Sea-level change: A scientific and societal challenge for the 21st century

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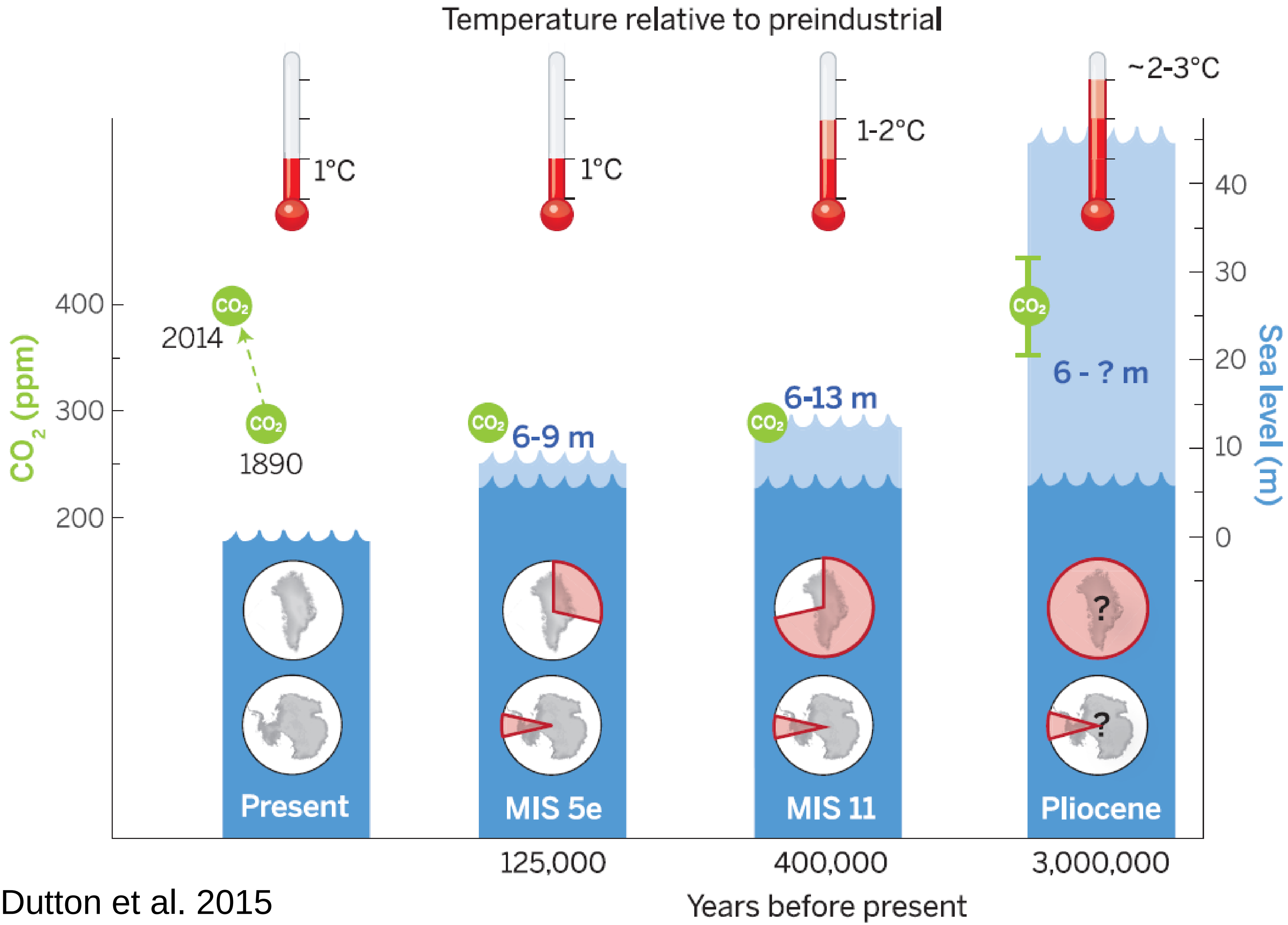
Our coastal society has developed during a period of stable (and in some places falling) relative sea level.

60-150 Million within 1 m of current sea level

The Gold Coast development over 1958-2007 (population 40,000 to 480,000 with 4 million visitors. Church et al. 2010

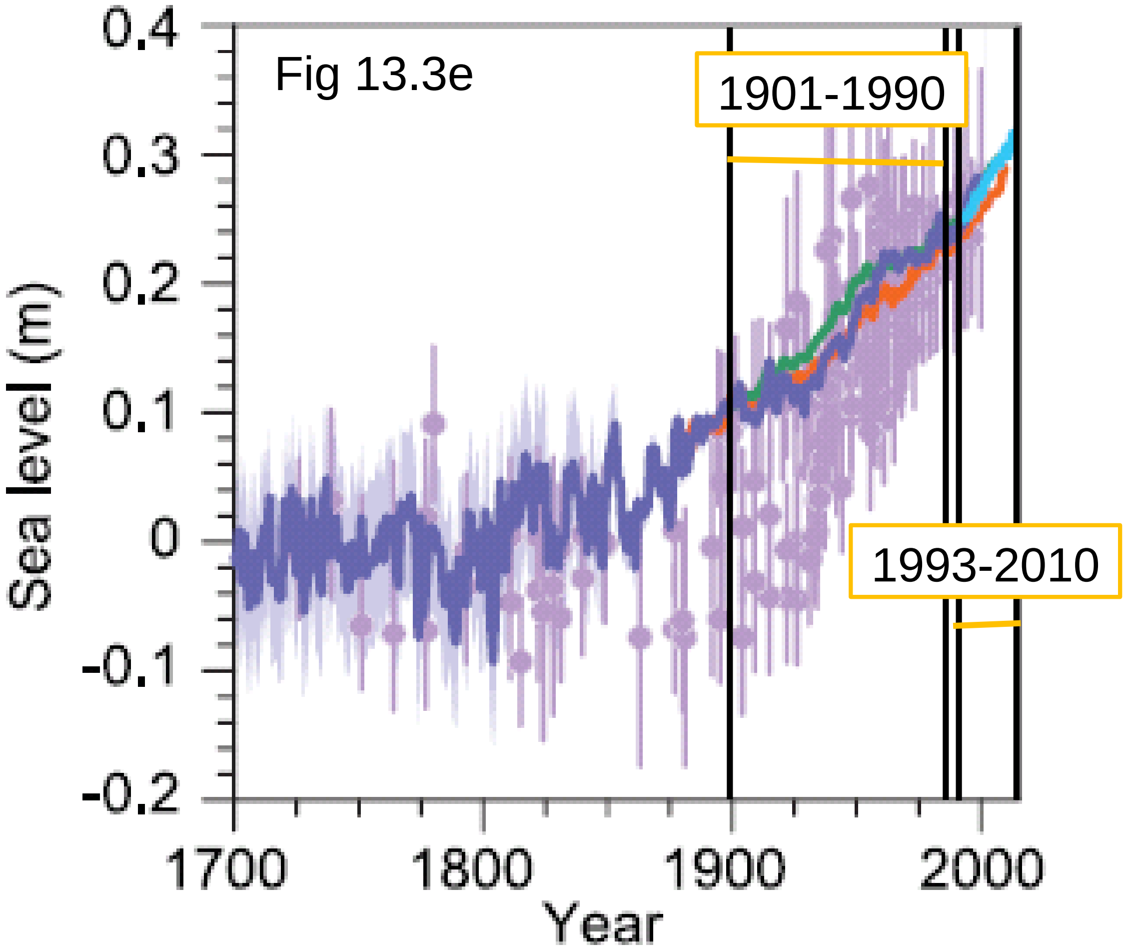
Sea level was higher during warm periods



Dutton et al. 2015

Rate of GMSLR has been greater since the mid-19th century

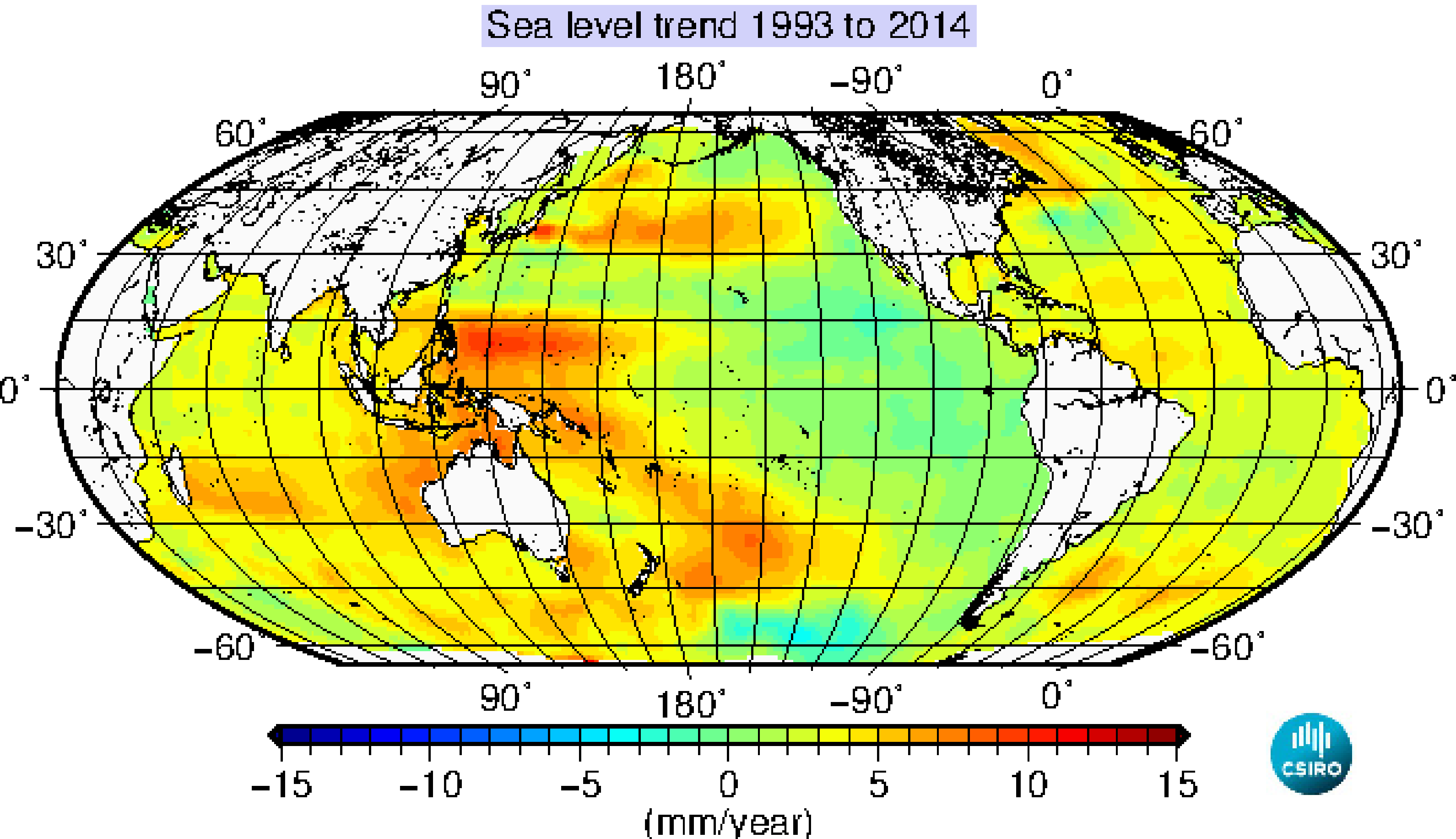
Rate during the last two millennia was of order a few tenths of mm yr^{-1}.



