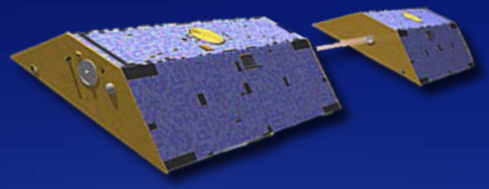


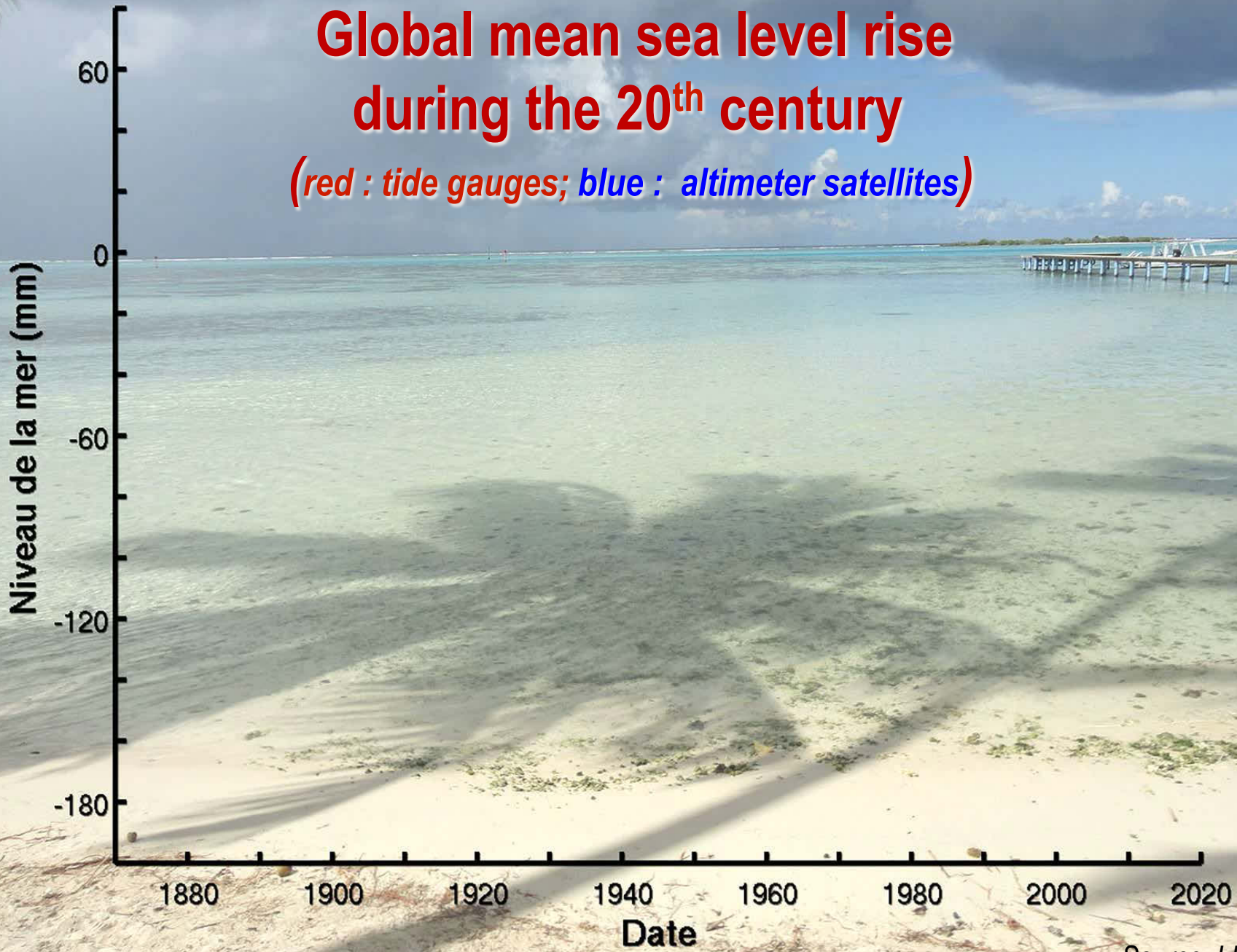
Sea level change
recent past, present, future

