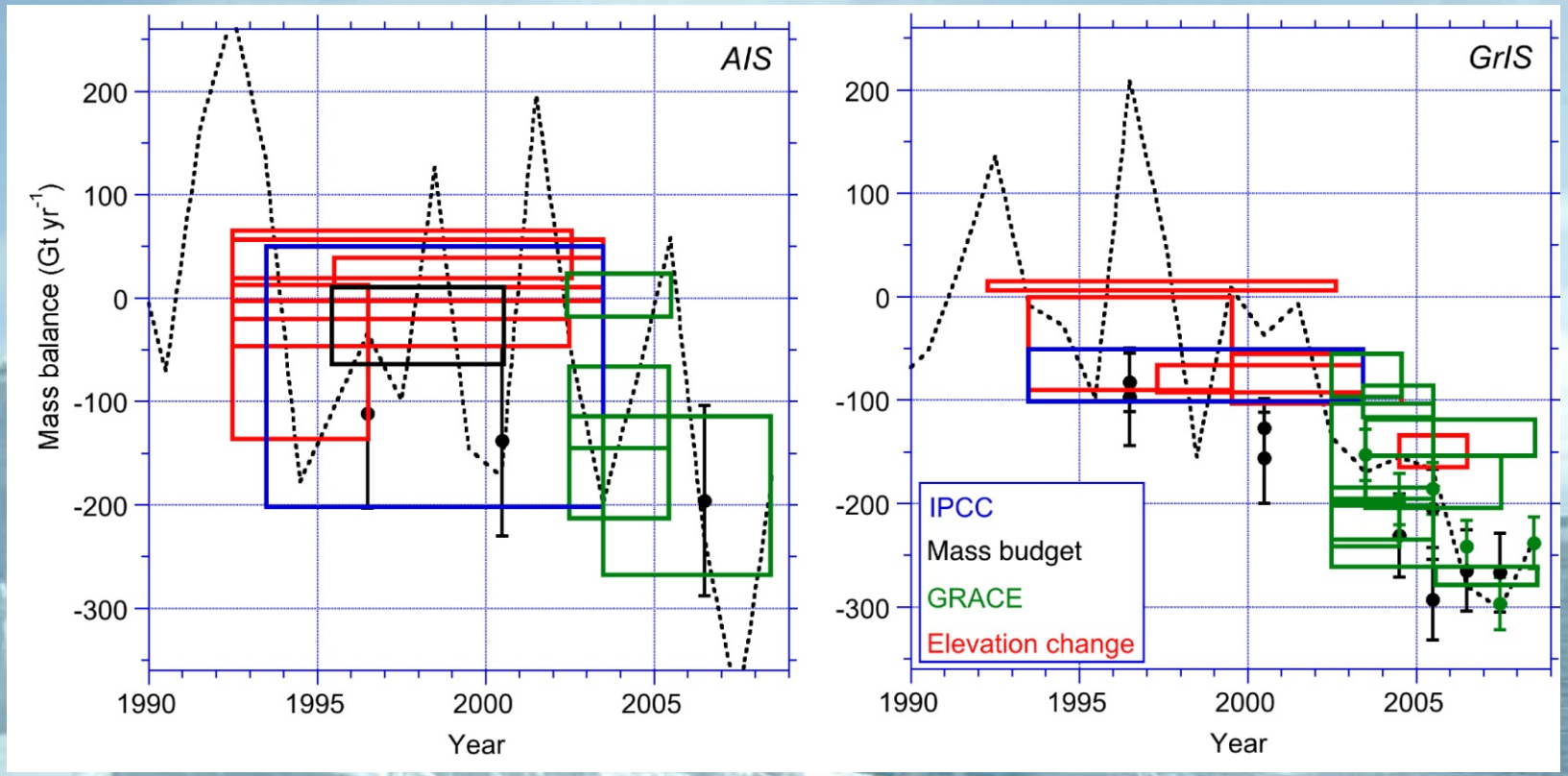
182 citations to date.....