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

Rate during 1993-2010 was 3.2 [2.8 to 3.6] mm yr^{-1}, but also high rates in 1920-1950

Satellite altimeter trends – 1993 to 2014

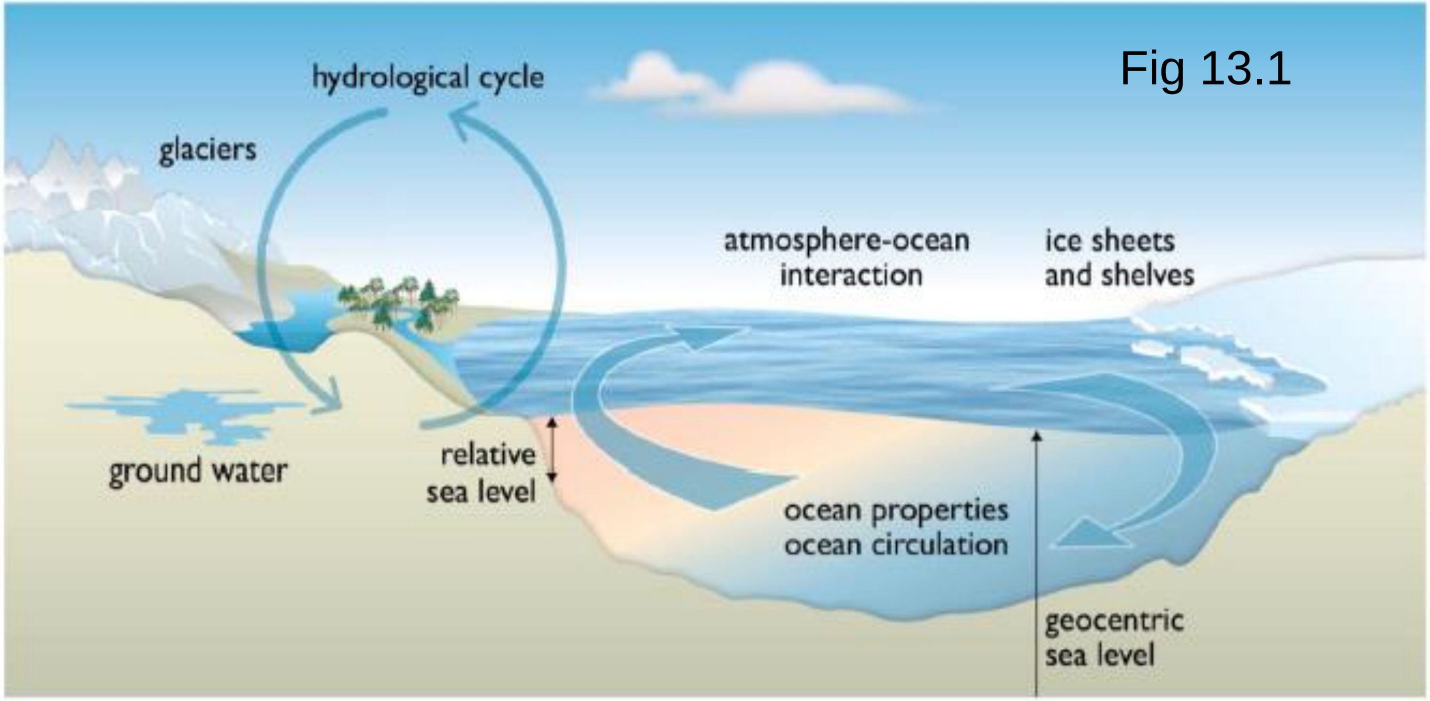


Causes of global mean sea level (GMSL) change

Warming (cooling) of the ocean (thermal expansion/contraction)

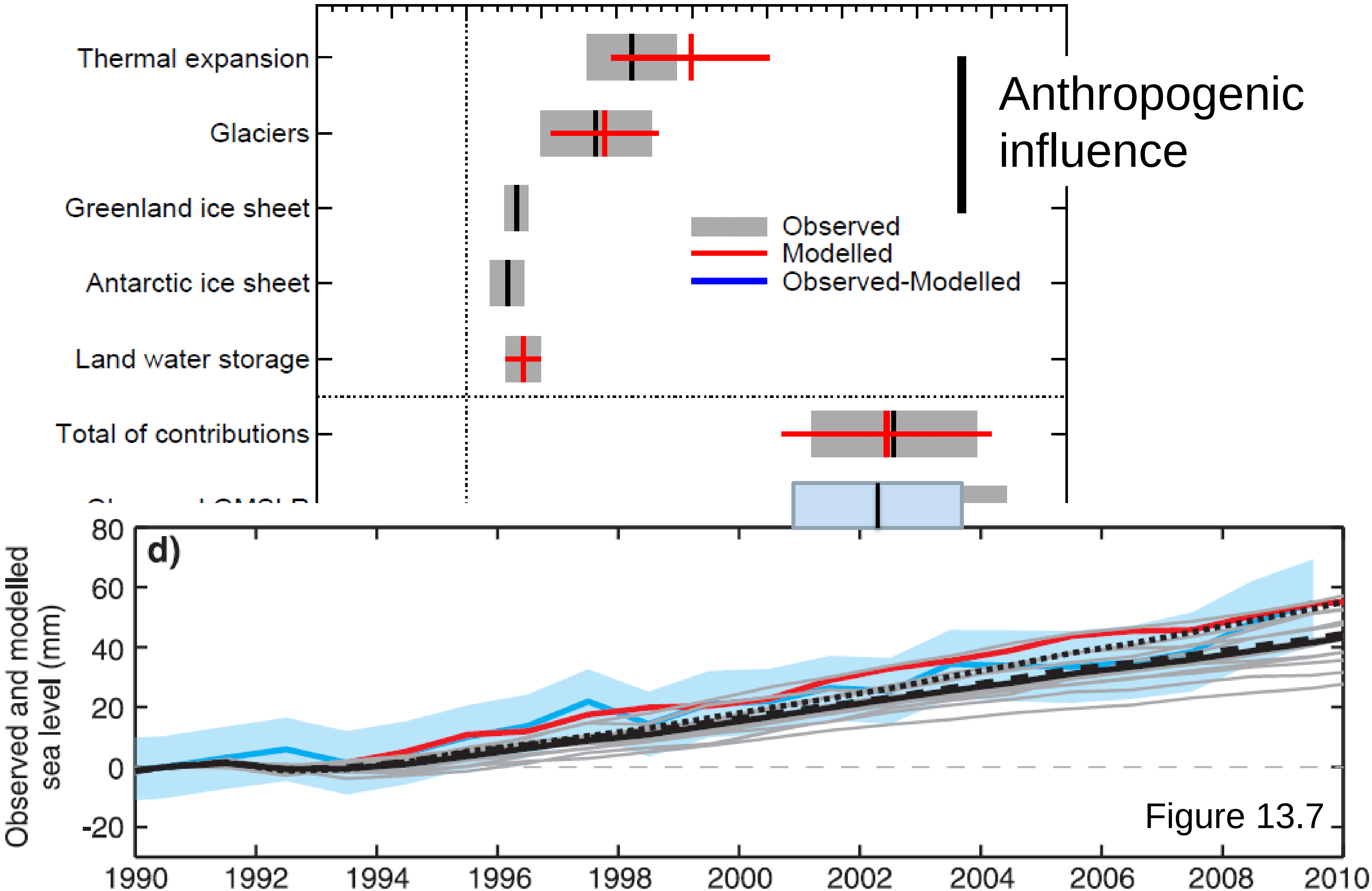
Change in mass of glaciers and ice sheets (Barystatic)

Changes in liquid water storage on land (Barystatic)



Relative sea level is also affected by ocean density and circulation, land movement, and distribution of mass on the Earth

Improved understanding of 20th century sea level change
Observed contributions explain observed GMSLR 1993-2010



Thermal expansion accounts for 30 to 55% of 21st century global mean sea level rise, and glaciers for 15 to 35%.

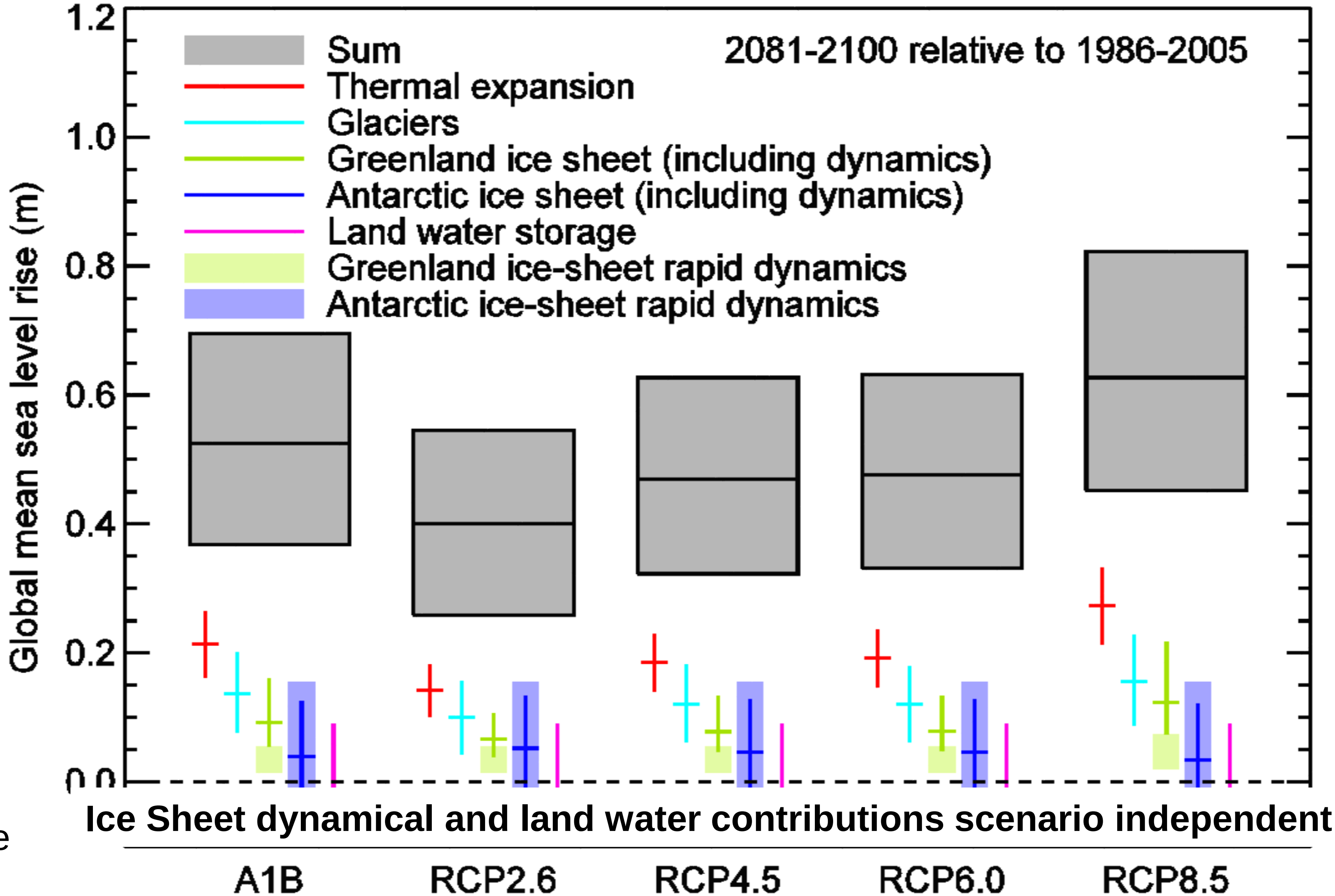
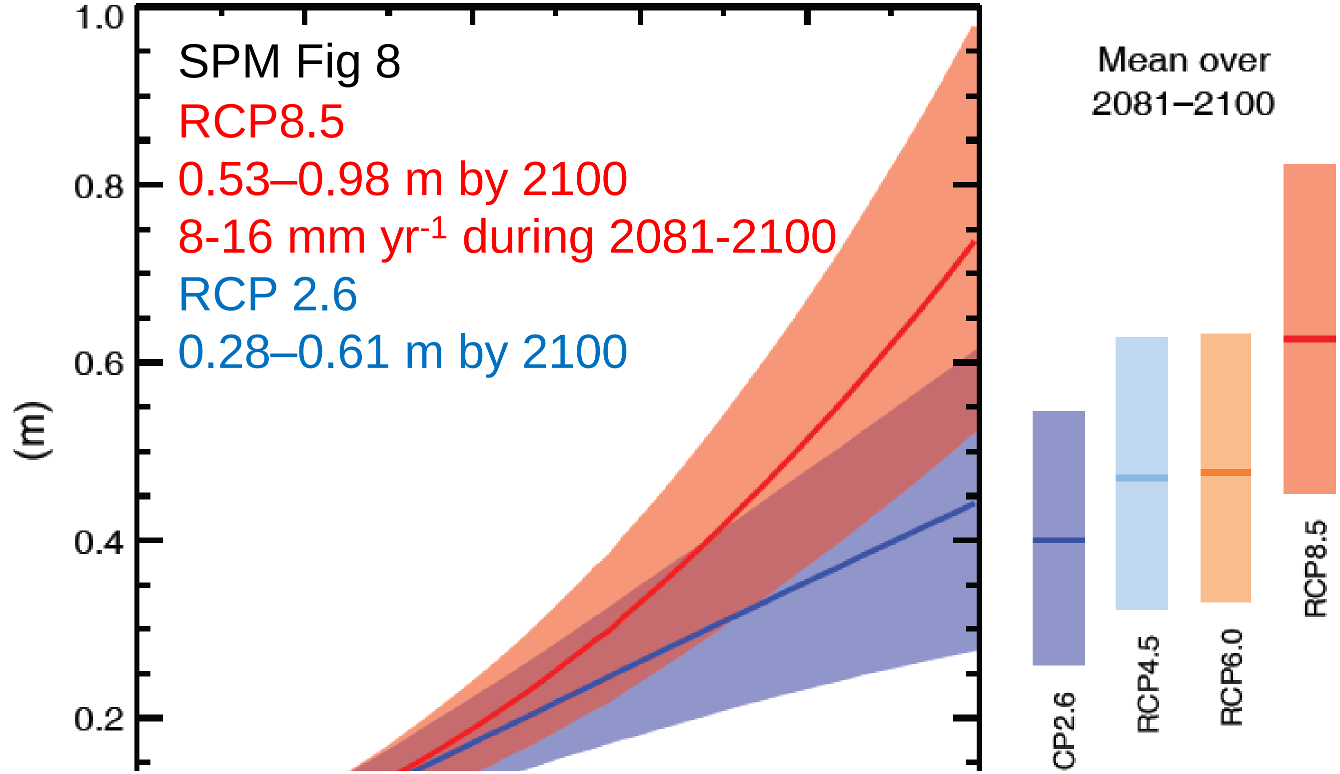