Anny Cazenave
LEGOS-CNES
Toulouse, France

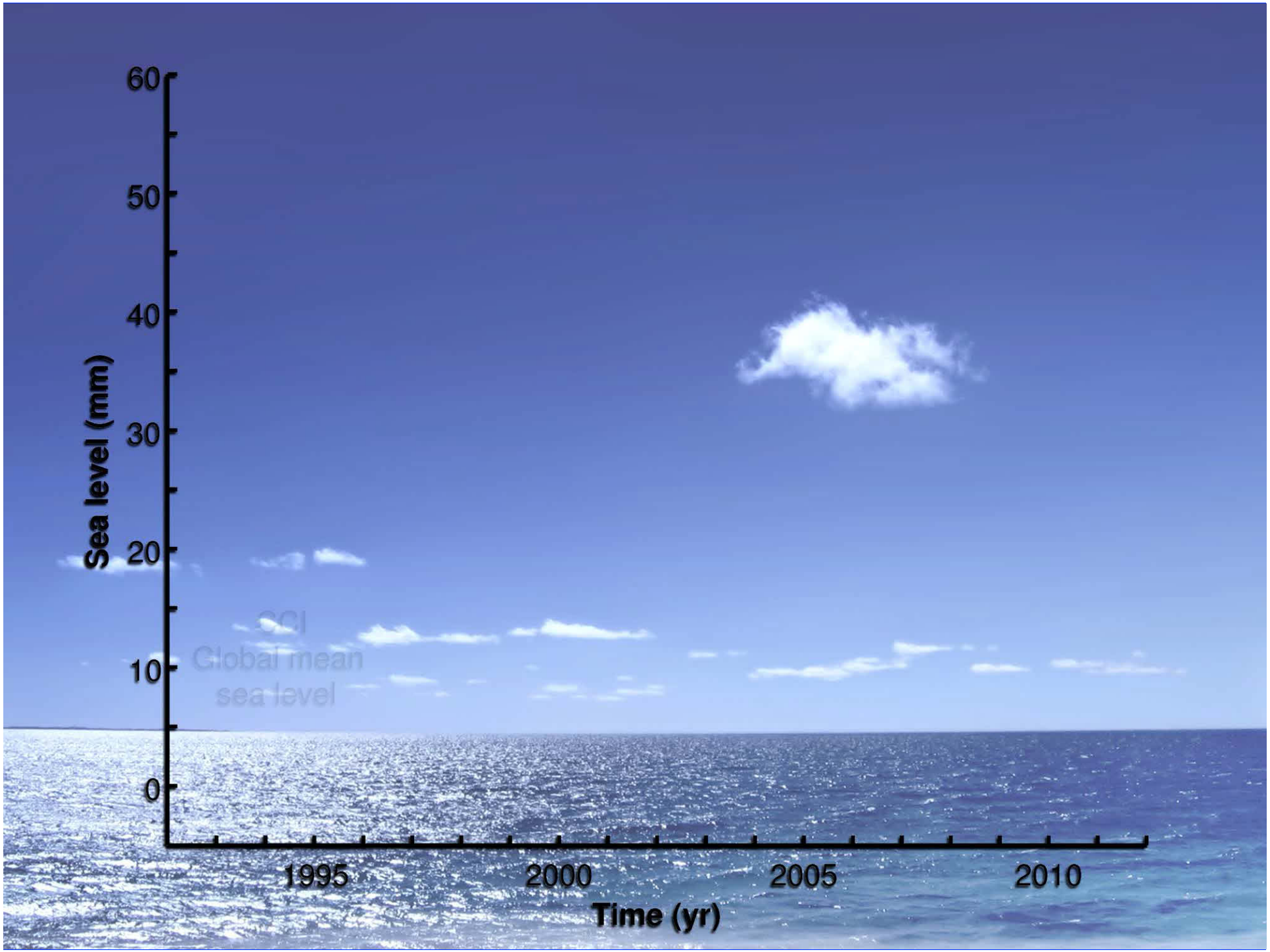
CCI_Colocation meeting, ESA/ESRIN

Global mean sea level rise during the 20th century

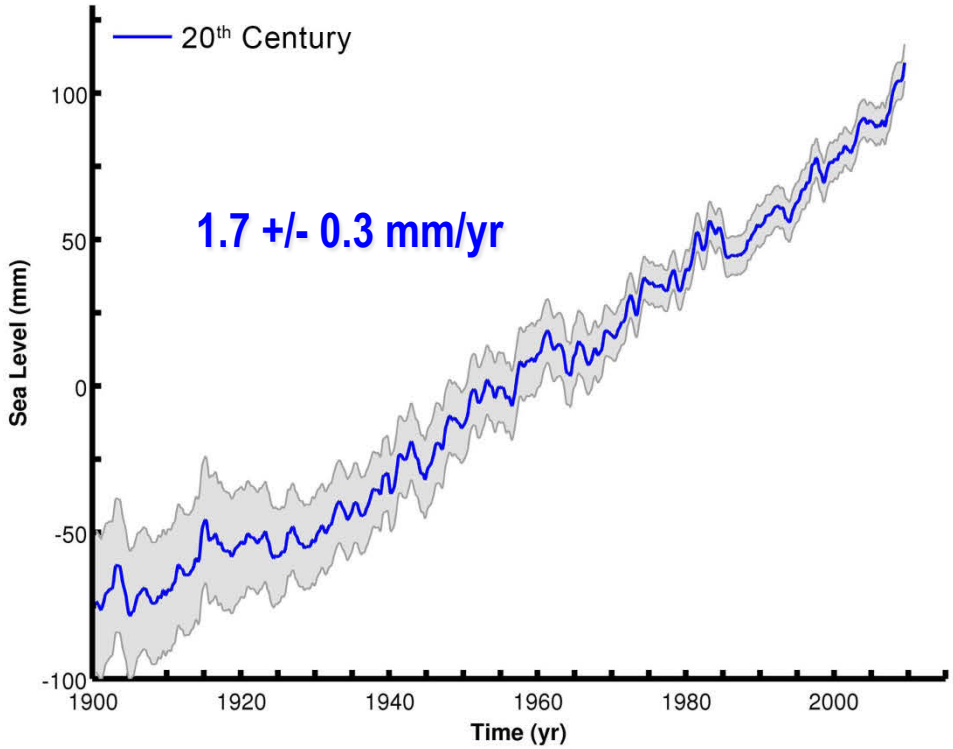
(red : tide gauges; blue : altimeter satellites)

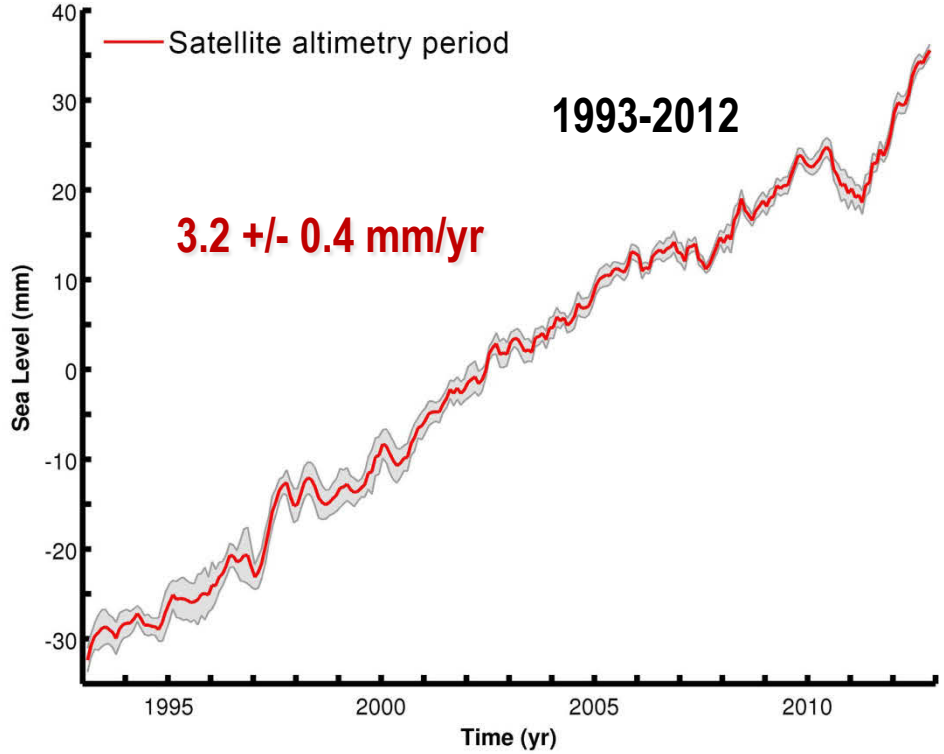


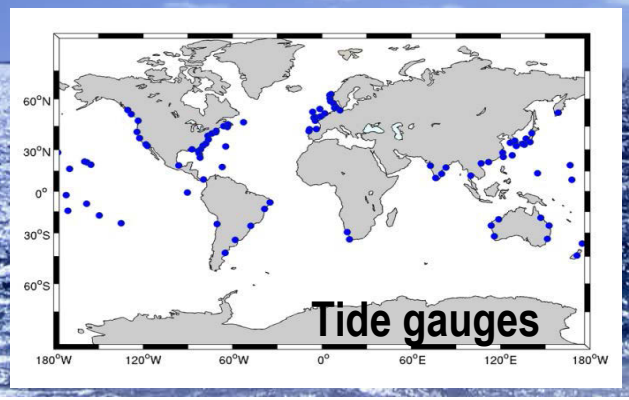
Source :LEGOS

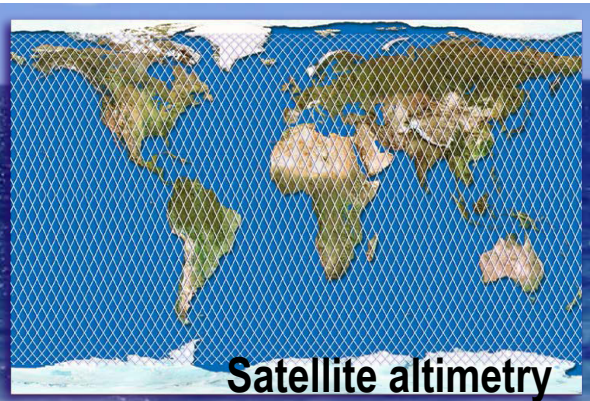

60
50
40
30
20
10
0
Sea level (mm)
CSI
Global mean
sea level
1995
2000
2005
2010
Time (yr)

