Sea level change in the Anthropocene

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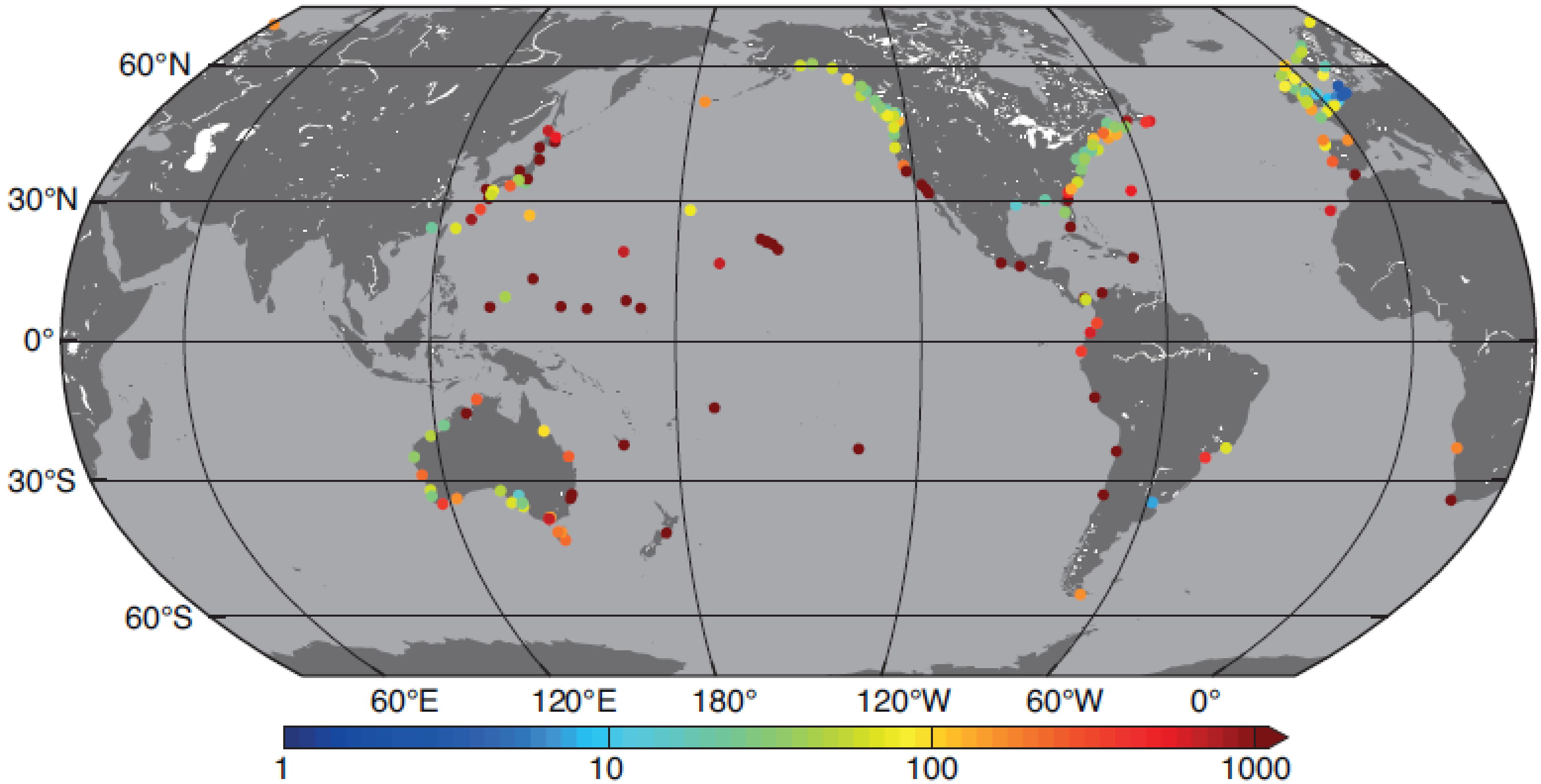
It is very likely that there will be a significant increase in the occurrence of sea level extremes in the 21st century



Multiplication factor for the frequency of a given sea level extreme for a uniform mean sea level rise of 0.5 m

Working Group 1 contribution to the
Fifth Assessment Report (2013) of the
Intergovernmental Panel on Climate Change

IPCC WG1 AR5 Fig 13.25a

Global mean sea level rise (GMSLR)

On climate timescales, GMSLR is caused by increase in ocean volume.

This in turn is caused by:

Warming the ocean (thermal expansion, global thermosteric sea level rise).

Adding mass to the ocean
(**barystatic** sea level rise, not ~~eustatic~~).

The latter is due to:

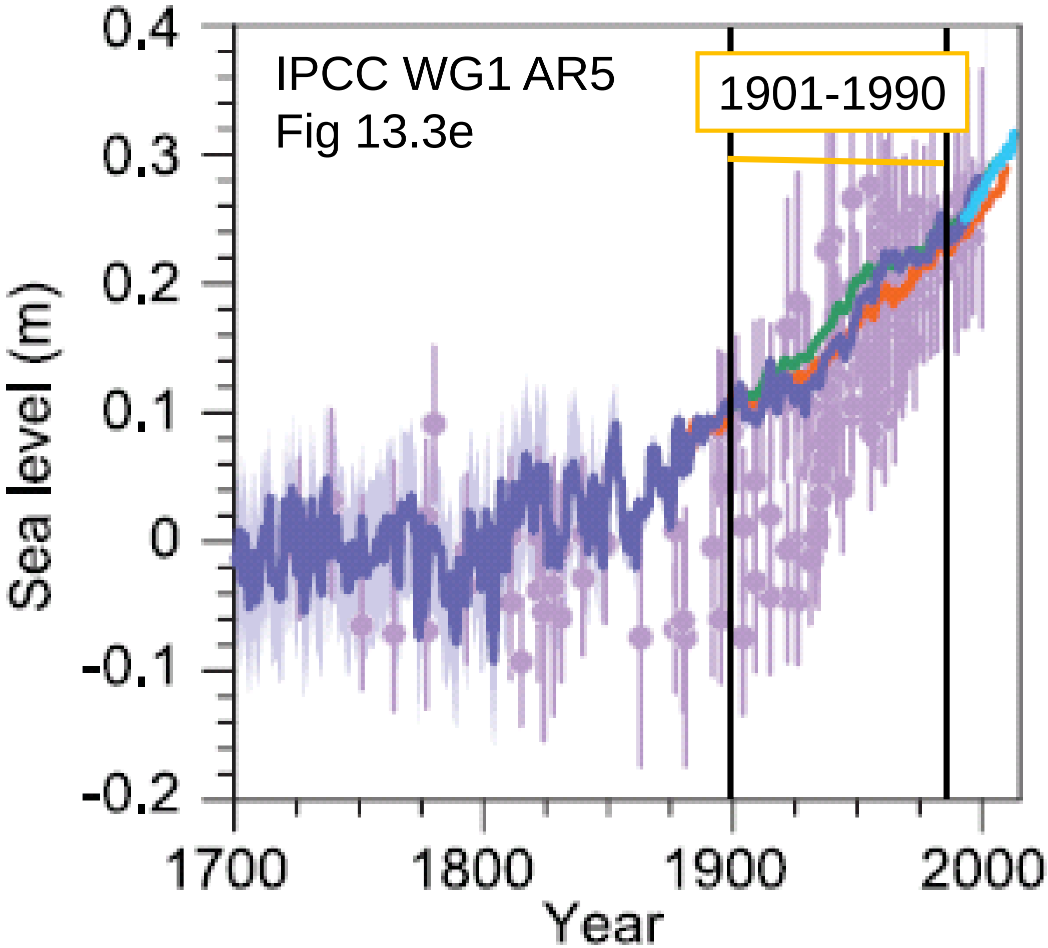
Loss of ice by glaciers.

Loss of ice by ice sheets.

Reduction of liquid water storage on land.

In order to understand the past and make projections for the future, we model each contribution and compare with observations.

The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia



Rate of GMSLR during the last two millennia was of order a few tenths of mm yr^{-1}.