Figure 13.10

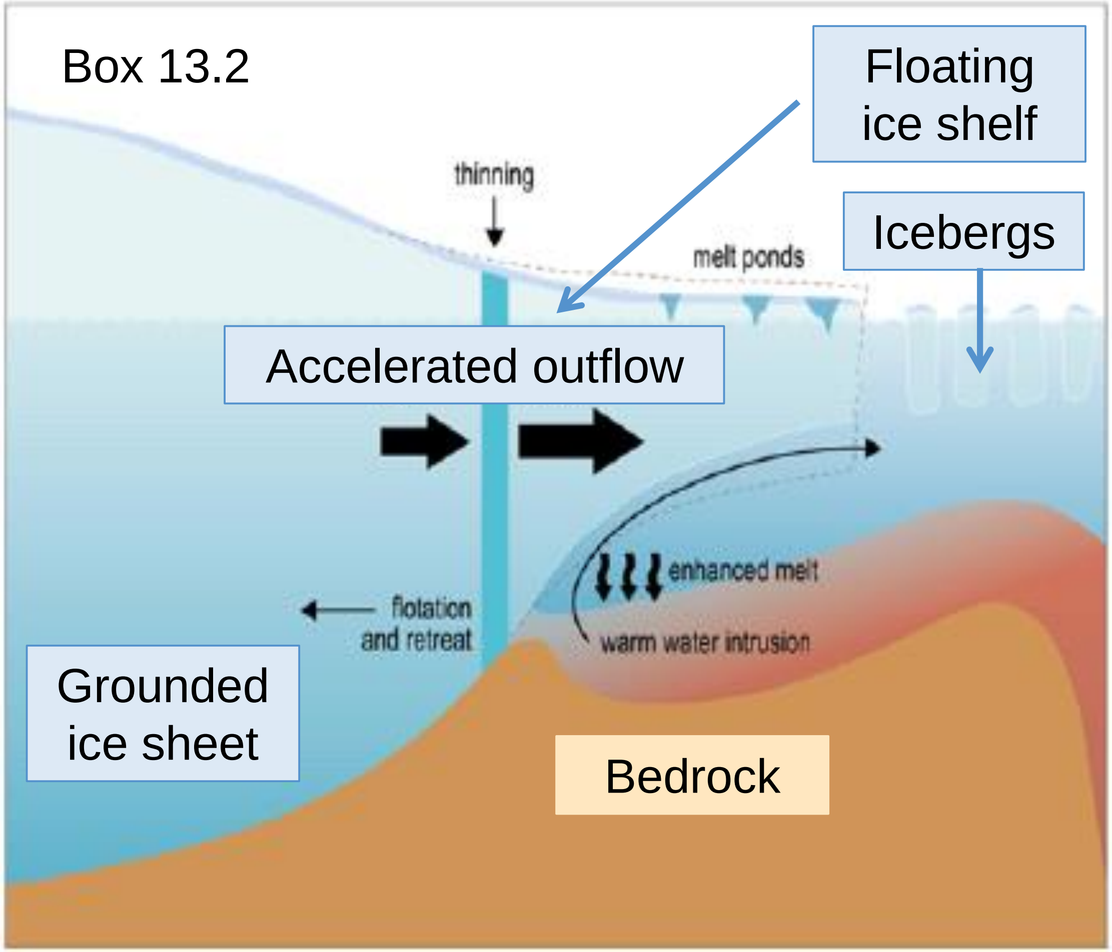
Projections of 21st-century GMSLR under RCPs

Medium confidence in *likely* ranges. *Very likely* that the 21st-century mean rate of GMSLR will exceed that of 1971-2010 under all RCPs.



Antarctic dynamics/ land water storage scenario independent
Then Greenland SMB, Antarctic and Greenland dynamics
Largest contributions: expansion, glaciers
Earlier emissions lead to larger sea-level rise

Potential rapid increase in ice sheet outflow



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 during the 21st century.

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.

Post AR5 estimates of dynamical Antarctic Ice Sheet contribution

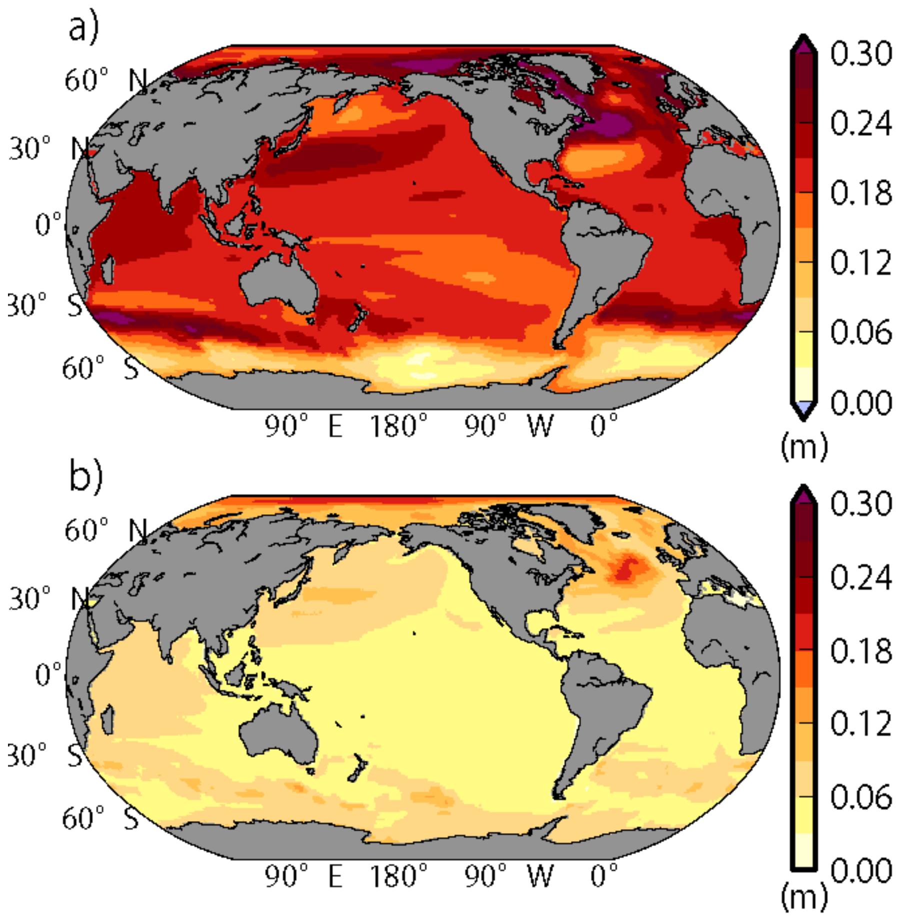
Reference	Region of ice sheet	Mass loss (m)	Period
AR5	all of Antarctica	-0.020 to 0.185	1996-2100
Favier et al. (2014)	PIG	0.009 to 0.025	2000-2050
Seroussi et al. (2014)	PIG	up to 0.020	2000-2050
Joughin et al. (2014)	TG	up to 0.025	2000-2100
Gong et al. (2014)	Lambert	up to 0.009	2000-2100
Sun et al. (2014)	Totten	up to 0.020	2000-2100
Cornford et al. (2015)	all of Antarctica	up to 0.200	2000-2100
Levermann et al. (2014)	all of Antarctica (RCP2.6)	0.02 to 0.140	2000-2100
Levermann et al. (2014)	all of Antarctica (RCP8.5)	0.04 to 0.210	2000-2100