Velicogna, 2009


But:
SLR rate
Cumulative trend
Cumulative SLR (cm)
SLR rate (cm/yr)
Year
0
10
20
30
40
50
60
70
80
90
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

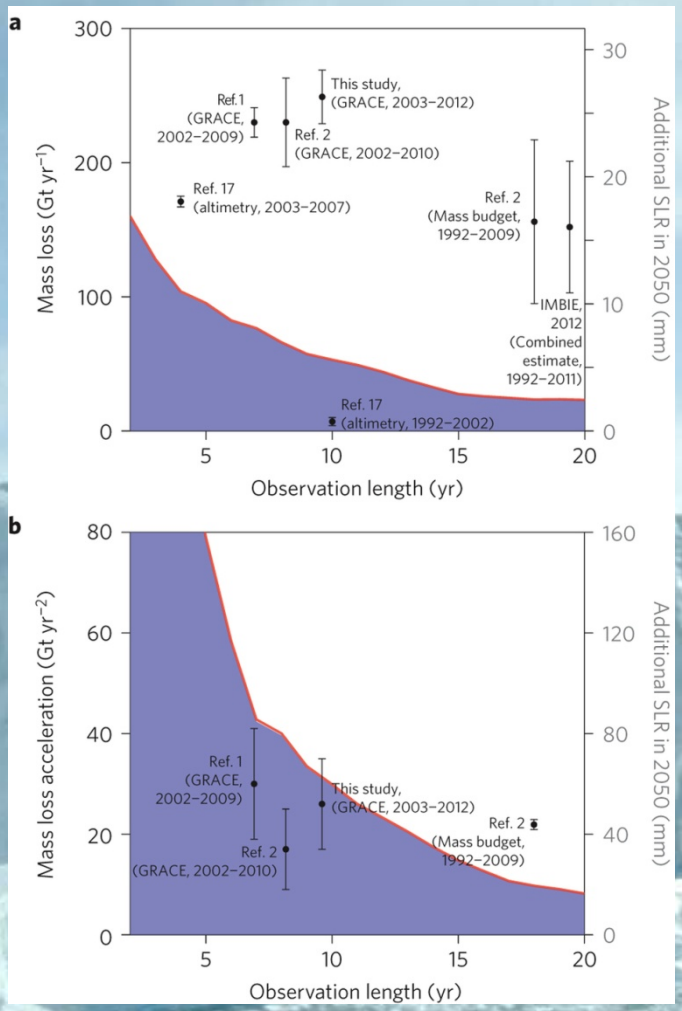
# Interannual variability:



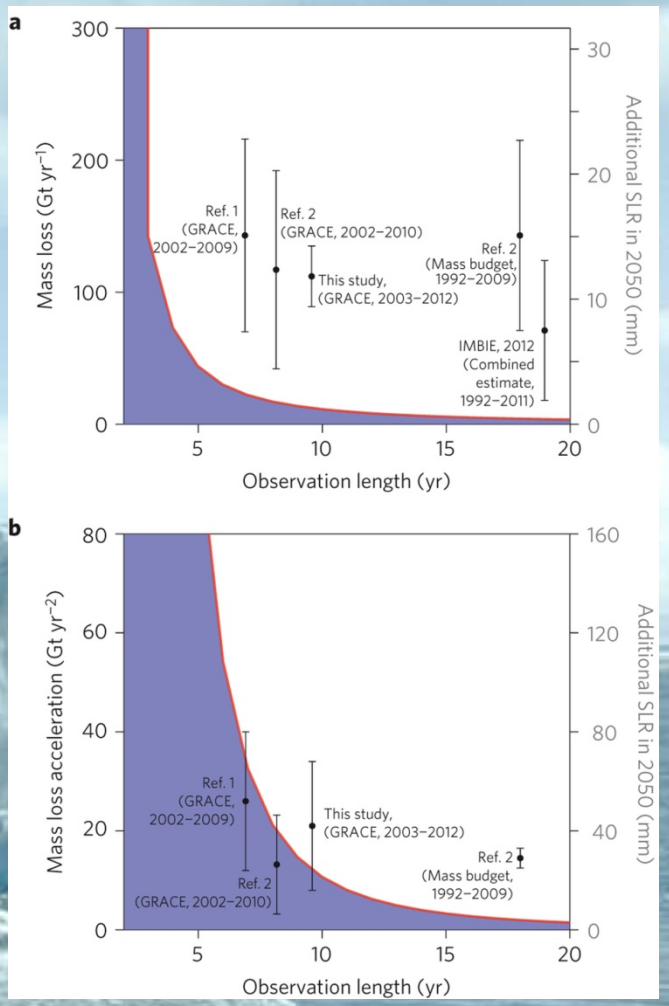

Van den Broeke, M. R., J. Bamber, J. Lenaerts, and E. Rignot (2011), Ice Sheets and Sea Level: Thinking Outside the Box, *Surveys in Geophysics, 32(4-5), 495-505.*