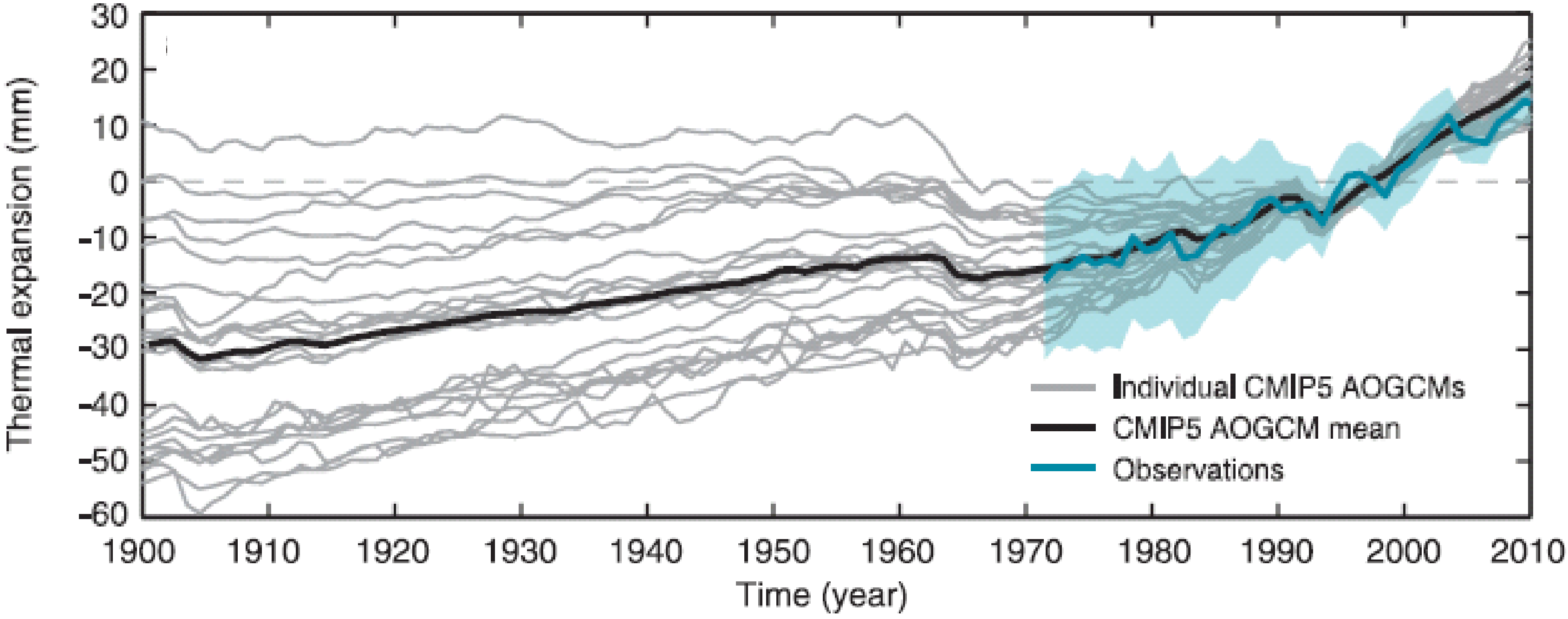
Rate during 1901-1990 was 1.5 [1.3 to 1.7] mm yr^{-1}.

Historical thermal expansion

Good observational estimates

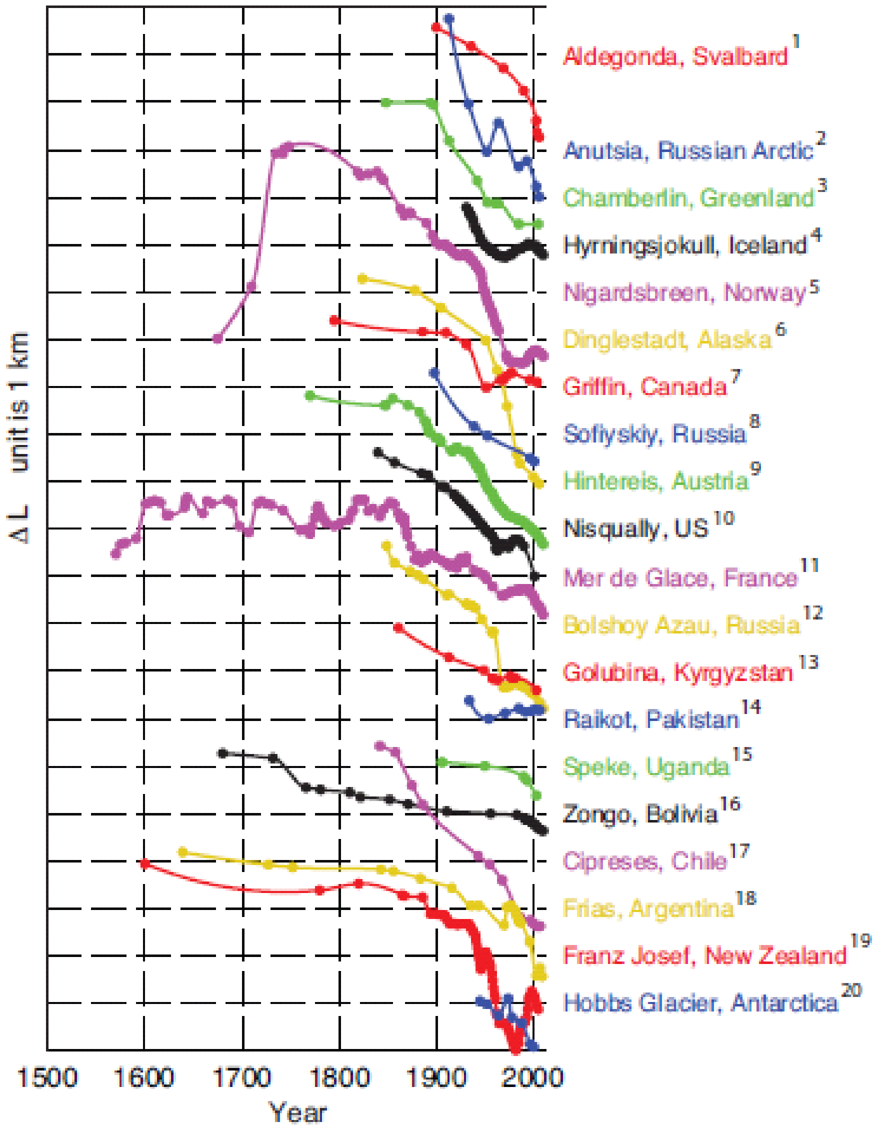
Consistency of historical simulations with observations

Consistency with the Earth energy budget



IPCC WG1 AR5 Fig 13.4a, change relative to 1986-2005

Historical glacier retreat



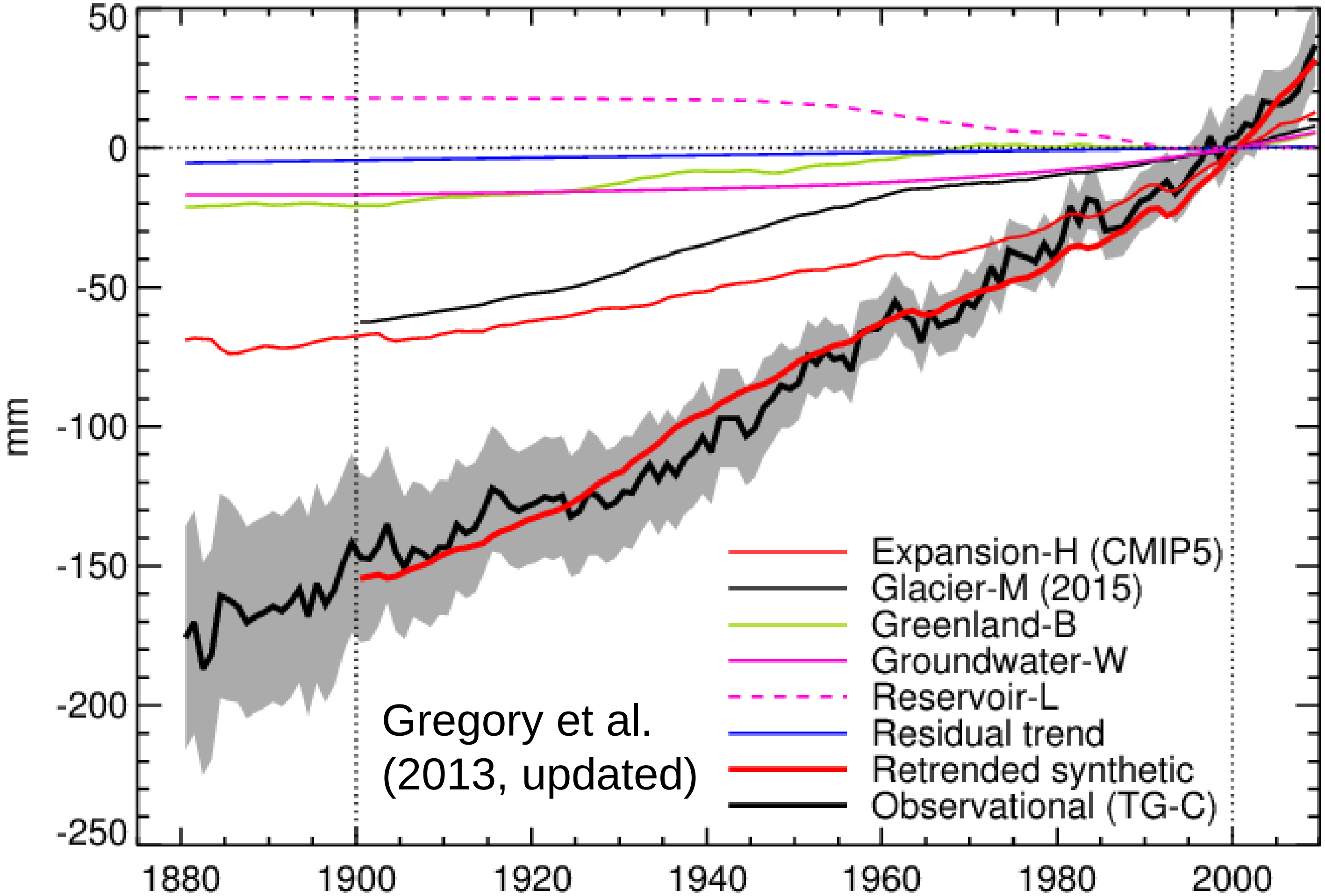
Glaciers worldwide have been retreating since the mid-19th century