Marine ice sheet instability initiated – long term Implications

Clark et al. 2015

A number of contributions to a non-uniform sea-level rise

Dynamical Ocean Response



Glacial isostatic

Glacier

Ice sheet mass loss

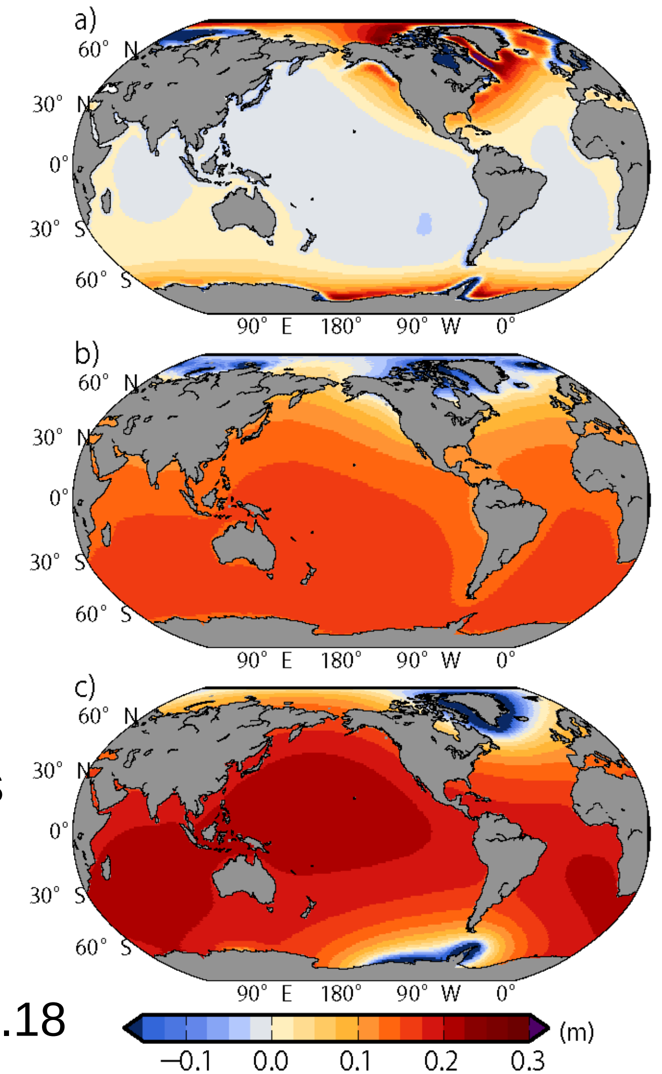


Figure 13.18

Very likely **sea level will rise in more than 95% of the ocean.**

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

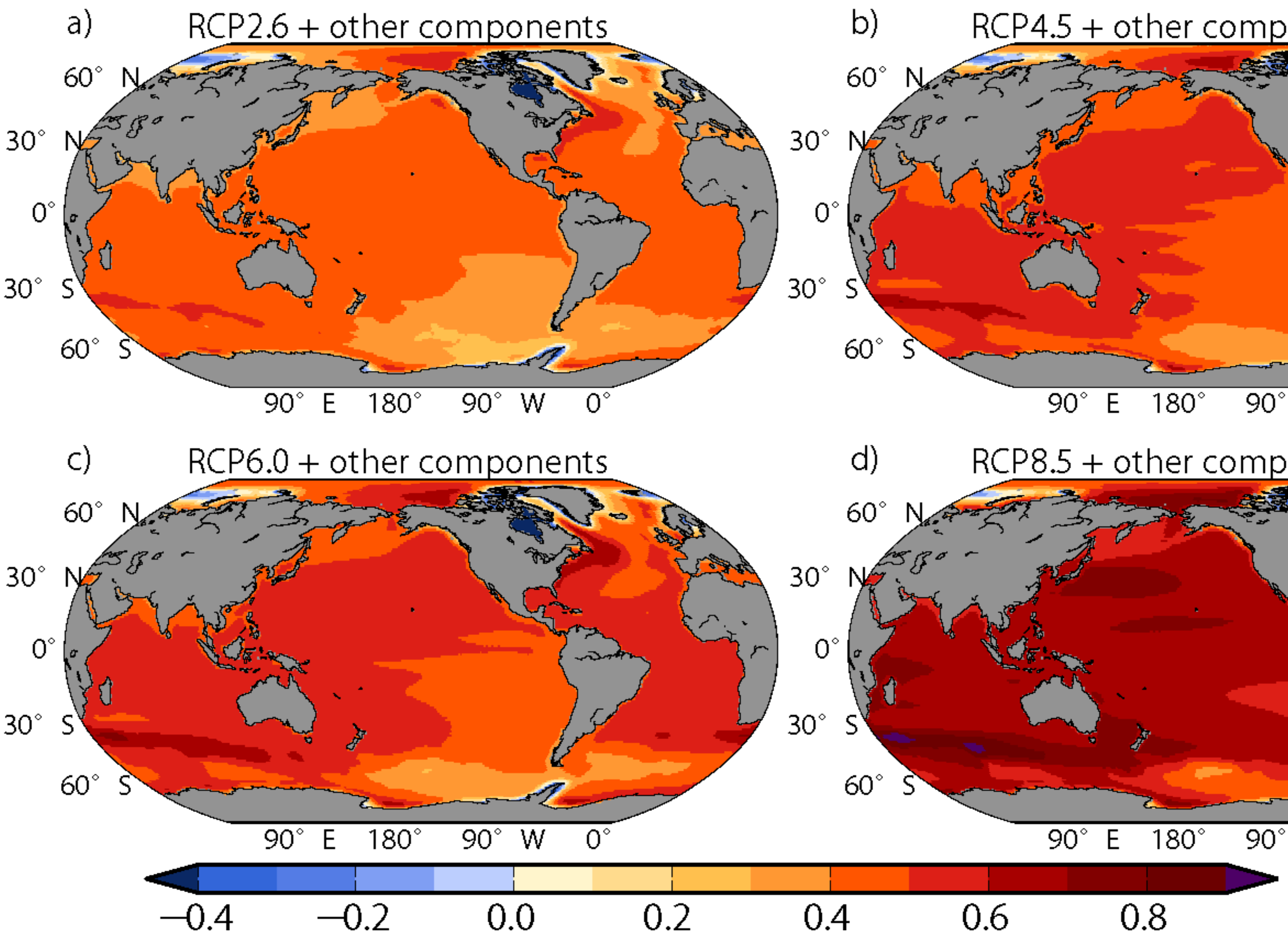


Figure 13.20

It is very likely that sea level will rise in more than about 95% of the ocean area by the end of the 21st century

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

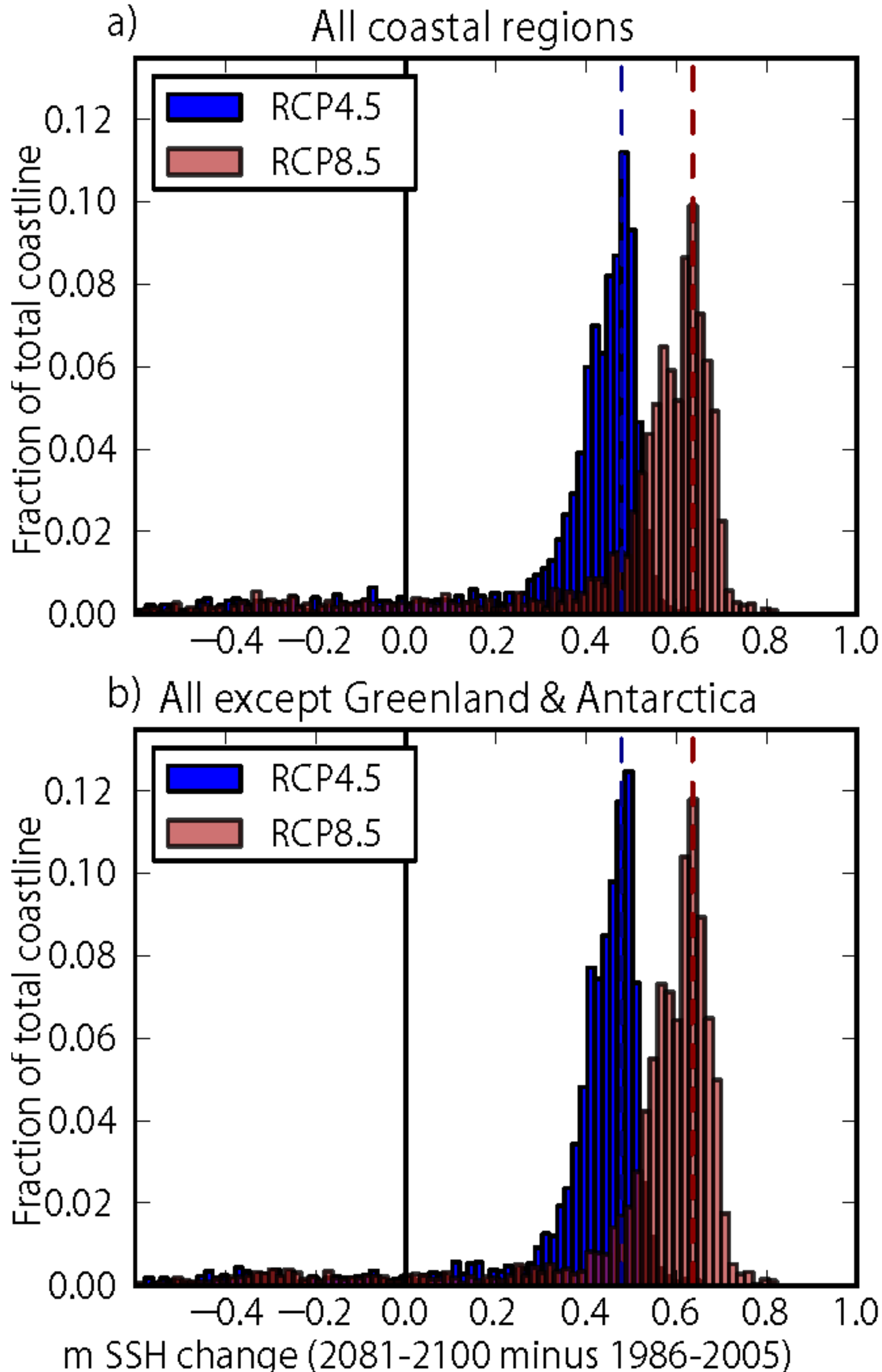


Figure 13.22

It is *virtually certain that global mean sea level rise will continue beyond 2100*.

Ranges from few available models, not a *likely* range.

Current models are *likely* to systematically underestimate Antarctica's contribution

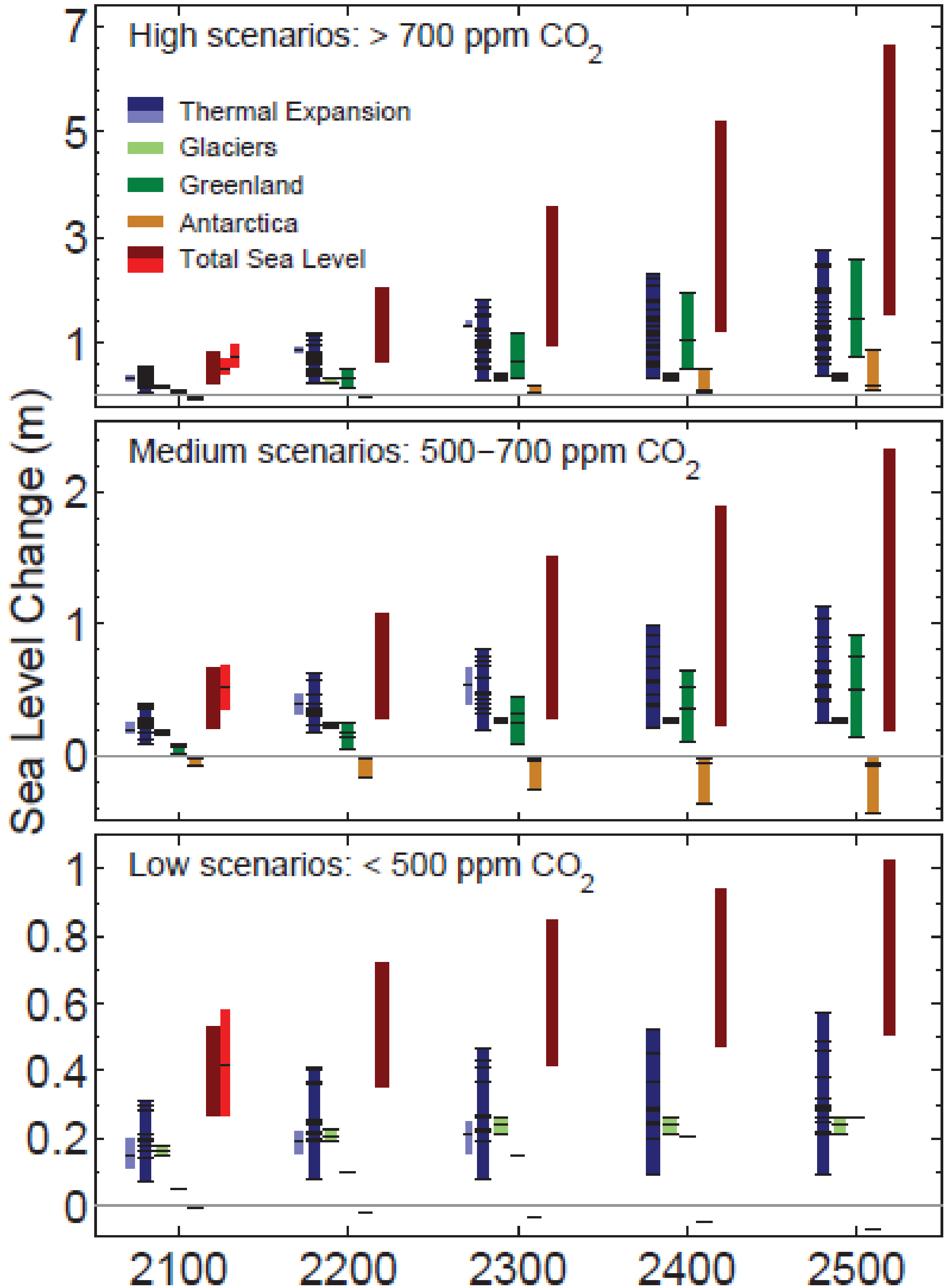


Figure 13.13

IPCC AR5 Working Group I
Climate Change 2013: The Physical Science Basis

Ocean thermal expansion to continue for centuries

GMSL rise of several meters could result from long-term mass loss by ice sheets (consistent with paleo data).

Sustained warming greater than
some threshold would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea level rise of up to 7 m.