Sea level rise : 20th century and past 2 decades









Question

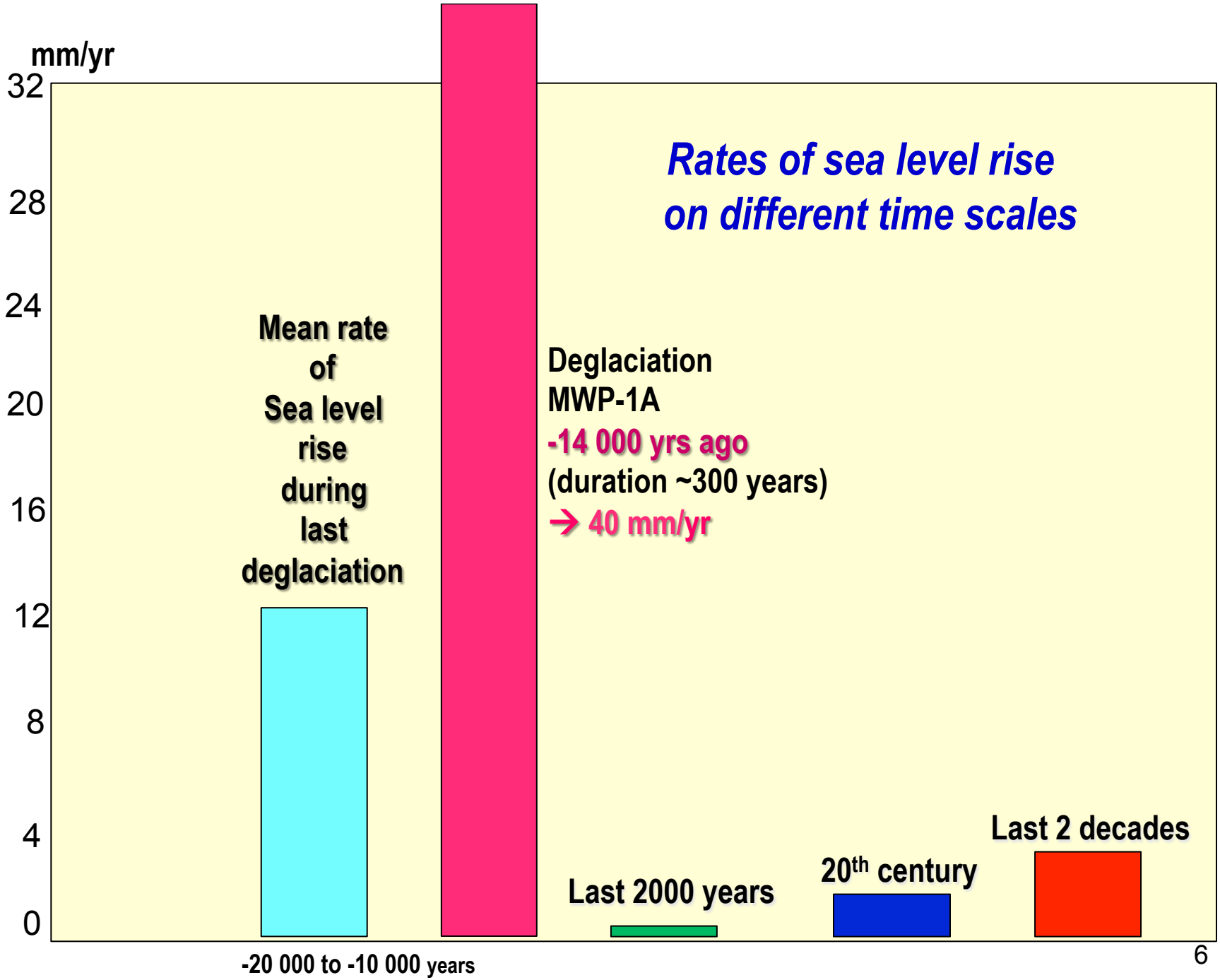
- **Is sea level rise accelerating?**

Yes!

Church et al. (2013) concludes that « the increased rate of sea level rise since 1990 is not part of a natural cycle but a direct response to increased radiative forcing on the climate system »

- **Is the current rate of rise unusual?**

Yes and no!