Consistency of historical simulations with observations

But the set of well-observed glaciers is a very small fraction of the total

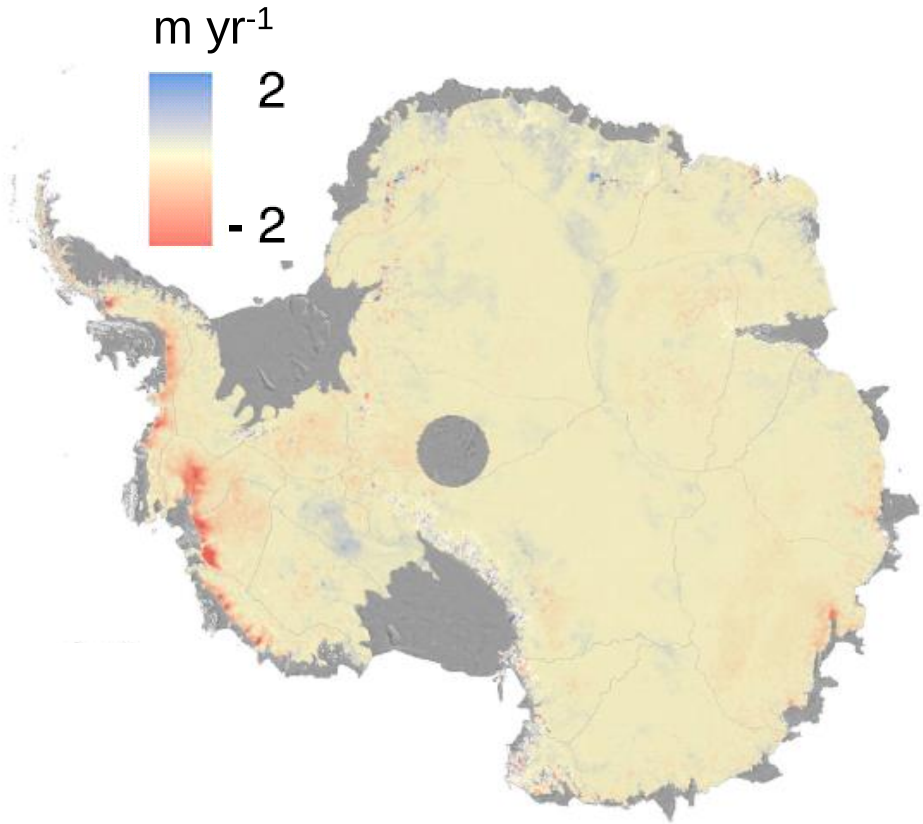
Leclercq et al. (2014)

Expansion + glaciers explain most of GMSLR 1901-1990

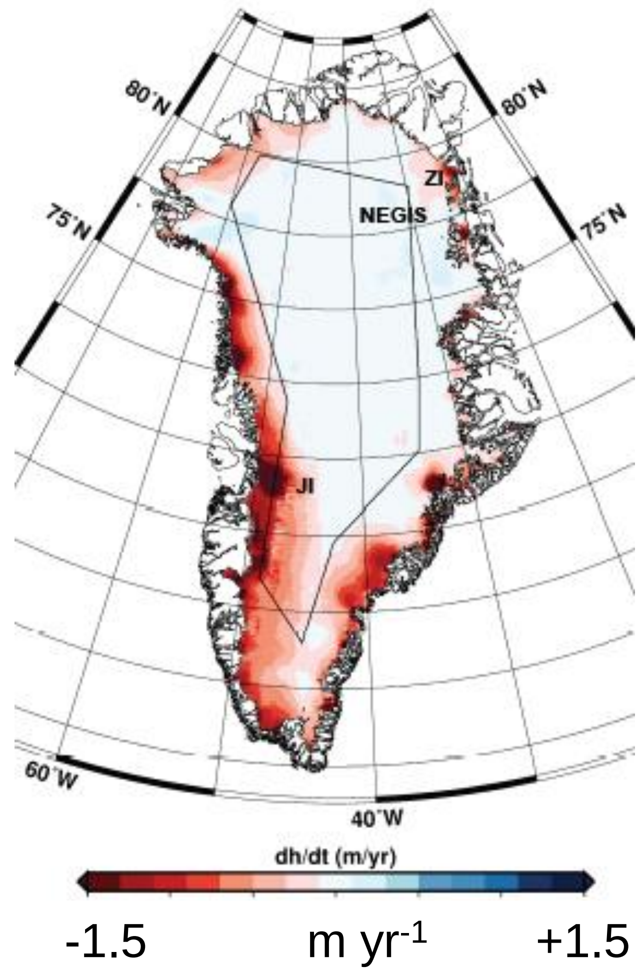


The remainder could be explained by mass loss from the Greenland ice sheet (especially during the early 20th century) and the Antarctic ice sheet (long-term). Land water storage change has made a small net contribution.

Mass loss of the Greenland and Antarctic ice-sheets



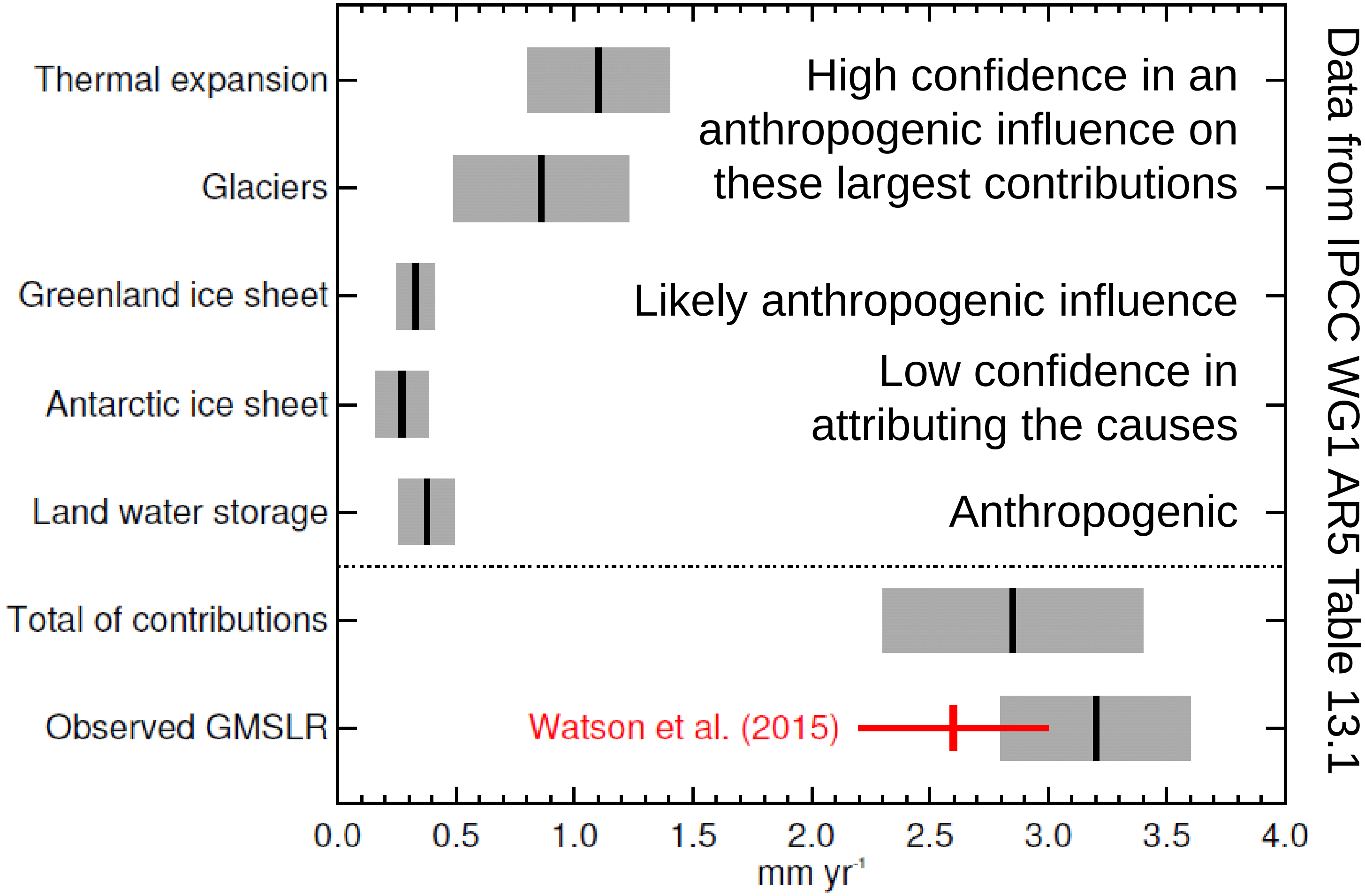
160 Gt yr^{-1}, 0.4 mm yr^{-1} SLE,
McMillan et al. (2014)