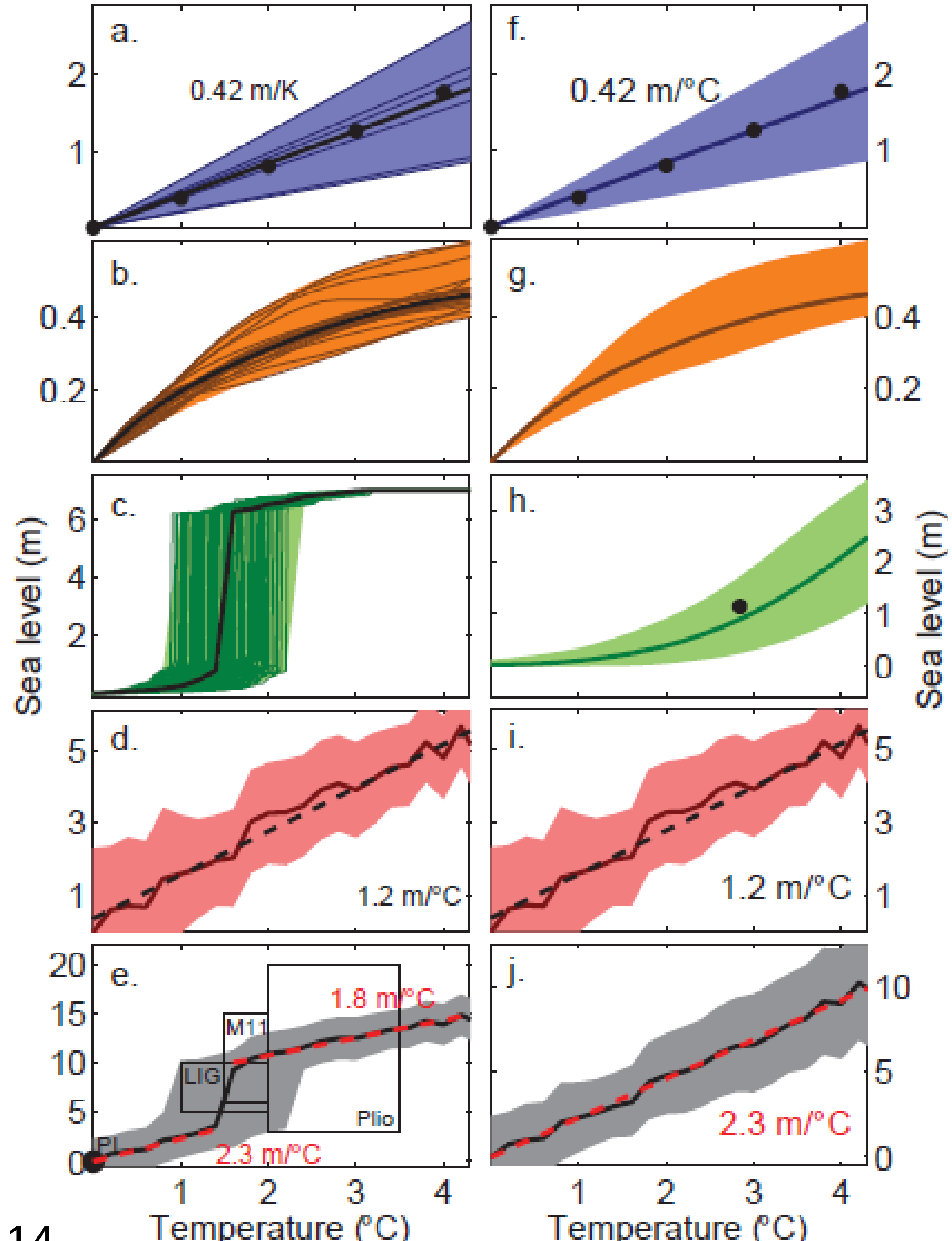
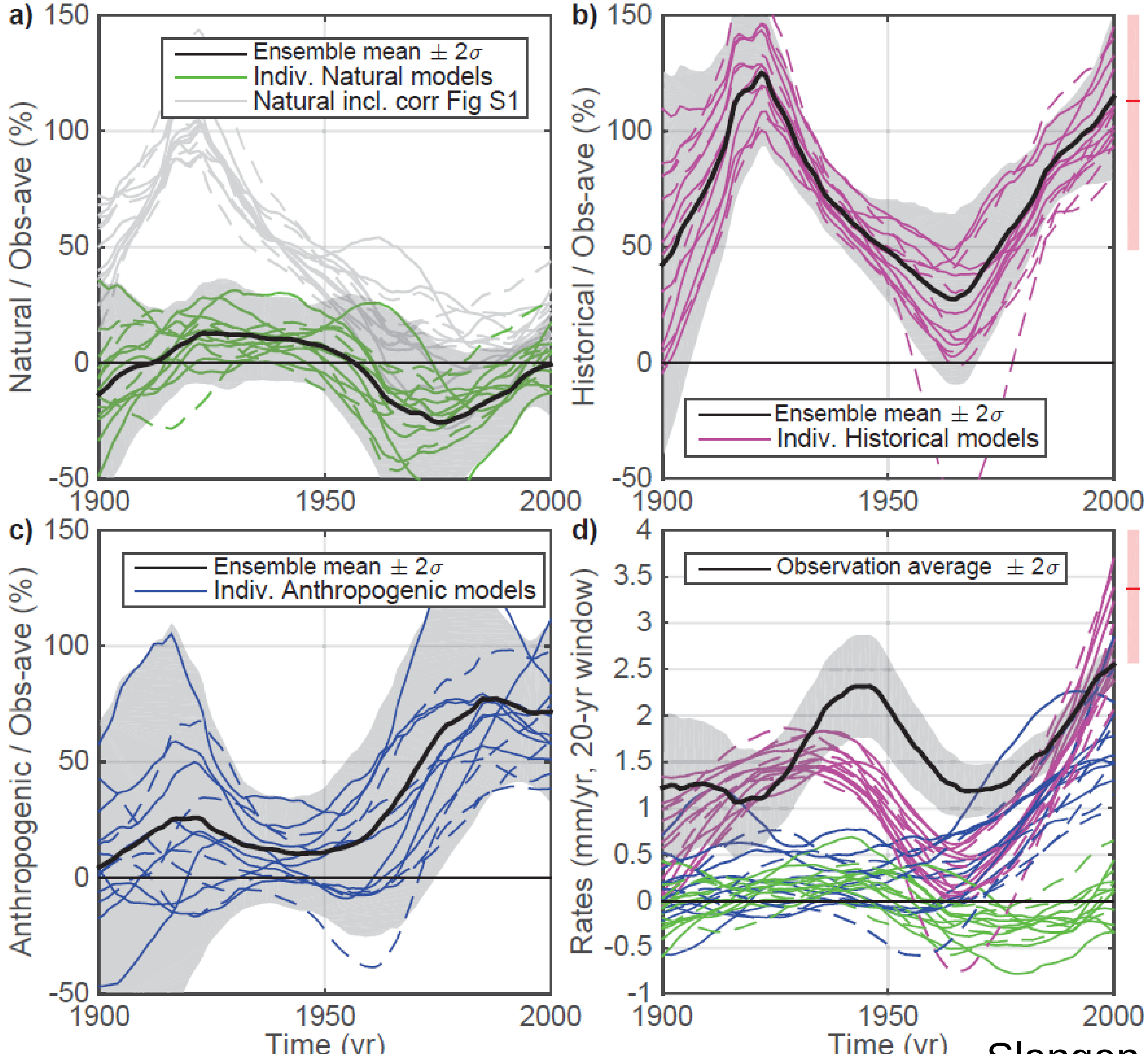


Figure 13.14

Attribution of sea level change to causes

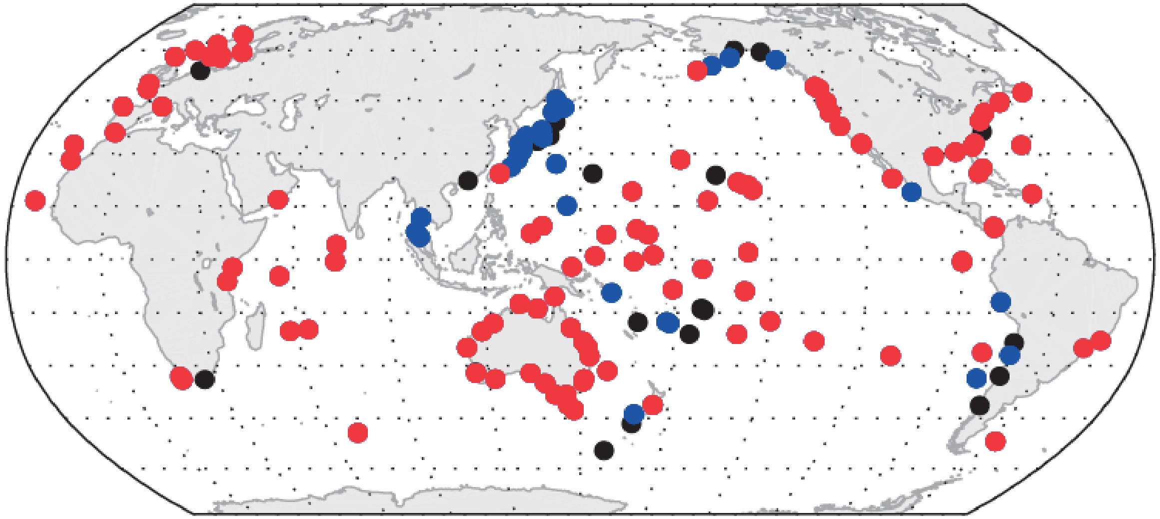


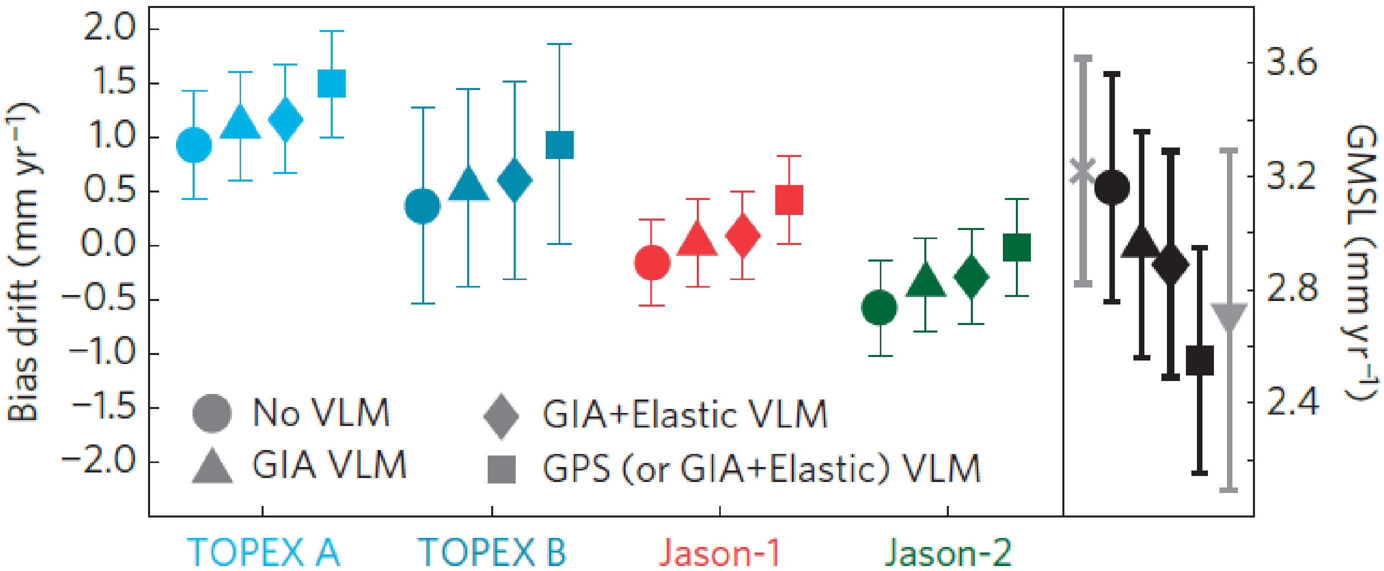
Slangen et al., in review

Requirements

- Reference frames and vertical land motion
- (<~0.2 mm/yr)
- Altimetry – <~0.2 mm/yr in GMSL, sub mm/yr regionally
- Tide gauges movements – TIGA and GPS/TG ties
- Rates and Absolute heights