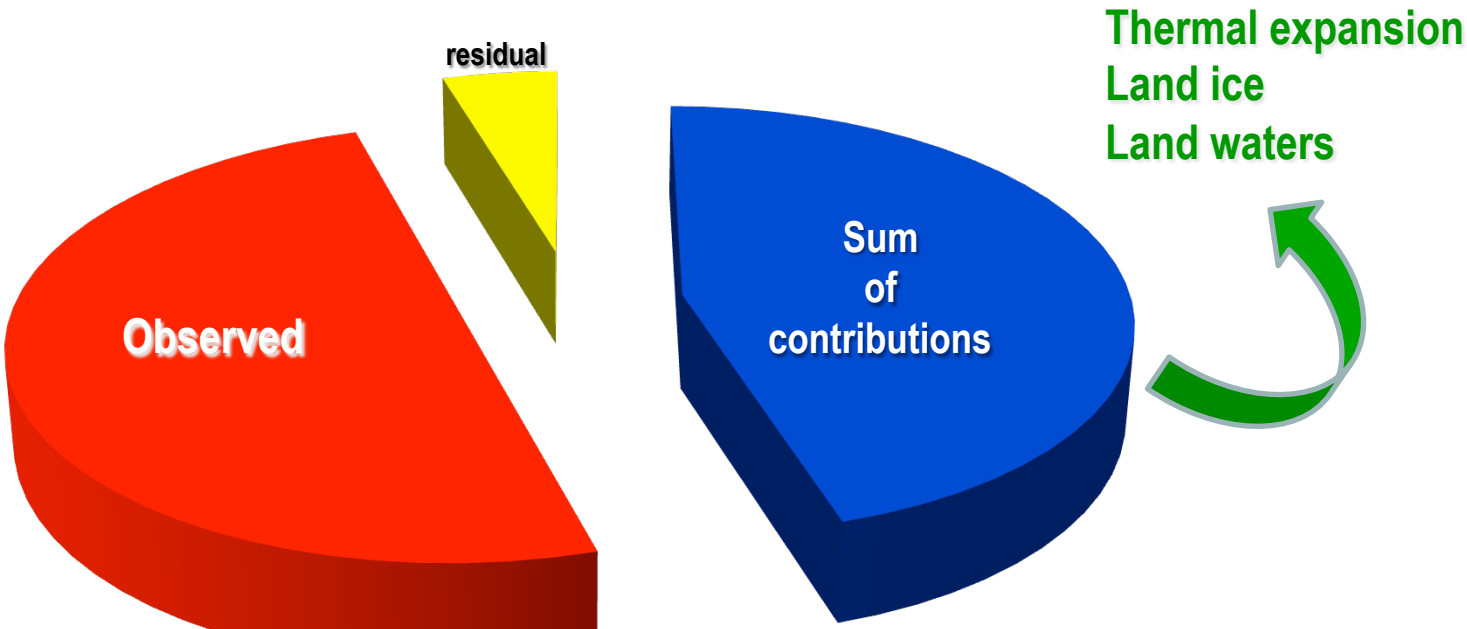

mm/yr
32
28
24
20
16
12
8
4
0
Rates of sea level rise
on different time scales
Mean rate
of
Sea level
rise
during
last
deglaciation
Deglaciation
MWP-1A
-14 000 yrs ago
(duration ~300 years)
→ 40 mm/yr
Last 2000 years
20th century
Last 2 decades
-20 000 to -10 000 years

Question

Can we close the sea level budget?

Observed sea level budget during the altimetry era (1993-2010)

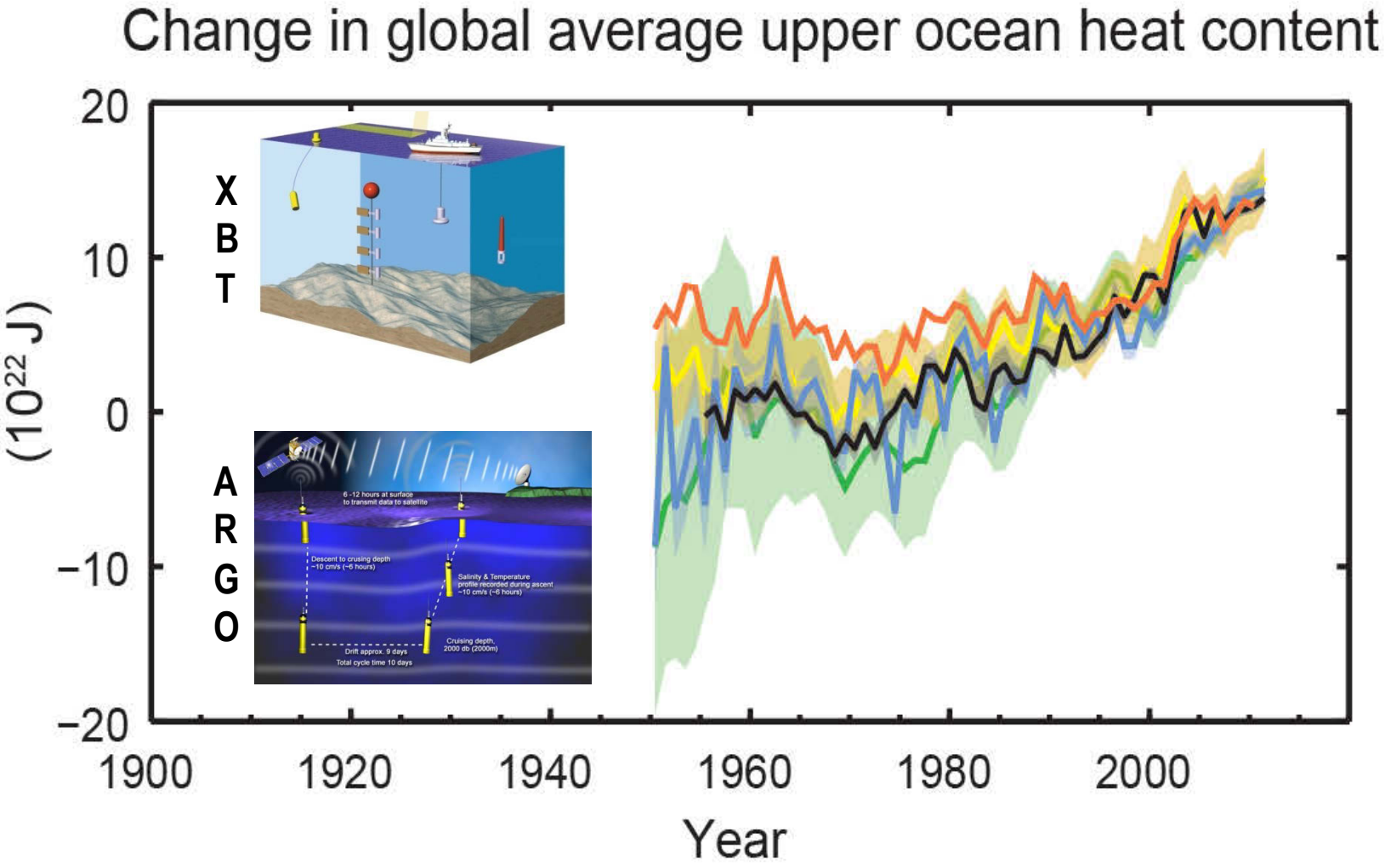
IPCC AR5



	Rate of rise
Sum Contrib.	2.8 +/- 0.5 mm/yr
Observed	3.2 +/- 0.4 mm/yr
Residual	0.4 mm/yr