# Is the acceleration statistically significant?

Greenland

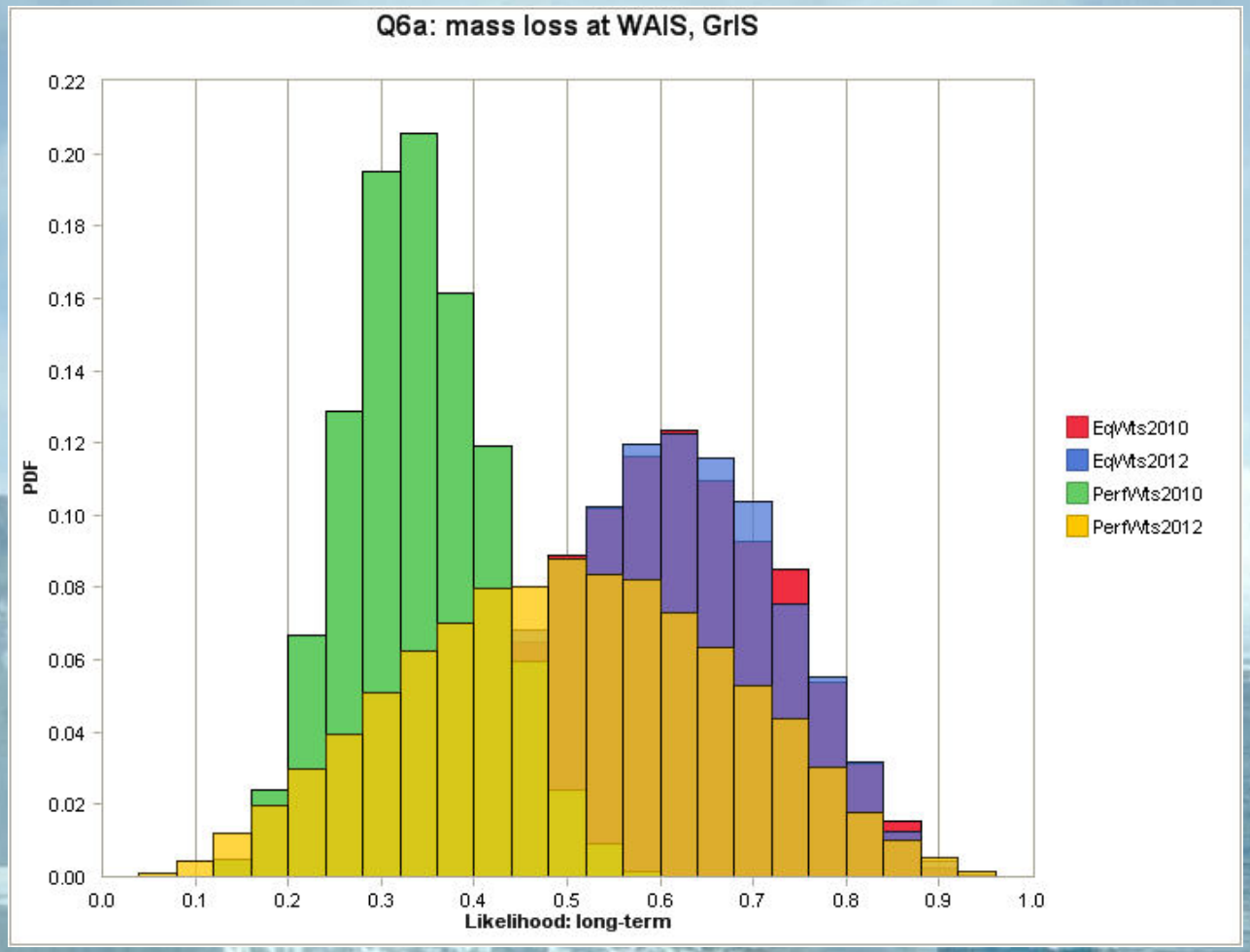



Antarctica



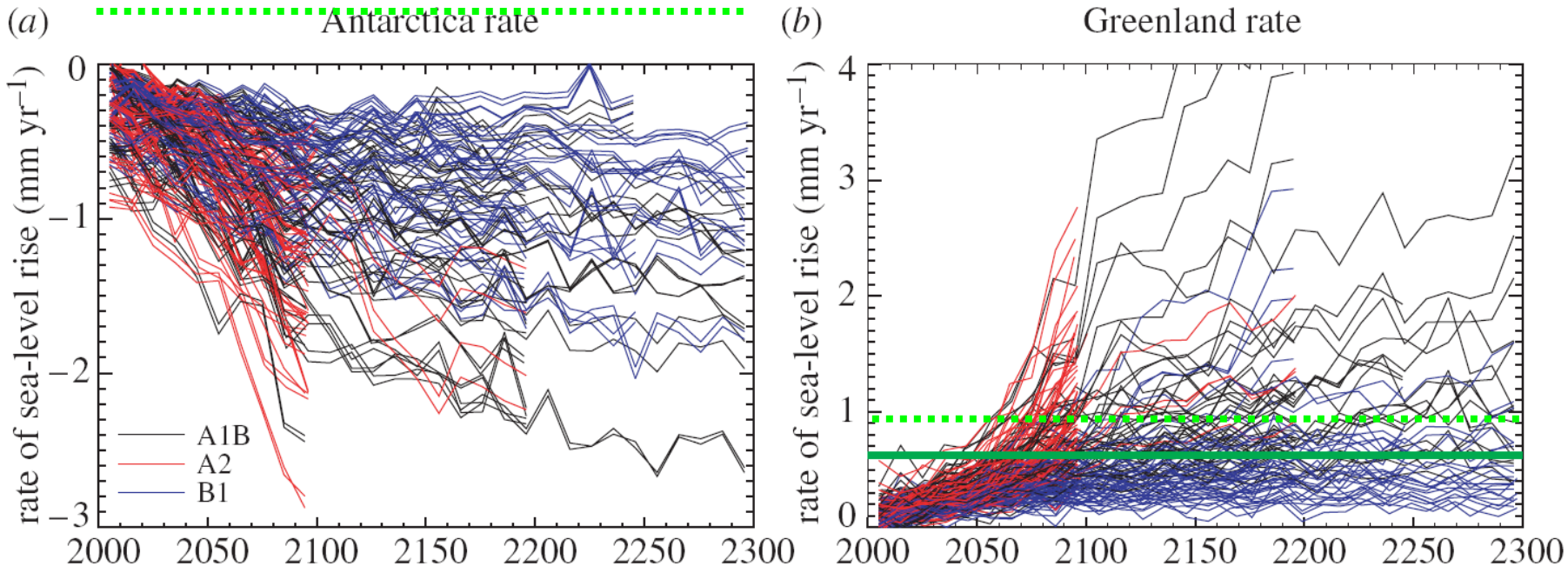

Wouters, B., J. L. Bamber, M. R. van den Broeke, J. T. M. Lenaerts, and I. Sasgen (2013), Limits in detecting acceleration of ice sheet mass loss due to climate variability, *Nat. Geosci.*

# Is the acceleration statistically significant?




Bamber, J. L., and W. P. Aspinall (2013), An expert judgement assessment of future sea level rise from the ice sheets, *Nature Clim. Change.*