375 Gt yr^{-1}, 1.1 mm yr^{-1} SLE,
Helm et al. (2014)

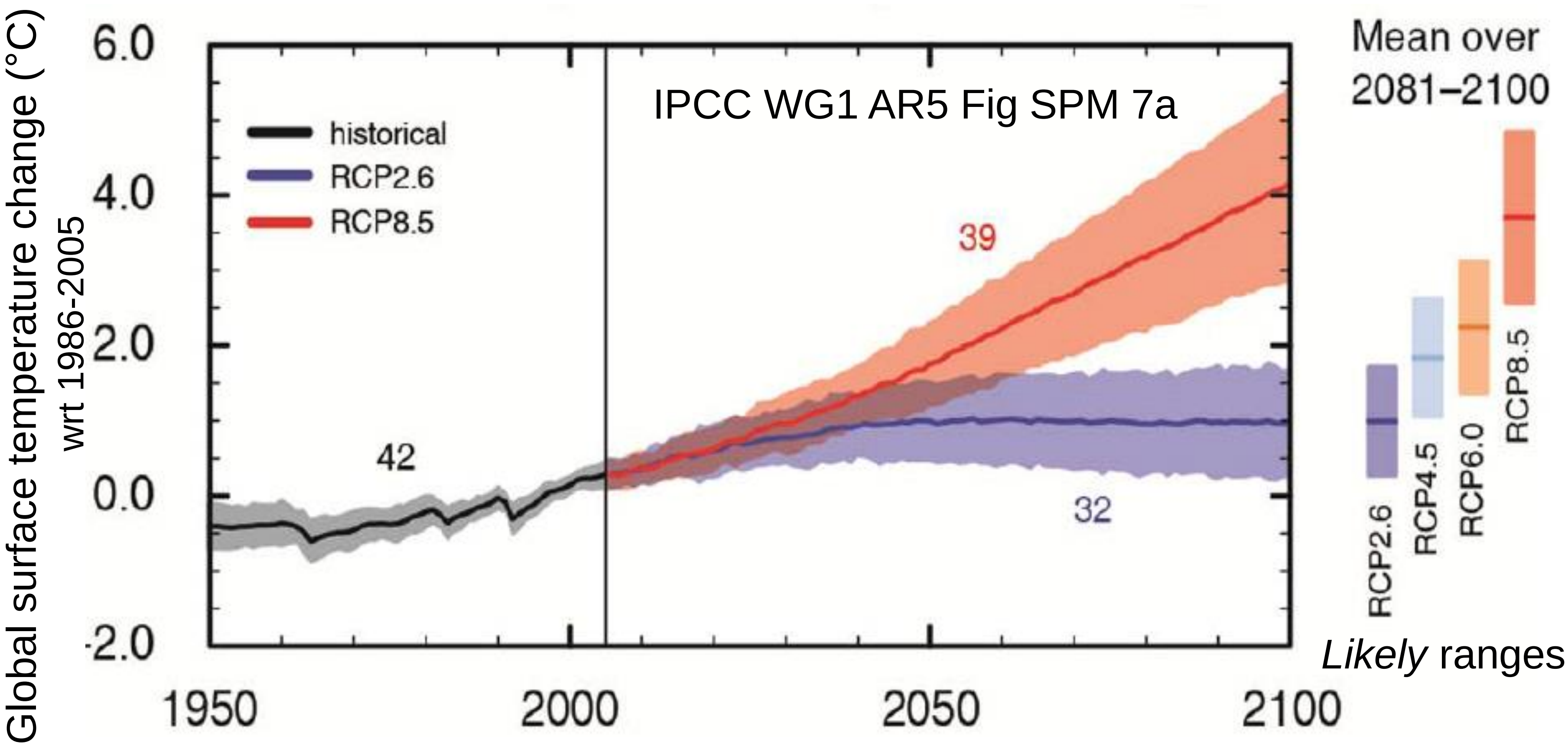
CryoSat-2 altimeter data 2010–2013

Satellite altimetry and tide-gauges show that the rate of GMSLR has been greater since the 1990s



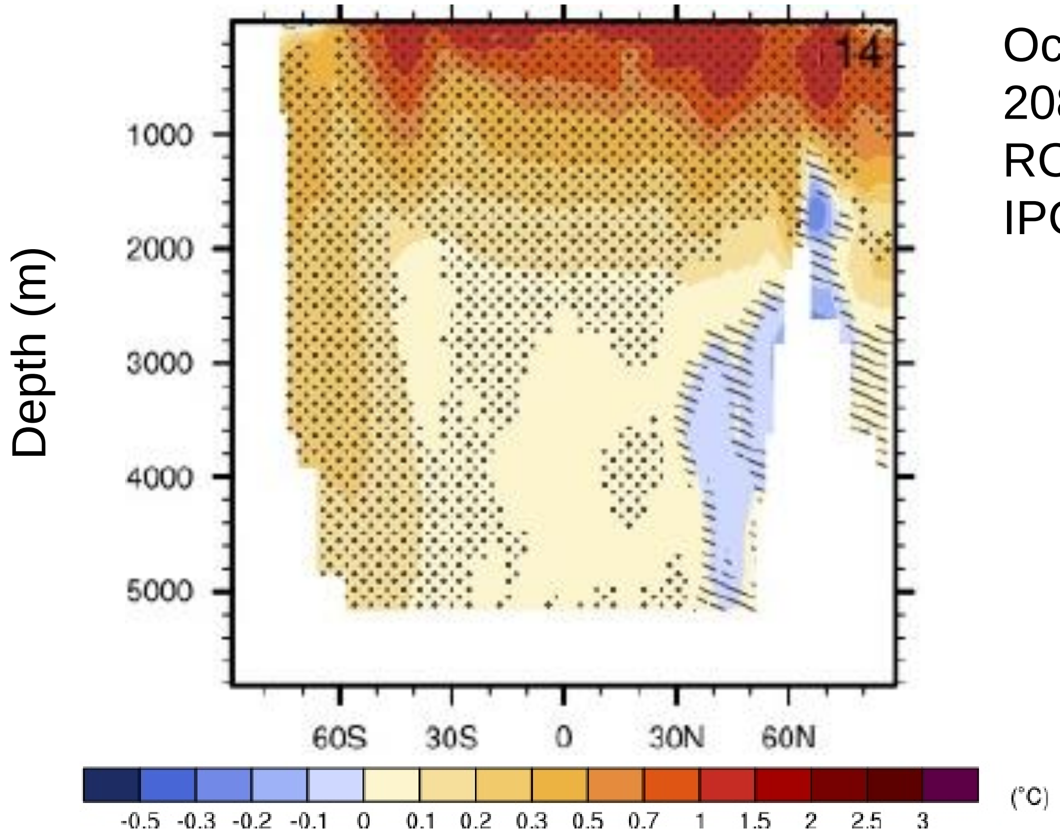
Observed GMSLR 1993-2010 is consistent with the sum of observed contributions. The greater rate of rise is a response to radiative forcing and increased loss of ice-sheet mass.

Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system



Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.