IPCC AR5

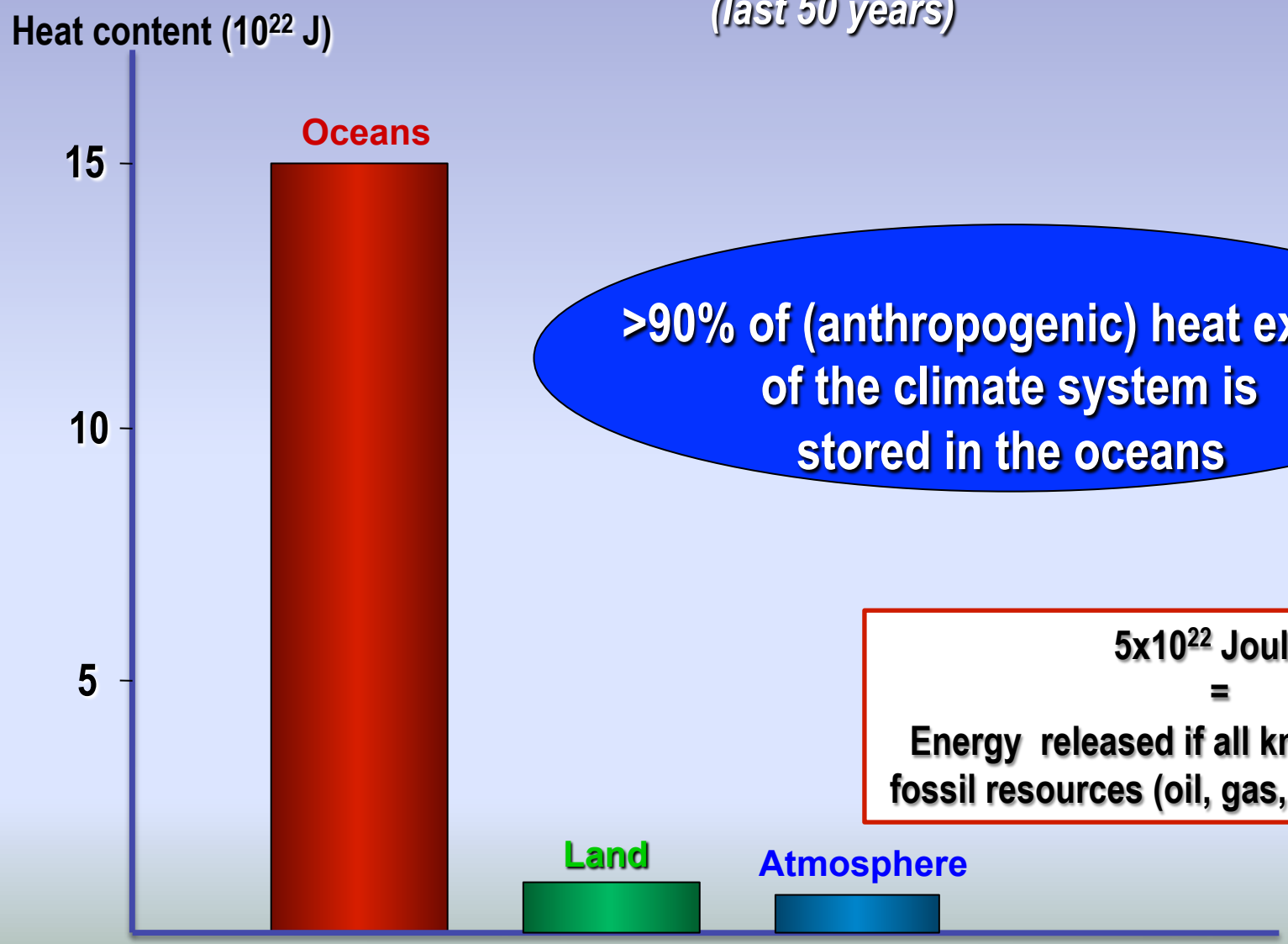
The ocean heat content is increasing



IPCC AR5

Thermal budget of the climate system

(last 50 years)

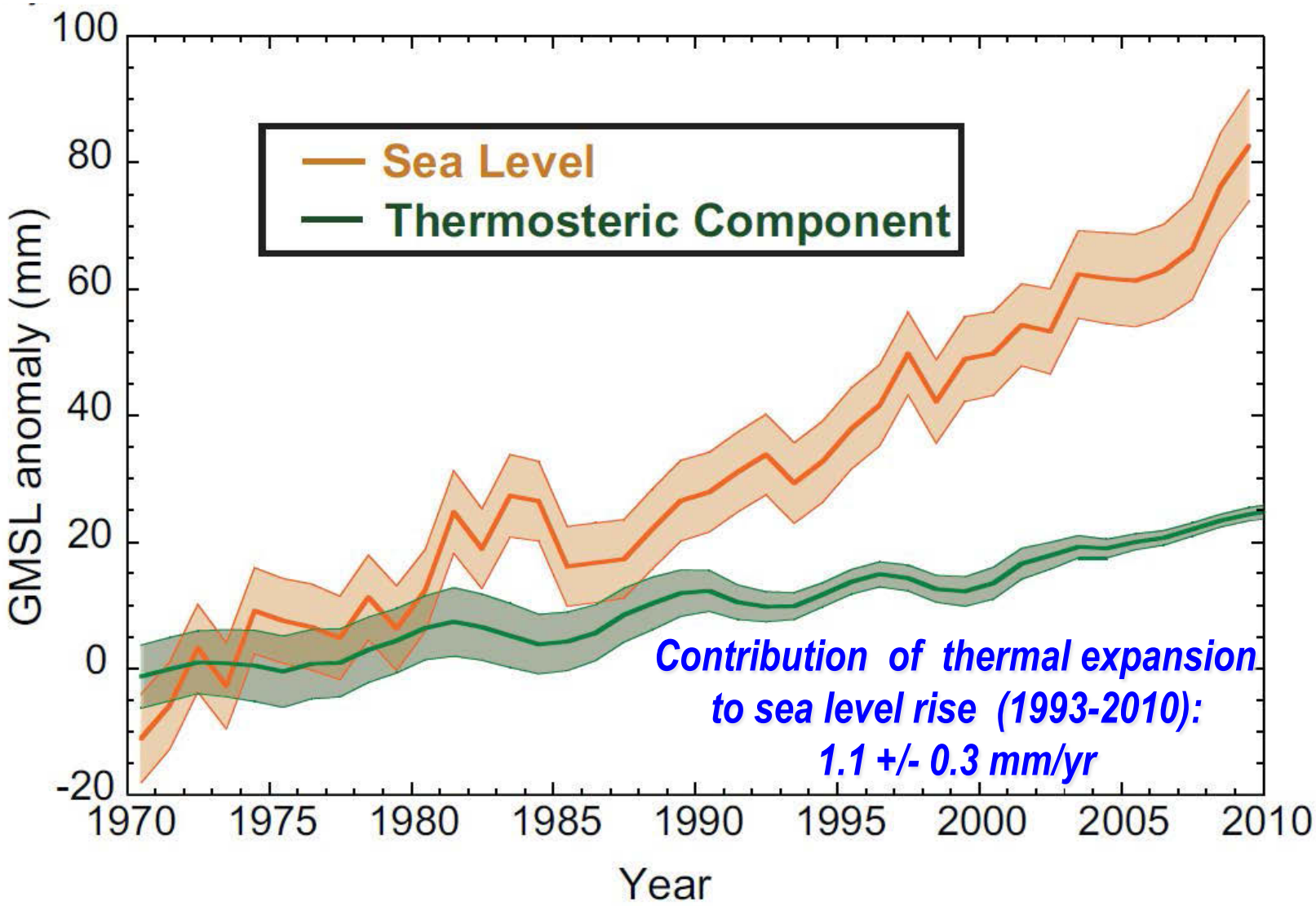


>90% of (anthropogenic) heat excess of the climate system is stored in the oceans

5×10^{22} Joules
=
Energy released if all known remaining fossil resources (oil, gas, coal) were burnt