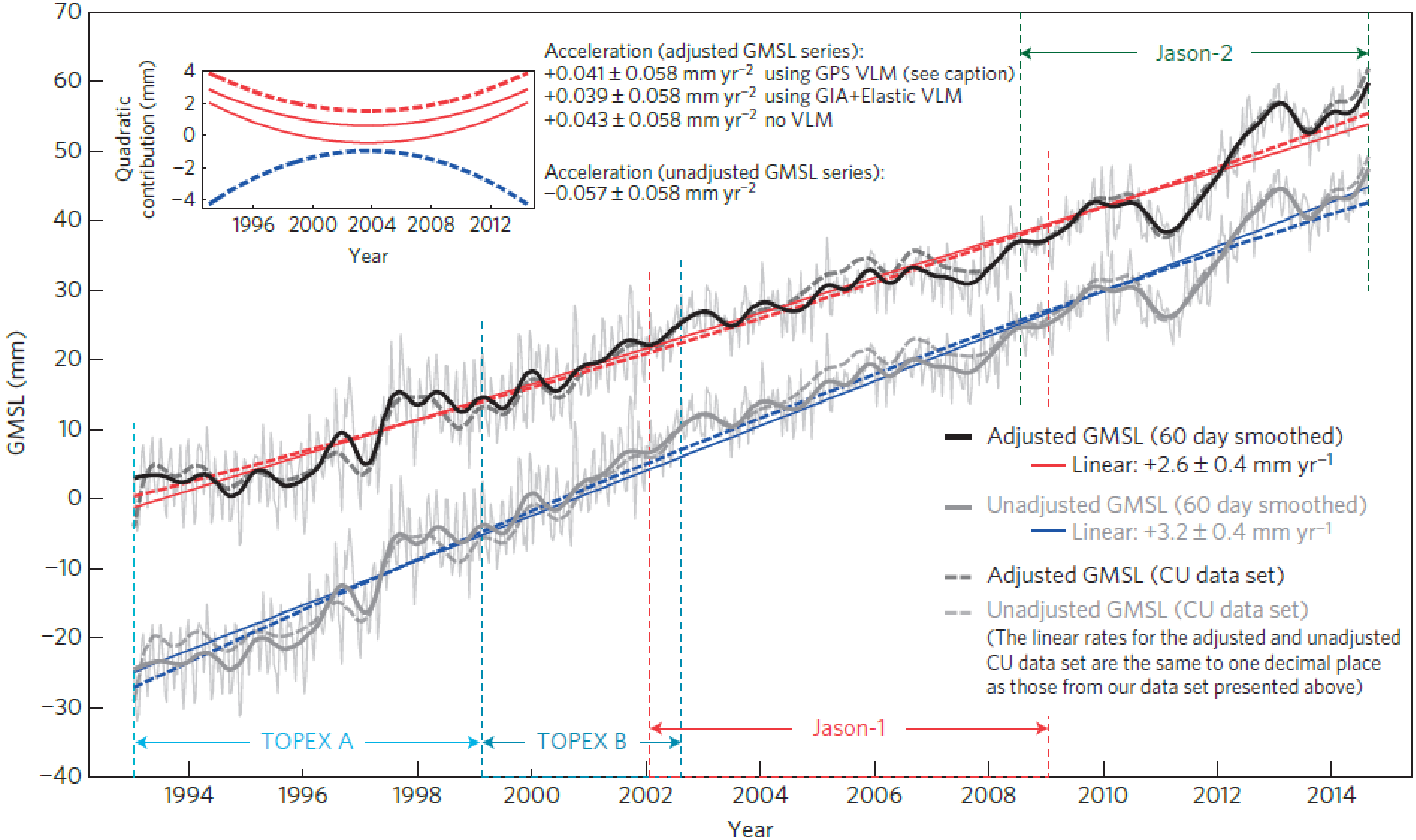
Satellite altimeter calibration





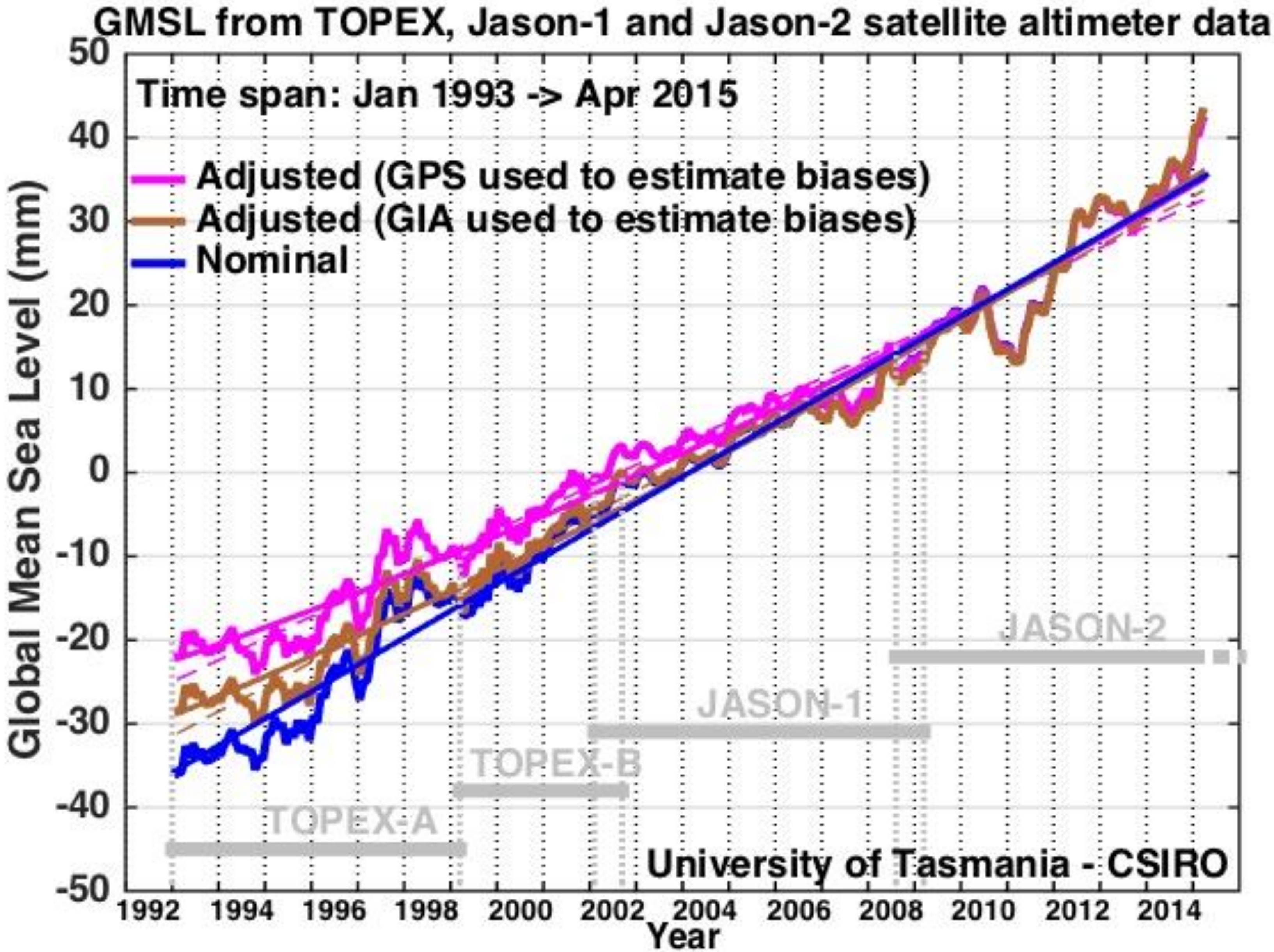
Watson et al. 2015

Calibration slightly decreases trend and increases acceleration



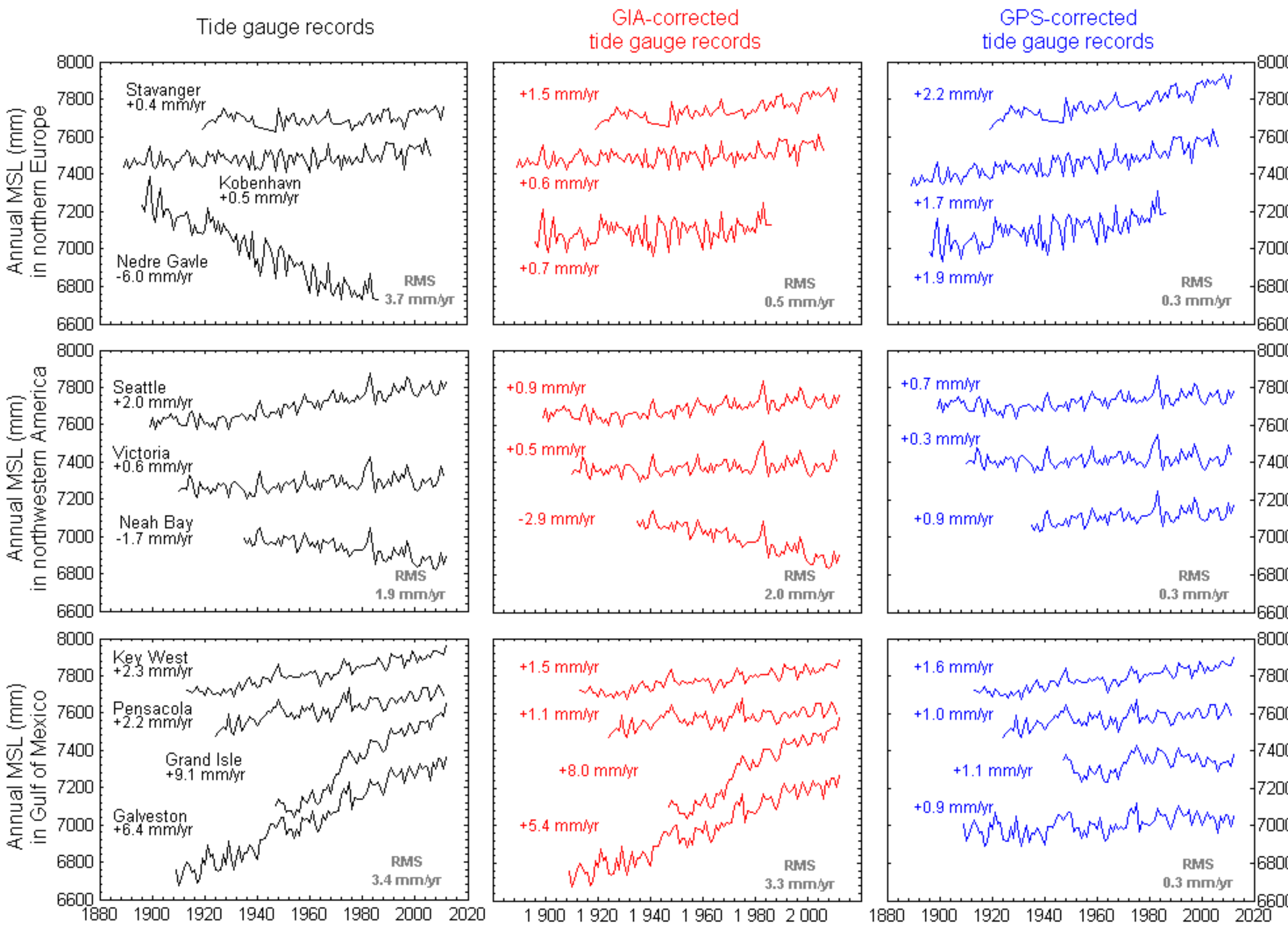
Watson et al. 2015

Reprocessed altimeter data has smaller trend and a positive acceleration (rather than a deceleration)



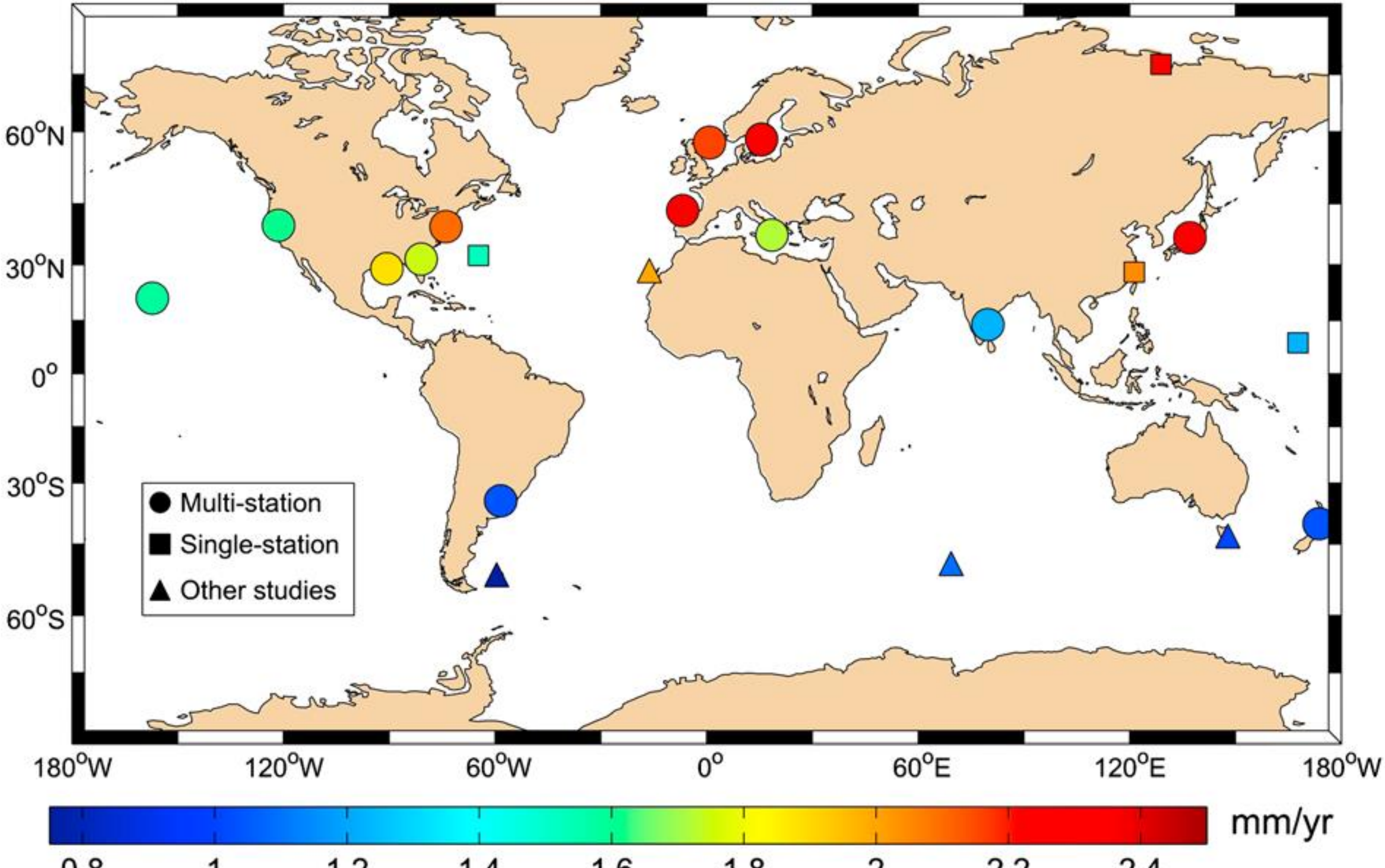
Watson et al. 2015

GPS rates seem to be more consistent than GIA rates – not used extensively for GMSL