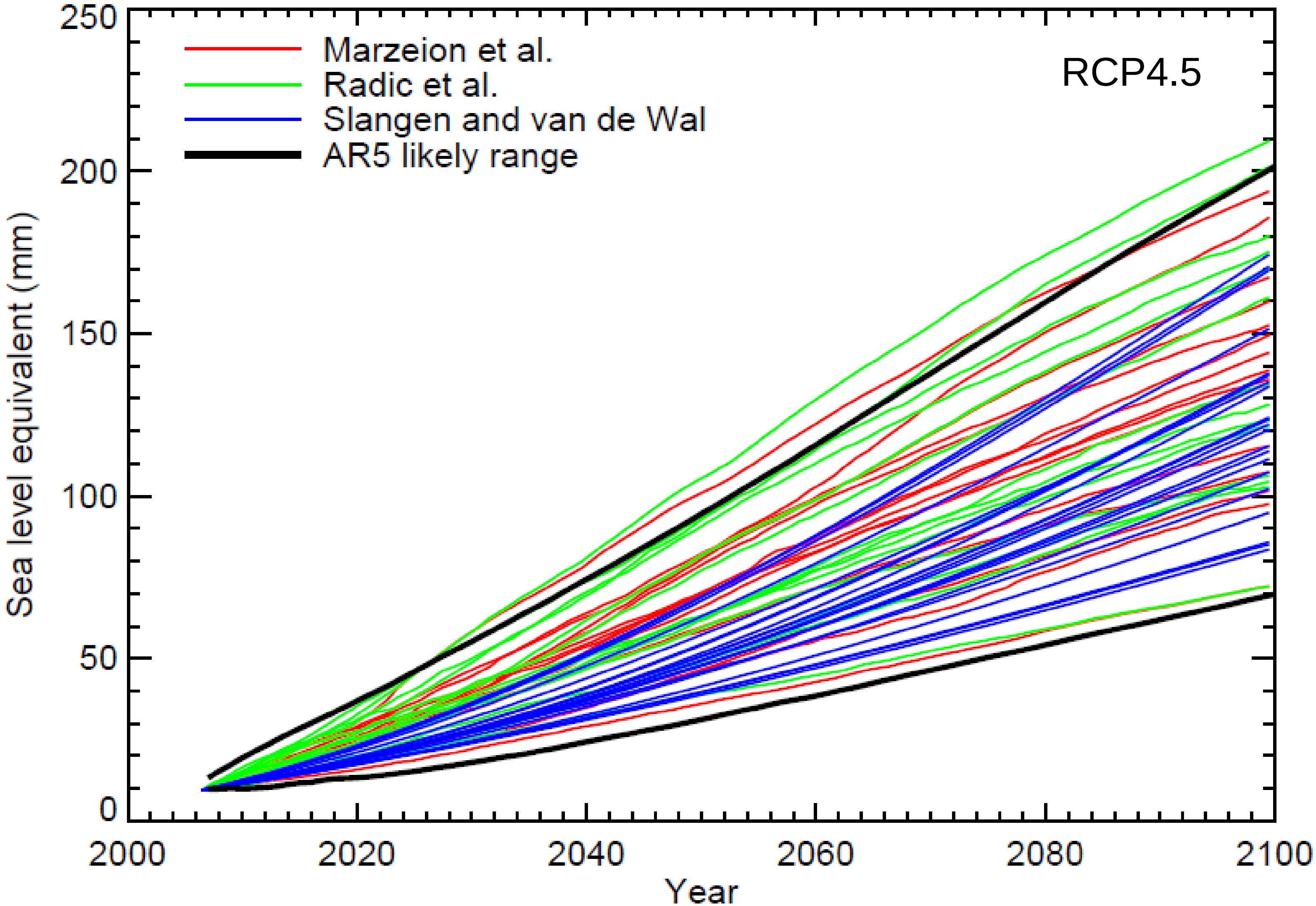
Heat will penetrate from the surface to the deep ocean



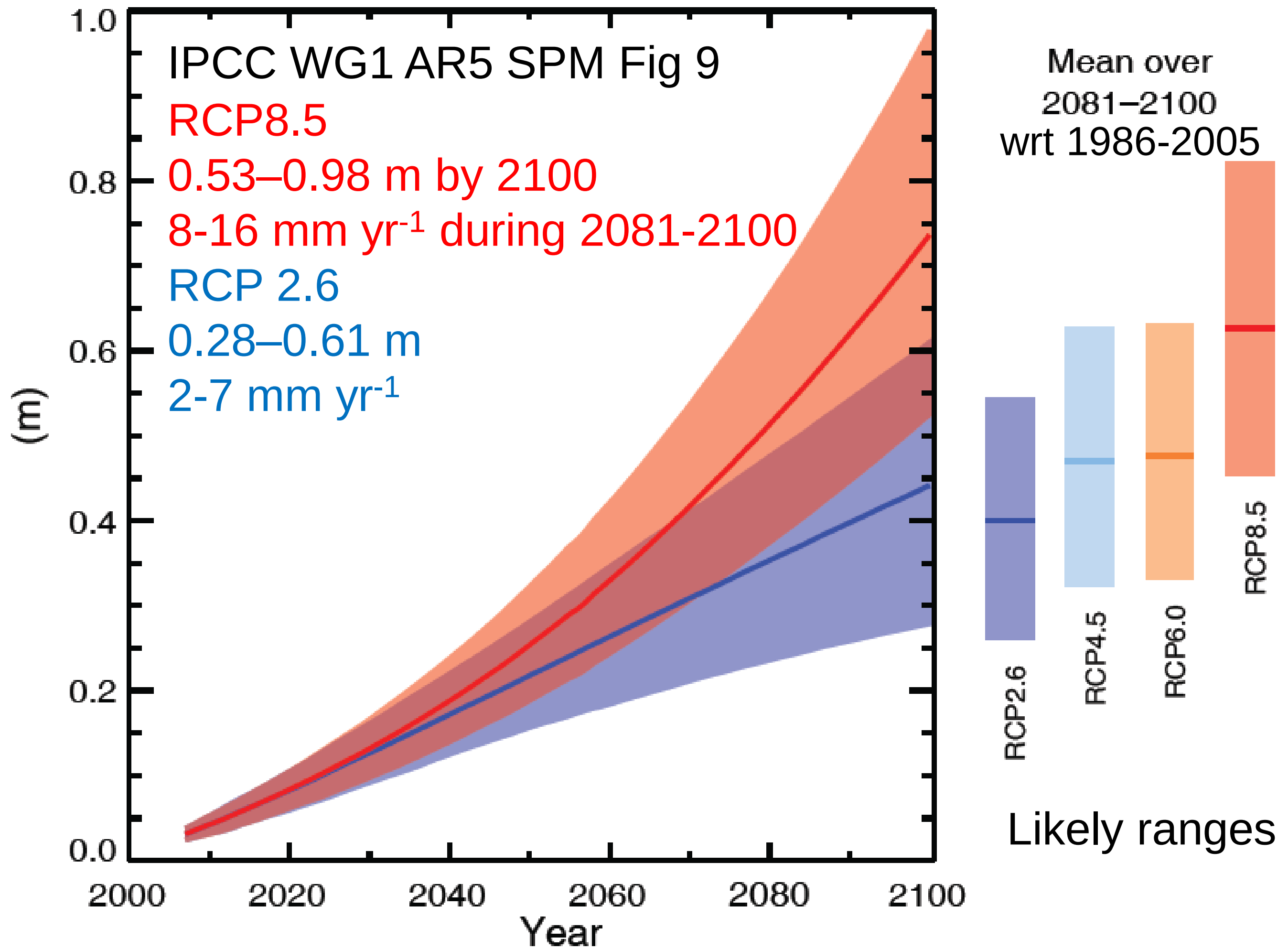
Ocean temperature change 2081-2100 wrt 1985-2005, RCP4.5
IPCC WG1 AR5 Fig 12.12

On the long term, thermal expansion gives 0.2-0.6 m of GMSLR per K of global mean surface temperature change.