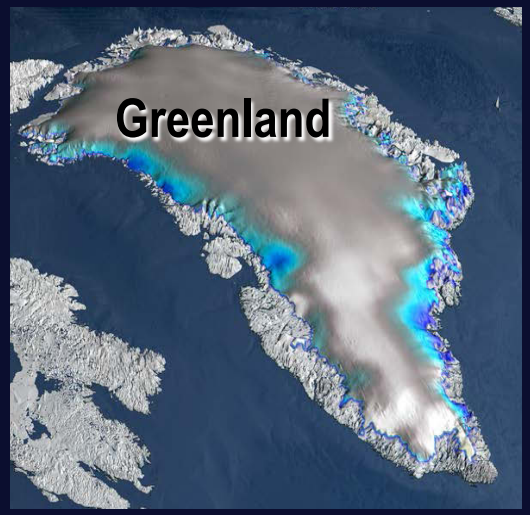
IPCC AR5

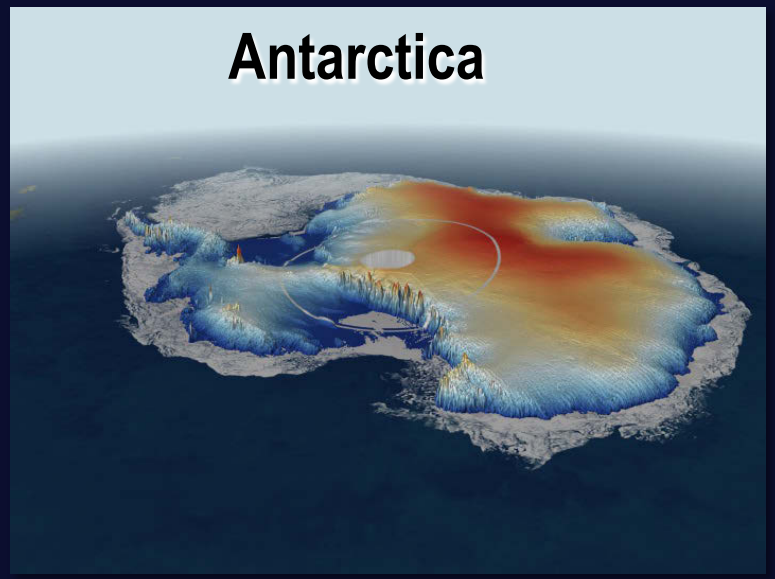
Thermosteric contribution to sea level rise



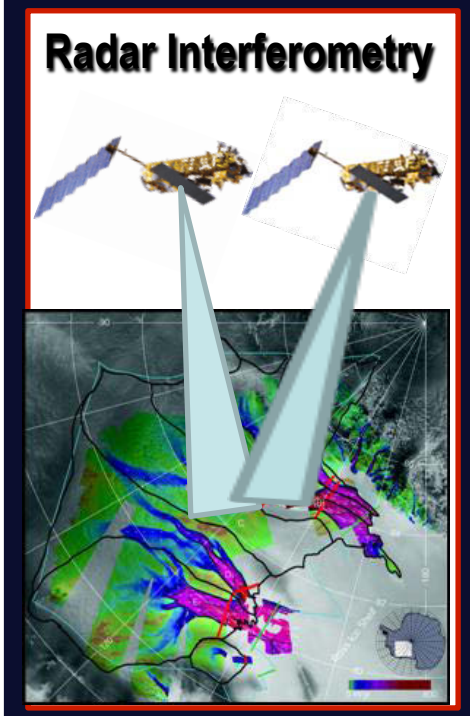
IPCC AR5

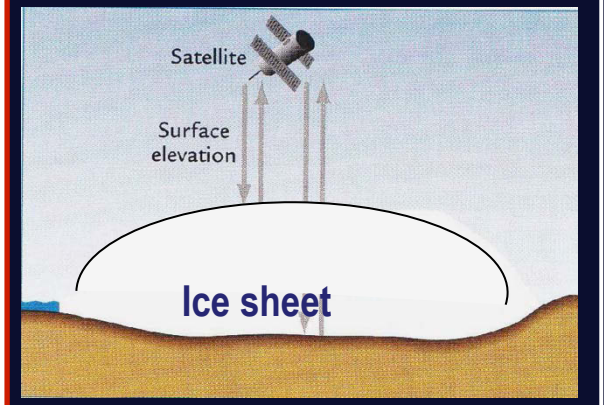
Since the early 1990s, ice sheet mass change measured from space