# AR4 predictions of future response:



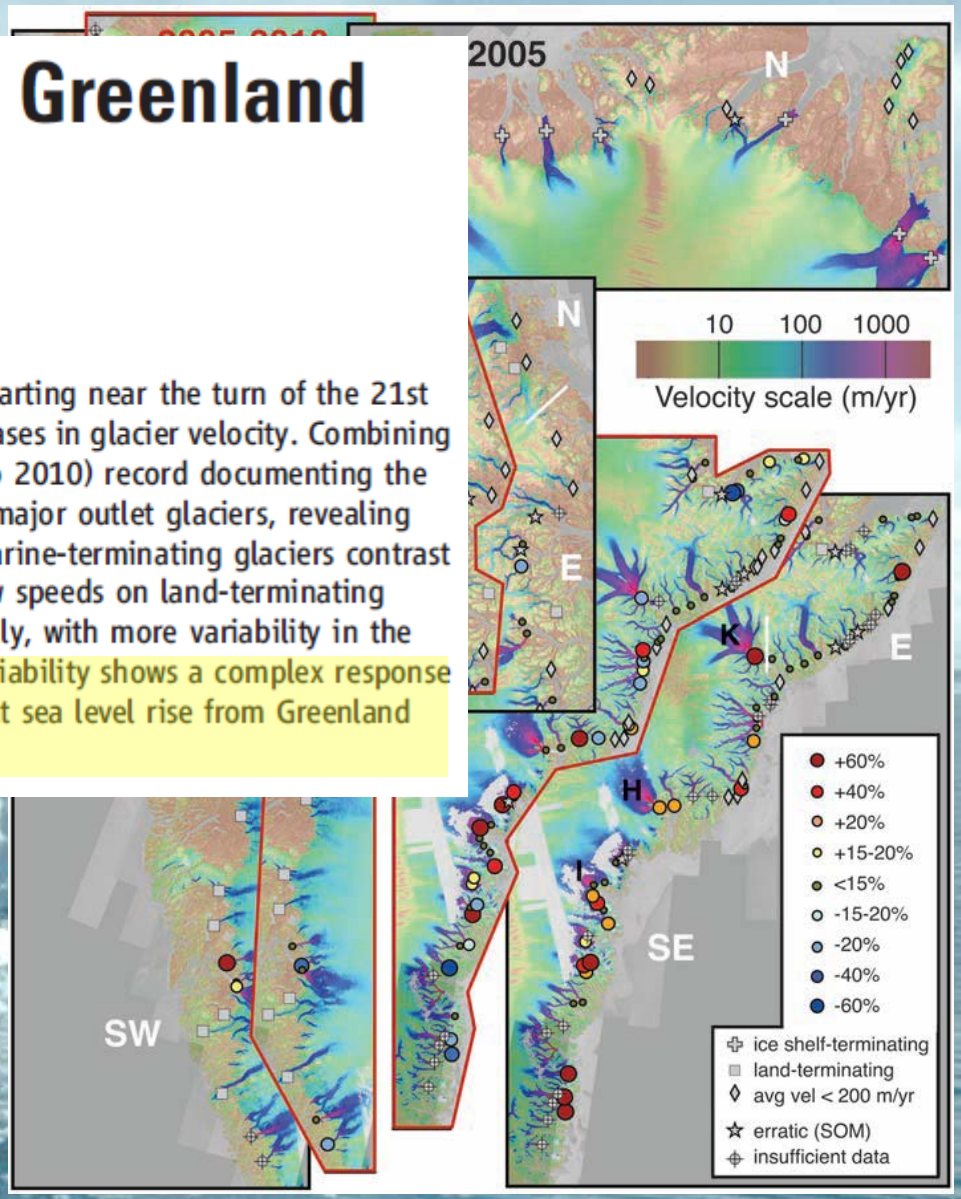

Gregory & Huybrechts, 2006, Phil Trans Roy Soc

# Why might the models be “wrong”

## 21st-Century Evolution of Greenland Outlet Glacier Velocities

T. Moon,[1,2]* I. Joughin,[2] B. Smith,[2] I. Howat[3,4]

Earlier observations on several of Greenland's outlet glaciers, starting near the turn of the 21st century, indicated rapid (annual-scale) and large (>100%) increases in glacier velocity. Combining data from several satellites, we produce a decade-long (2000 to 2010) record documenting the ongoing velocity evolution of nearly all (200+) of Greenland's major outlet glaciers, revealing complex spatial and temporal patterns. Changes on fast-flow marine-terminating glaciers contrast with steady velocities on ice-shelf–terminating glaciers and slow speeds on land-terminating glaciers. Regionally, glaciers in the northwest accelerated steadily, with more variability in the southeast and relatively steady flow elsewhere. Intraregional variability shows a complex response to regional and local forcing. Observed acceleration indicates that sea level rise from Greenland may fall well below proposed upper bounds.




And prior to 1992?
Intentionally left blank!

# Summary, Conclusions & Challenges

- Big advances since AR4 especially in errors
- Extrapolation of trends “unsafe”
- Is it weather or is it climate? =>
- Are deterministic models suitable tools?
- How do we extend the time series backward?