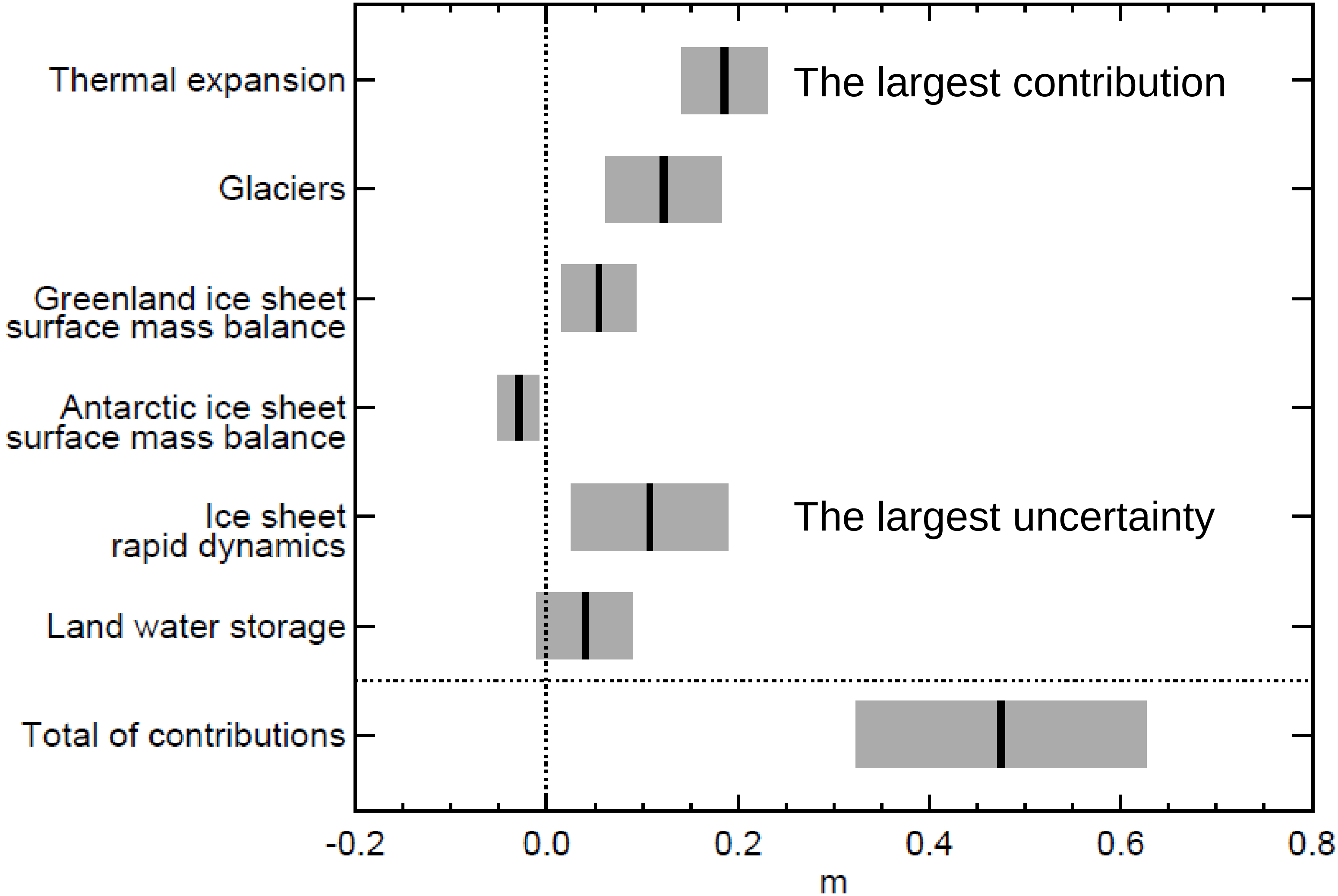
Global glacier volume is projected to decrease by 15 to 55% for RCP2.6, and by 35 to 85% for RCP8.5



It is very likely that the 21st-century mean rate of GMSLR will exceed that of 1971-2010 under all RCPs

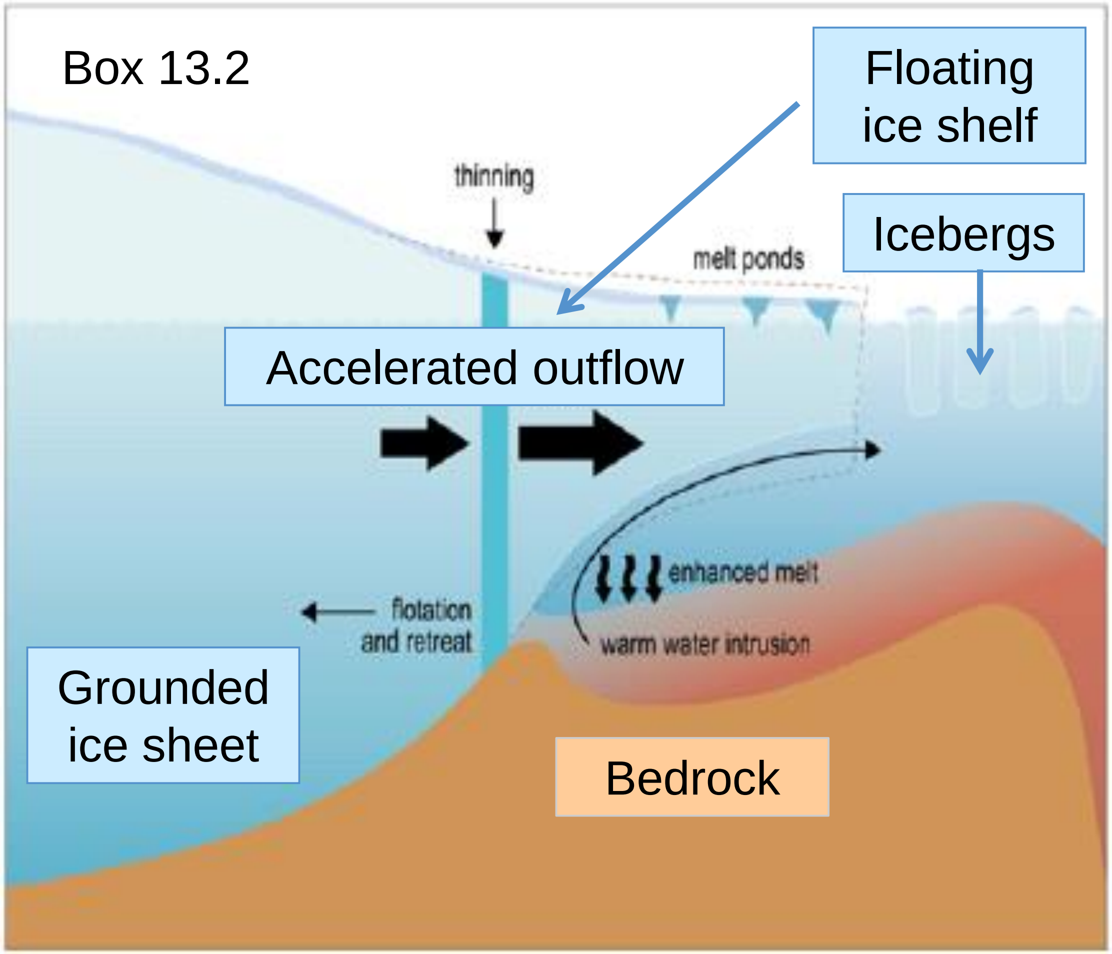


Projection for 2081-2100 under RCP4.5



Data from IPCC WG1 AR5 Table 13.5

Rapid increase in ice sheet outflow (especially Antarctica)



Only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause GMSL to rise substantially above the likely range during the 21st century.

Medium confidence that this additional contribution would not exceed several tenths of a metre.

Current evidence and understanding do not allow a quantification of either the timing of its onset or of the magnitude of its multi-century contribution.

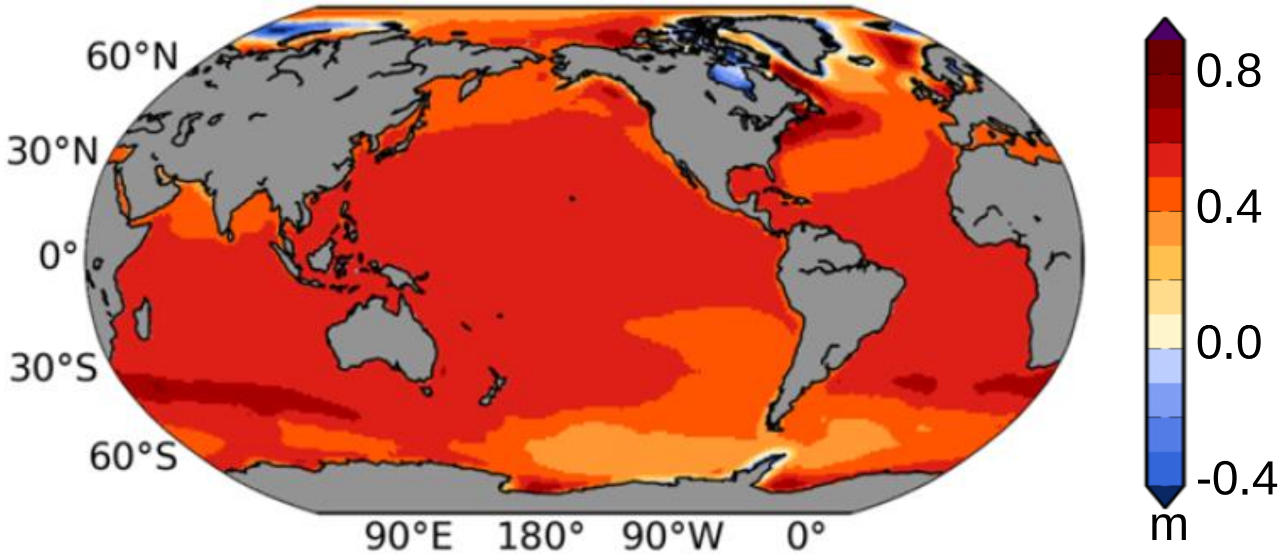
Increased Greenland surface mass loss in a warmer climate

Sustained global warming greater than a certain threshold above pre-industrial would lead to the near-complete loss of the Greenland ice sheet over a millennium or more.