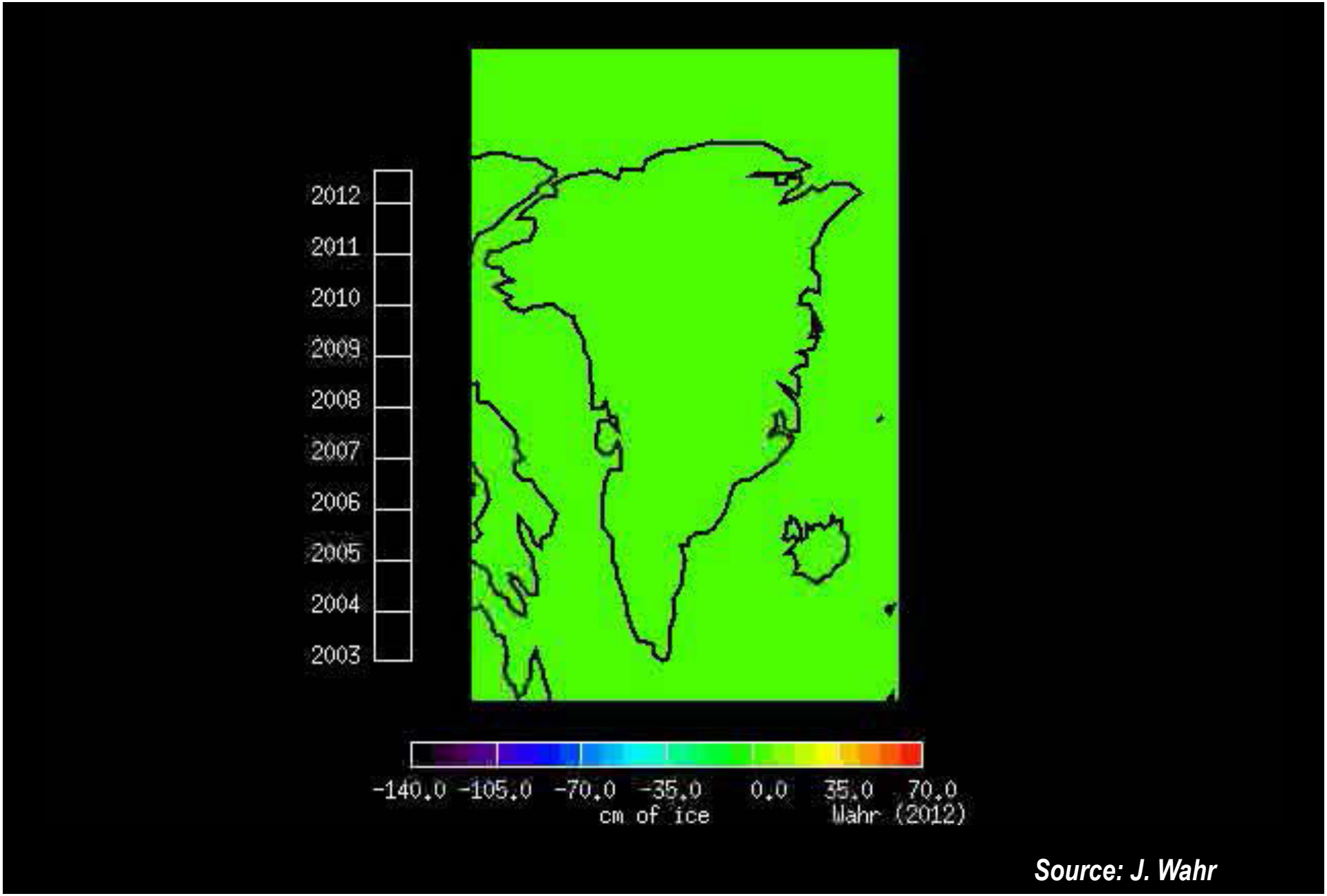
« GRACE »
space gravimetry





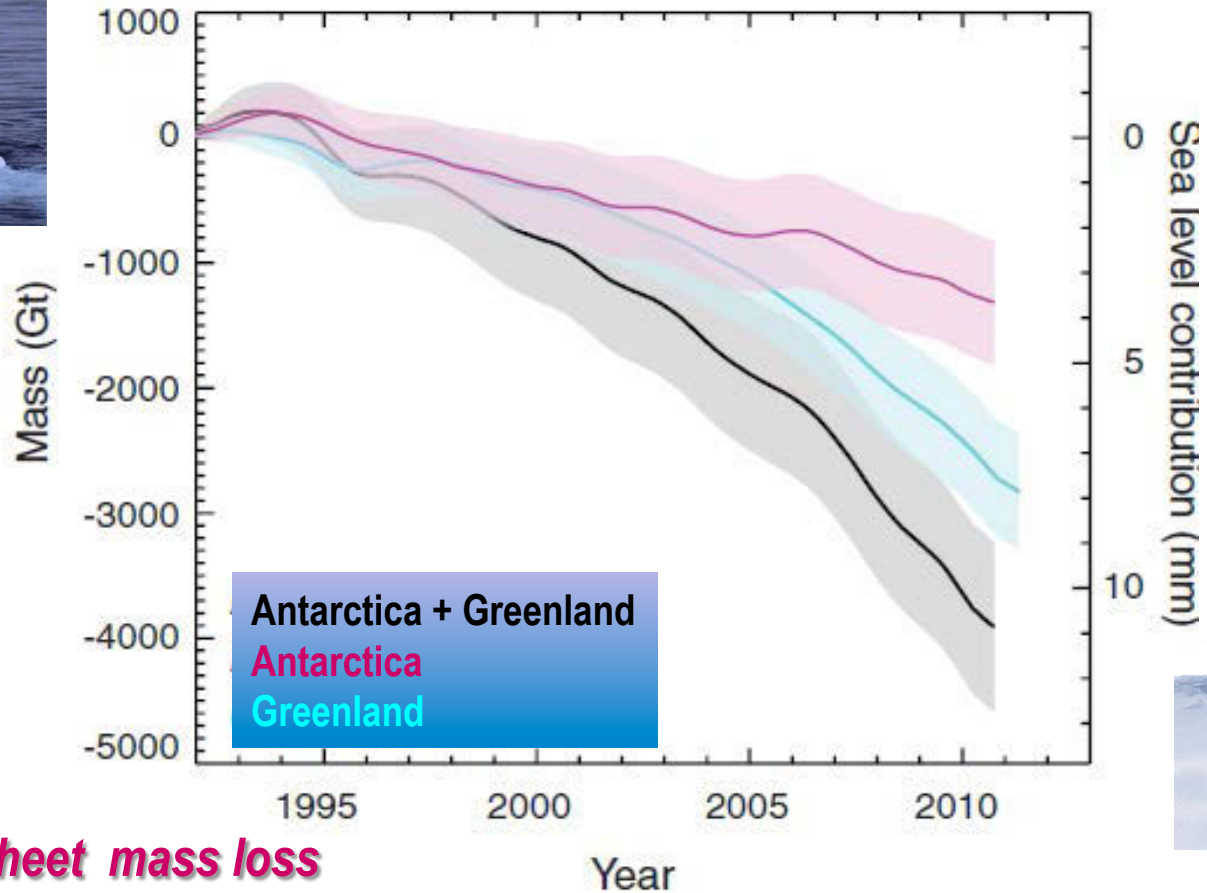
Radar & laser altimetry

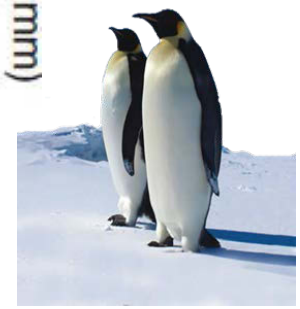
Ice mass loss of the Greenland ice sheet (blue-violet-black) between 2003 and 2012 observed by GRACE



Source: J. Wahr

Ice mass loss from Greenland and Antarctica measured by space techniques since 1990 (in Gt) → mass loss acceleration since 10-15 years