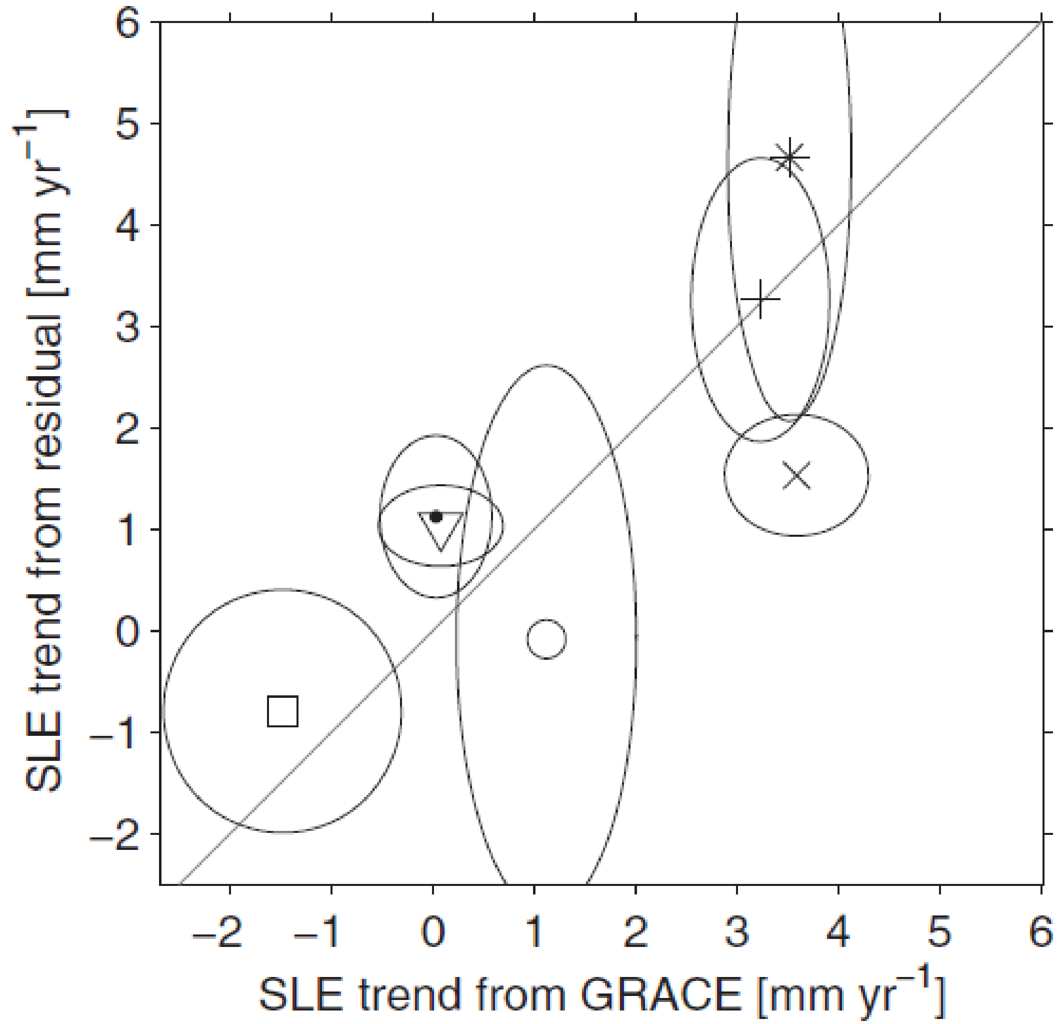
Wopplemann et al.

Long term tide gauge rates Hemispherical differences?



Wopplemann et al.

First comparison of oceanic and gravitational estimate of regional mass change in the ocean

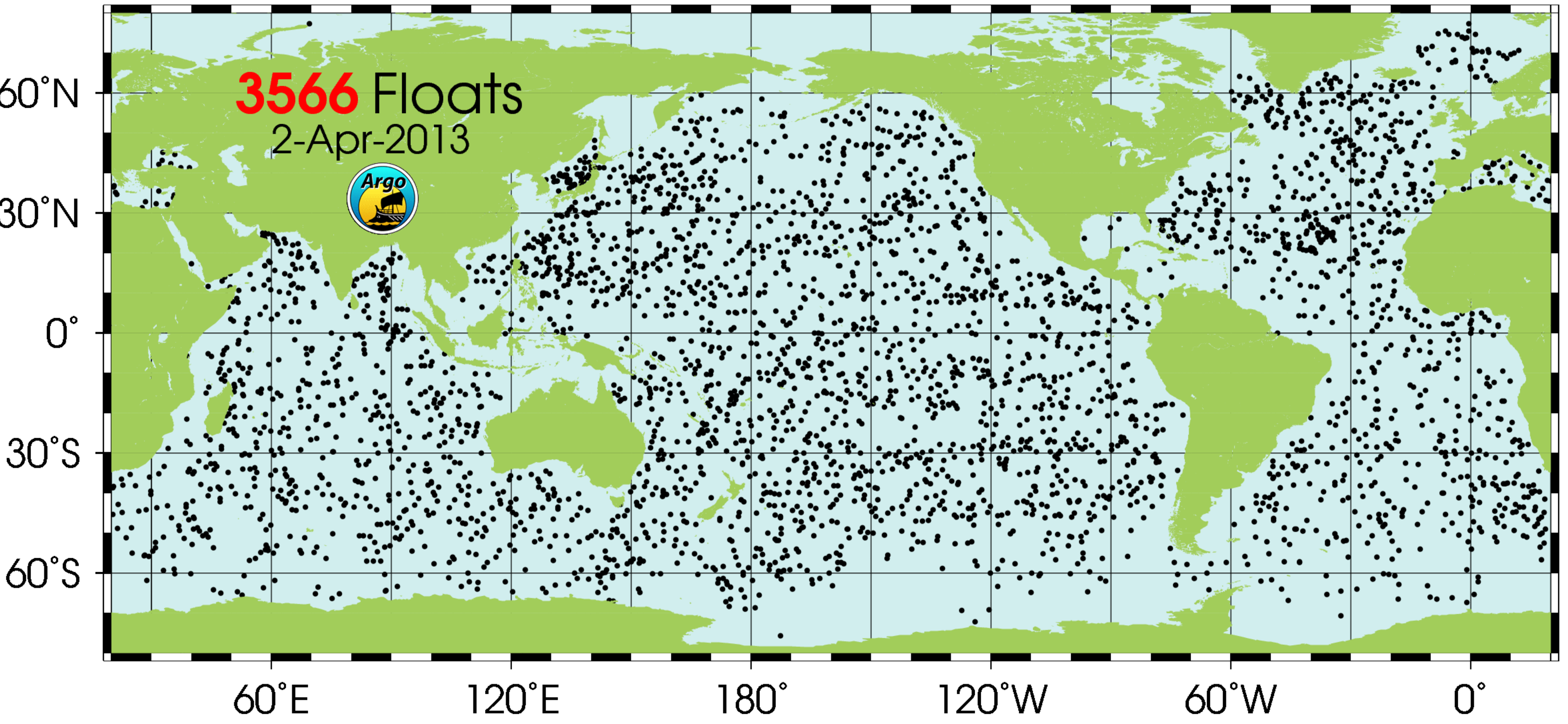


Valuable to be able to use this approach to back out ice sheet contributions

Purkey et al. 2014

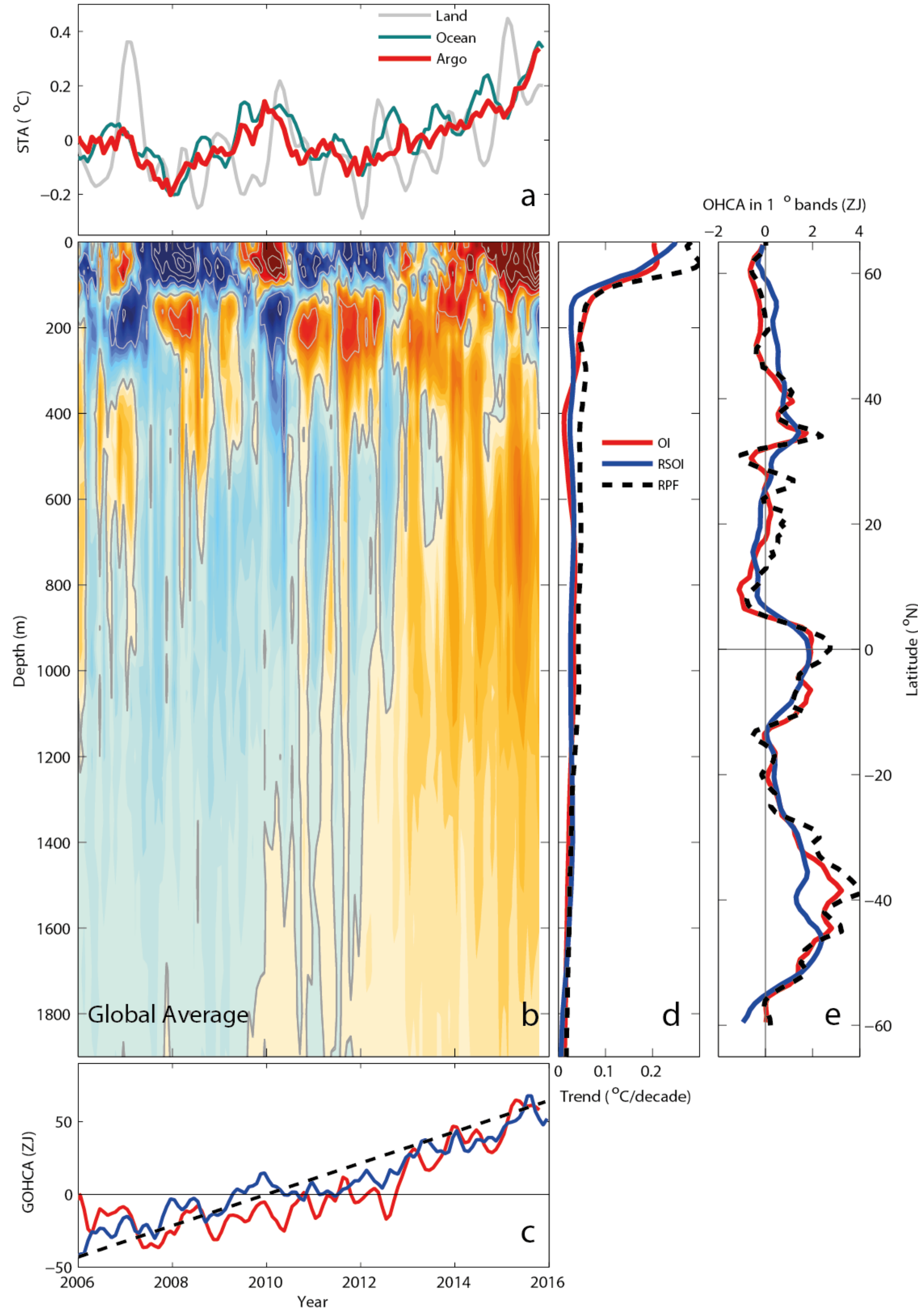
The Argo Array provides high-quality, global coverage to 2000 m, from about 2006

- Map ocean heat content and steric sea level
- Quality control of data important. Beware of biases from historical data bases.
- Coverage not complete