Studies with fixed ice-sheet topography indicate the threshold is greater than 2°C but less than 4°C. The one study with a dynamical ice sheet suggests the threshold is greater than about 1°C.

Decrease in the Greenland ice sheet mass loss may be irreversible, depending on the duration and degree of exceedance of the threshold.

Regional sea level rise by the end of the 21st century

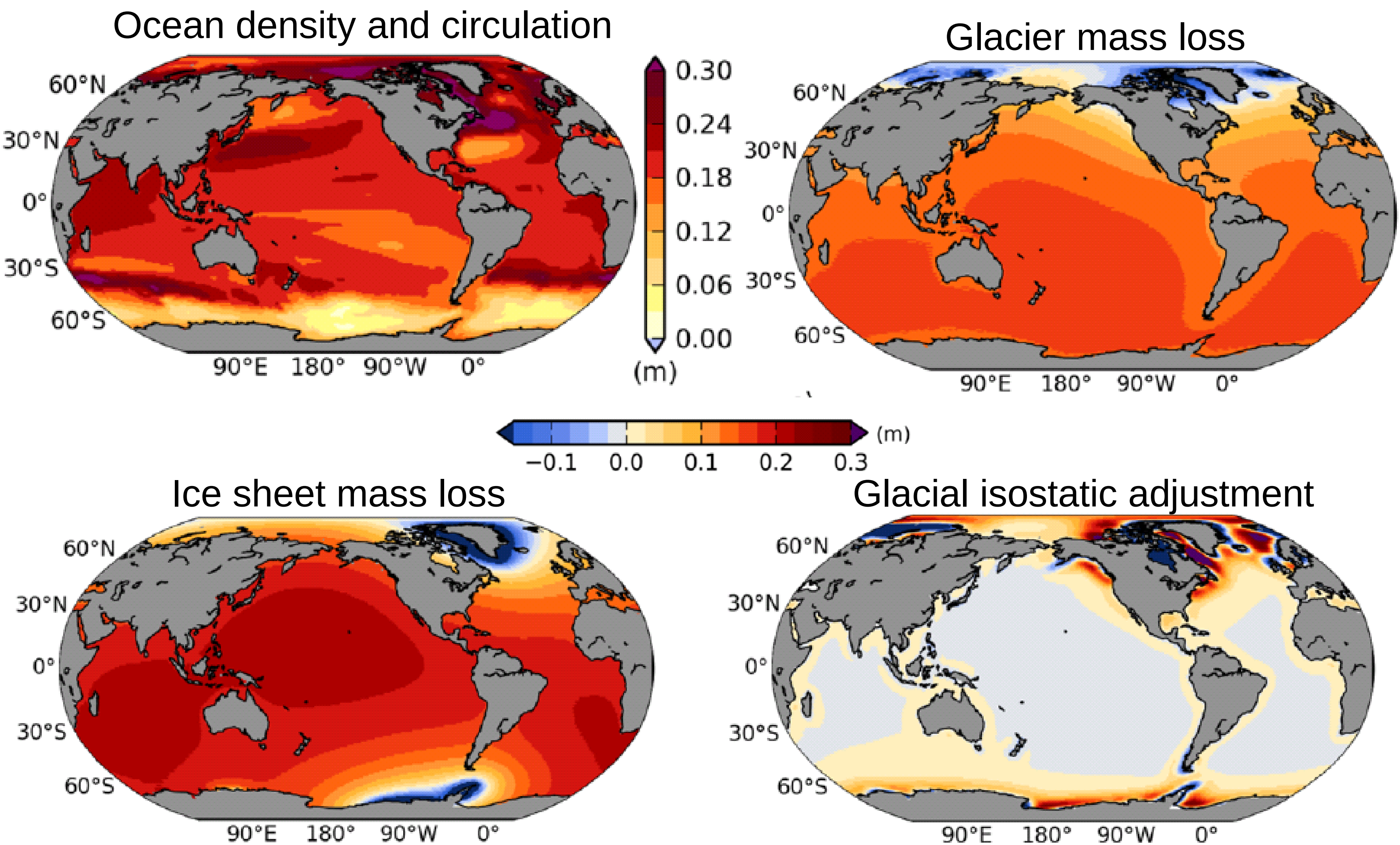


IPCC WG1 AR5 Fig 13.20b

It is very likely that sea level will rise in more than about 95% of the ocean area.

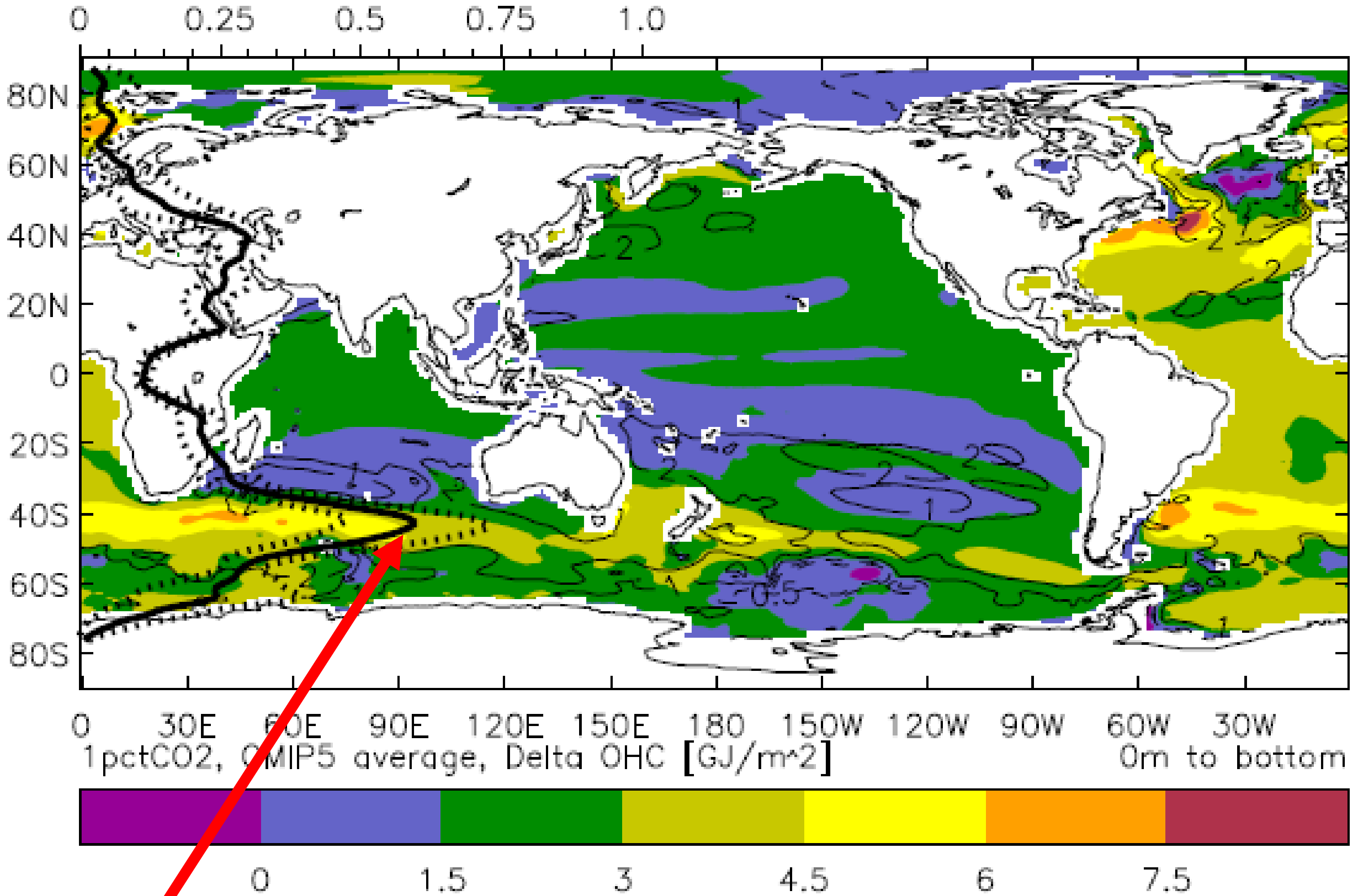
About 70% of the coastlines worldwide are projected to experience sea level change within 20% of the global mean sea level change.