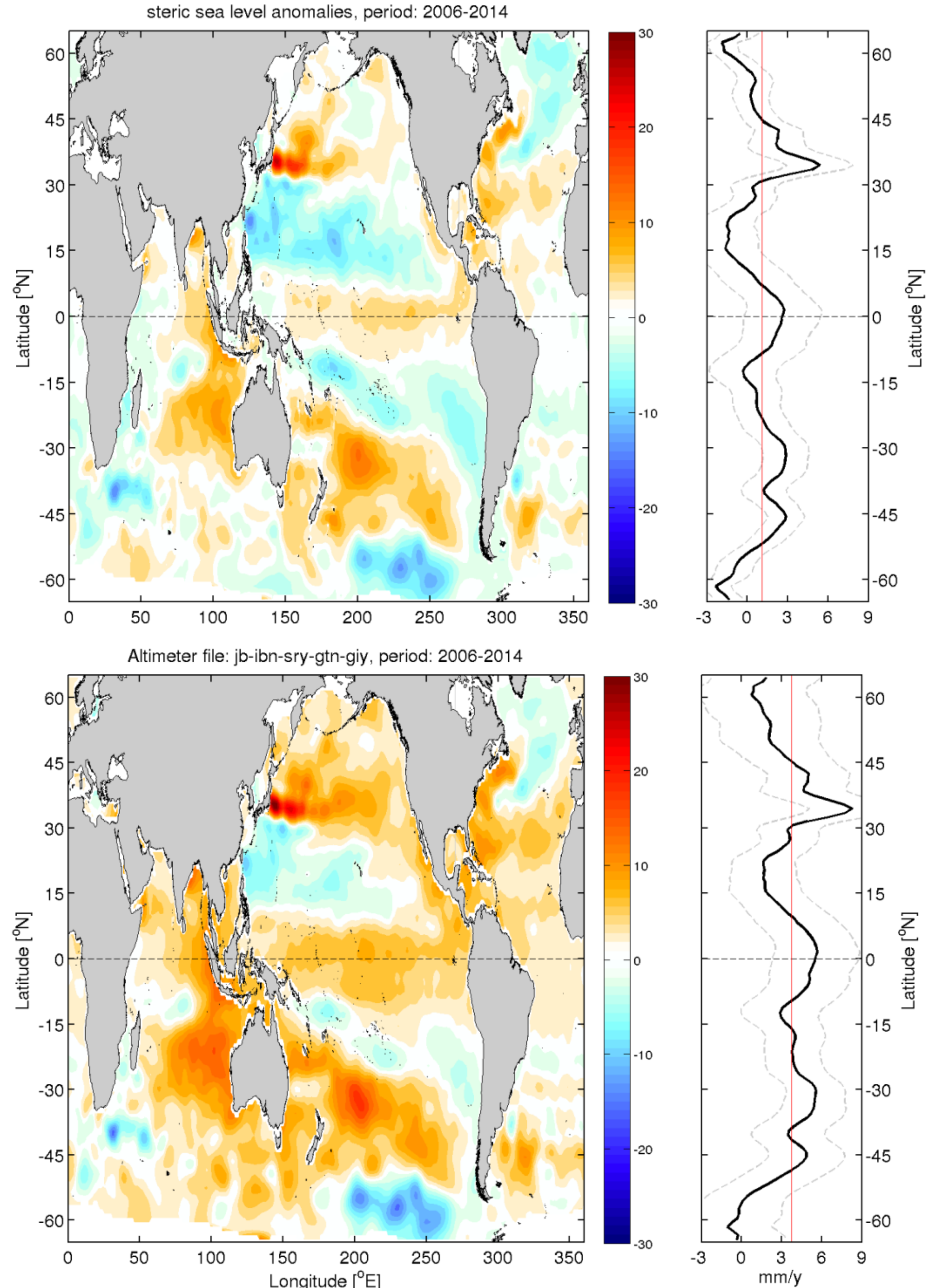
Update to late 2015

Steady heating of ocean, particularly Southern Ocean and from 300 m to 2000 m

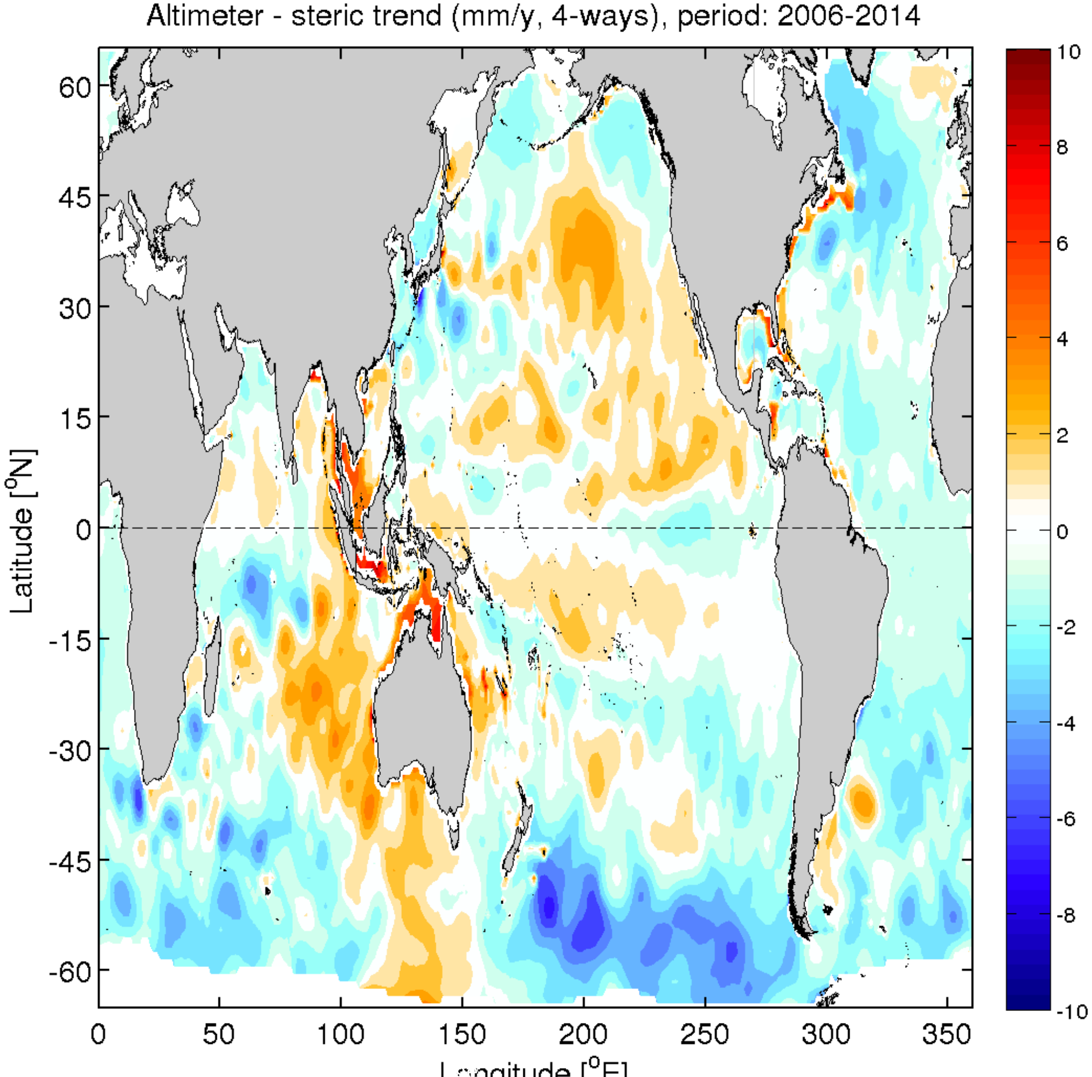


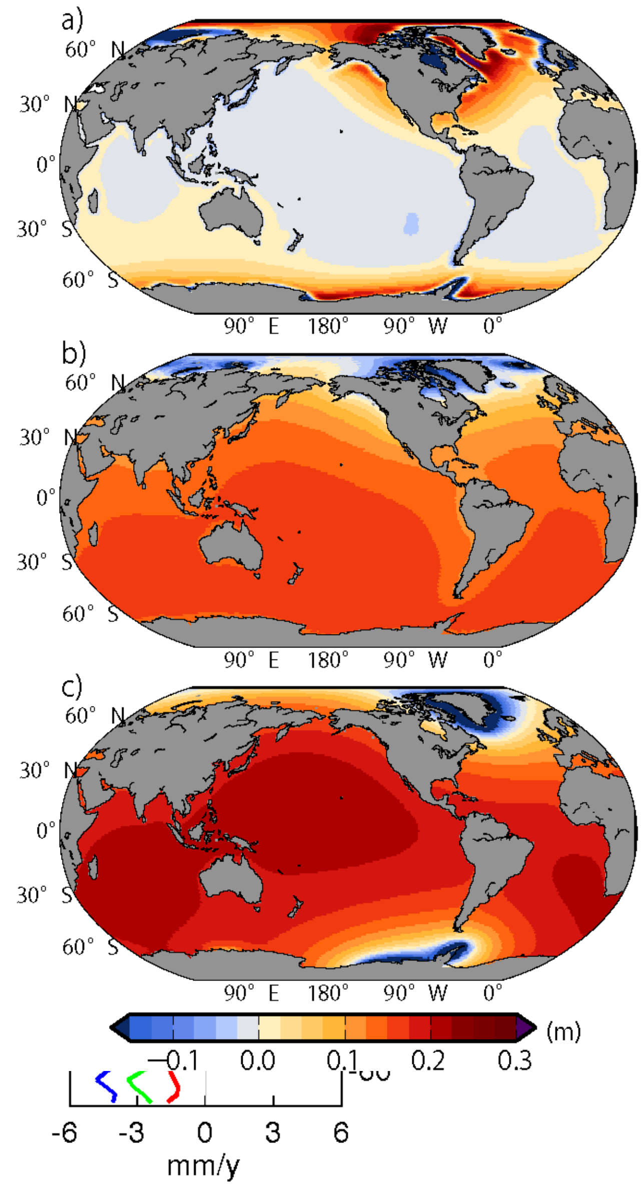
Wijffels et al. 2016

Altimeter and steric sea level trends 2006 to 2014



Differences between Altimeter and steric trends – mean removed





Key messages

•In warmer climates, sea level was higher. The rate of rise has increased.

•Sea level rise - 0.19 [0.17 to 0.21] m over 1901-2010. 20th Century GMSL change accounted for. Thermal expansion and glacier contribution D&A.

•It is *very likely* that the rate of rise will increase under all scenarios. Sea level rise by 2100 compared with 1986–2005: *likely* 0.44 [0.28–0.61] m for RCP2.6, 0.74 [0.53–0.98] m for RCP8.5.

•Collapse of marine-based sectors of Antarctic IS, if initiated, would add no more than several tenths of a meter by 2100.

•70% of the coastline to experience sea level change within 20% of global mean

•*Very likely* increase in the occurrence of sea level extremes.

•*Virtually certain* that sea level rise will continue for many centuries; the amount of rise dependent on future emissions.

•Significant uncertainties and demanding requirements.

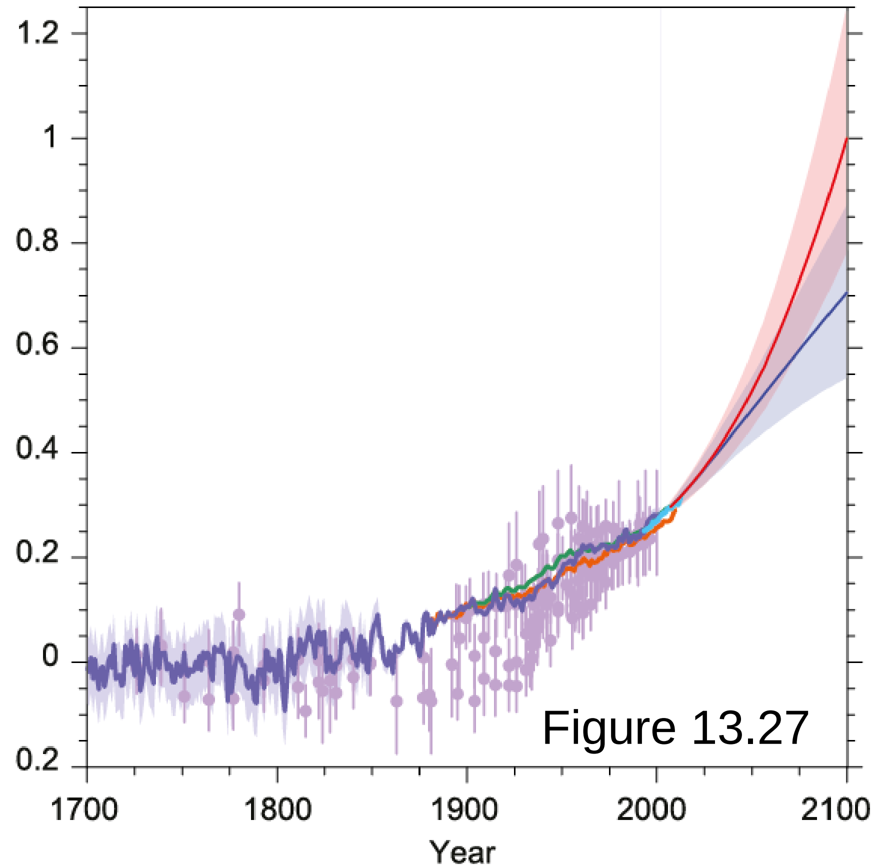


Figure 13.27

Thank you

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