Contributions to the geographical variation of sea level rise



Figures 13.16 and 13.18, for RCP4.5 2081-2100

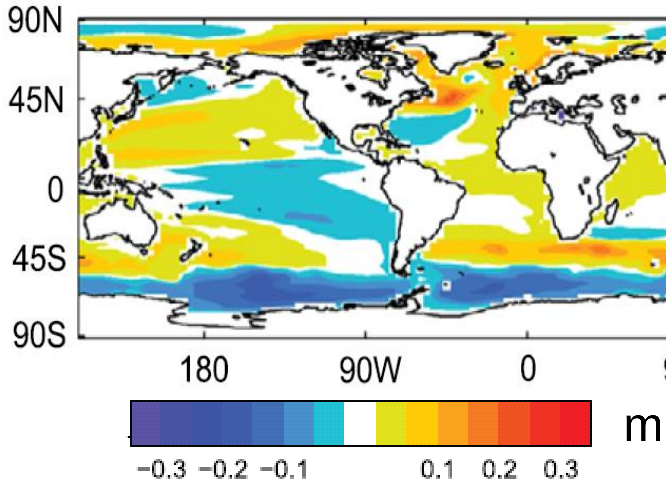
Sea level change resembles ocean heat content change



Southern Ocean dominates ocean heat uptake

Kuhlbrodt and Gregory (2012)

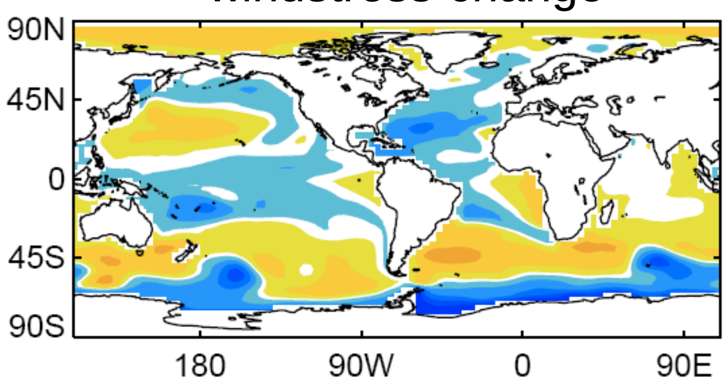
Effect of surface flux changes on sea level



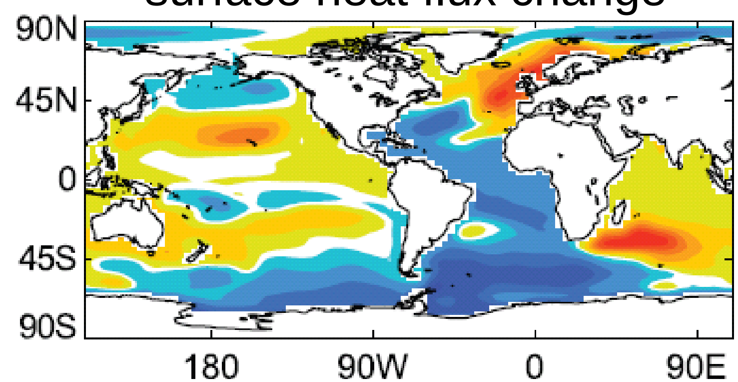
Change in ocean dynamic topography in CMIP5 ensemble mean

Change in ocean dynamic topography in forced by CMIP5 …

windstress change



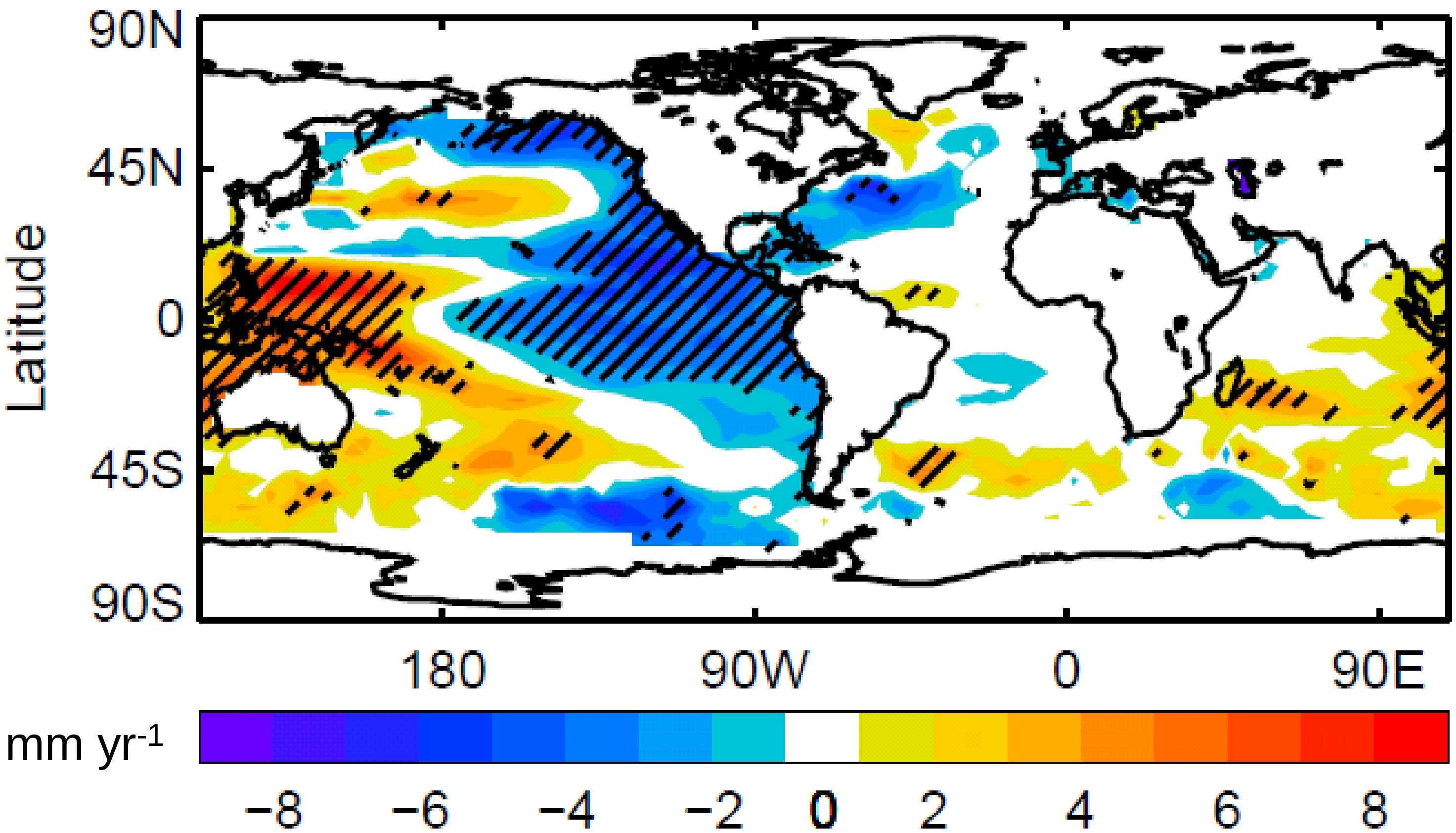
surface heat flux change



Bouttes and Gregory (2014)

Can we detect the pattern of forced sea level change?

Observed rate of sea level change 1993-2012 (relative to GMSLR)



Hatched regions are inconsistent with unforced variability in at least 2/3 of models

Bilbao et al. (2015)

Conclusions

We can account for GMSLR during 1901–2010, in terms of thermal expansion, land ice loss, and change in liquid water storage on land.

It is very likely that there is a substantial anthropogenic contribution to global mean sea level rise since the 1970s.

The likely range of GMSLR for 2081–2100 compared with1986–2005 is 0.26–0.55 m for RCP2.6, 0.45–0.82 m for RCP8.5.

The collapse of marine-based sectors of the Antarctic Ice Sheet, if initiated, would add no more than several tenths of a meter during the 21st century.

It is very likely that sea level will rise in more than about 95% of the ocean area, but with a strong regional pattern.

It is very likely that there will be a significant increase in the occurrence of sea level extremes.

It is virtually certain that global mean sea level rise will continue for many centuries beyond 2100.

Important uncertainties remain in modelling past and future changes in ocean heat uptake, regional sea level rise and ice sheets. These are subjects of the WCRP Grand Challenge on regional sea level change.