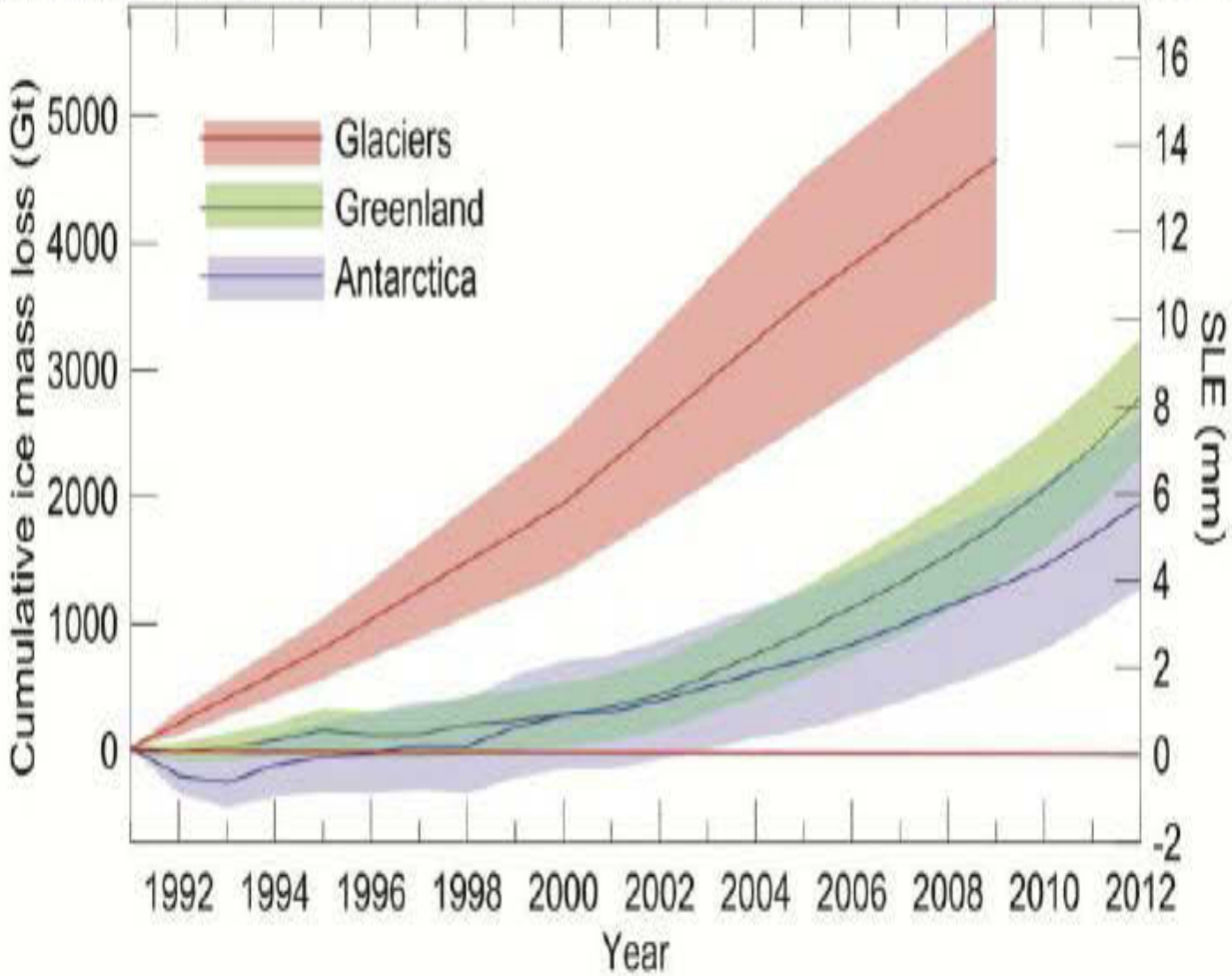
Rate of ice sheet mass loss

Greenland : 34 +/- 40 Gt/yr (1992-2001); 215 (+/- 60) Gt/yr (2002-2011)

Antarctica : 30 +/- 67 Gt/yr (1992-2001); 147 (+/- 74) Gt/yr (2002-2011)

Shepherd et al., 2012
IPCC AR5

Contribution of Glaciers and Ice Sheets to Sea Level Change

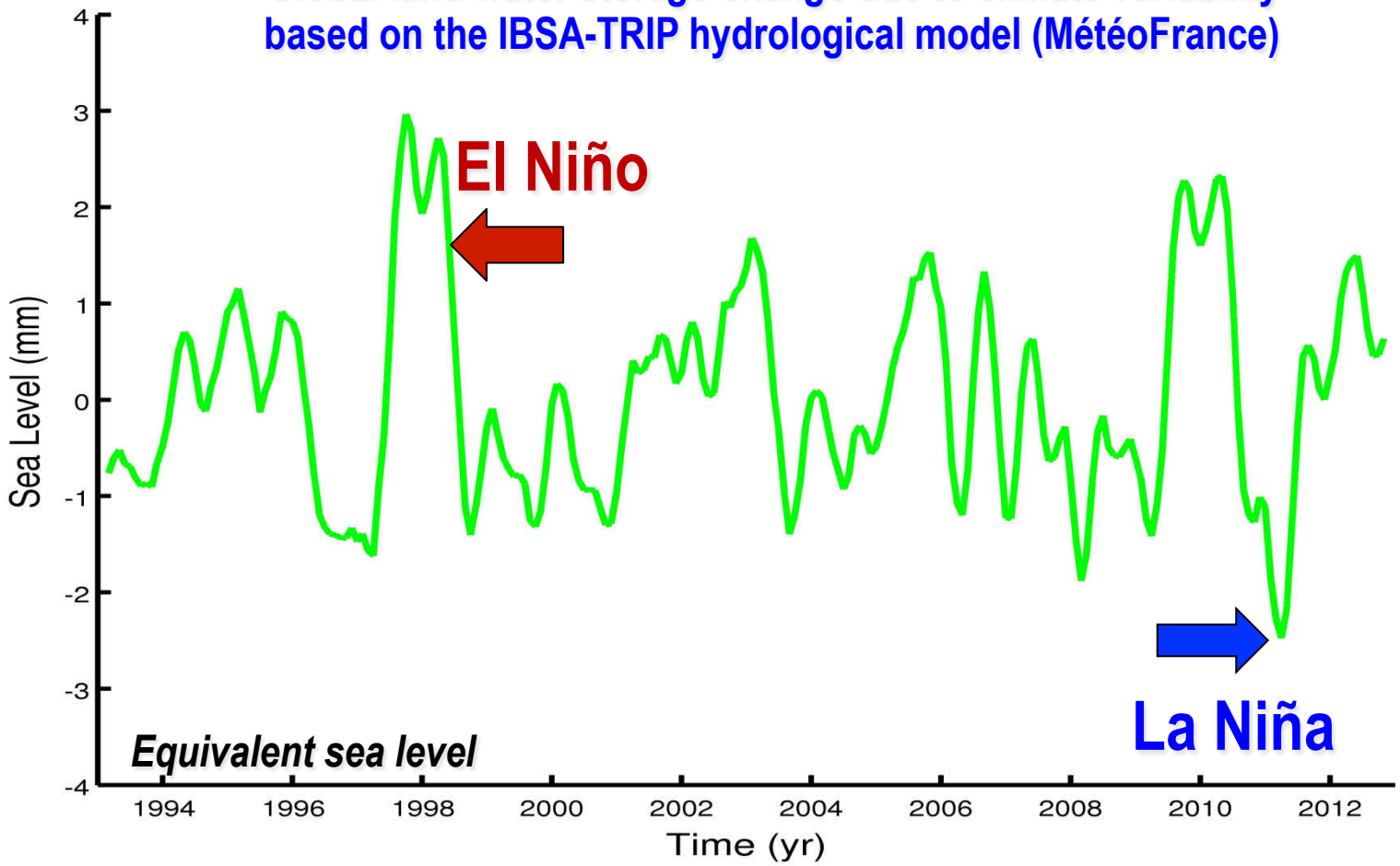


Cumulative ice mass loss from glacier and ice sheets (in sea level equivalent) is 1.0 to 1.4 mm/yr for 1993-2009 and 1.2 to 2.2 mm/yr for 2005-2009.

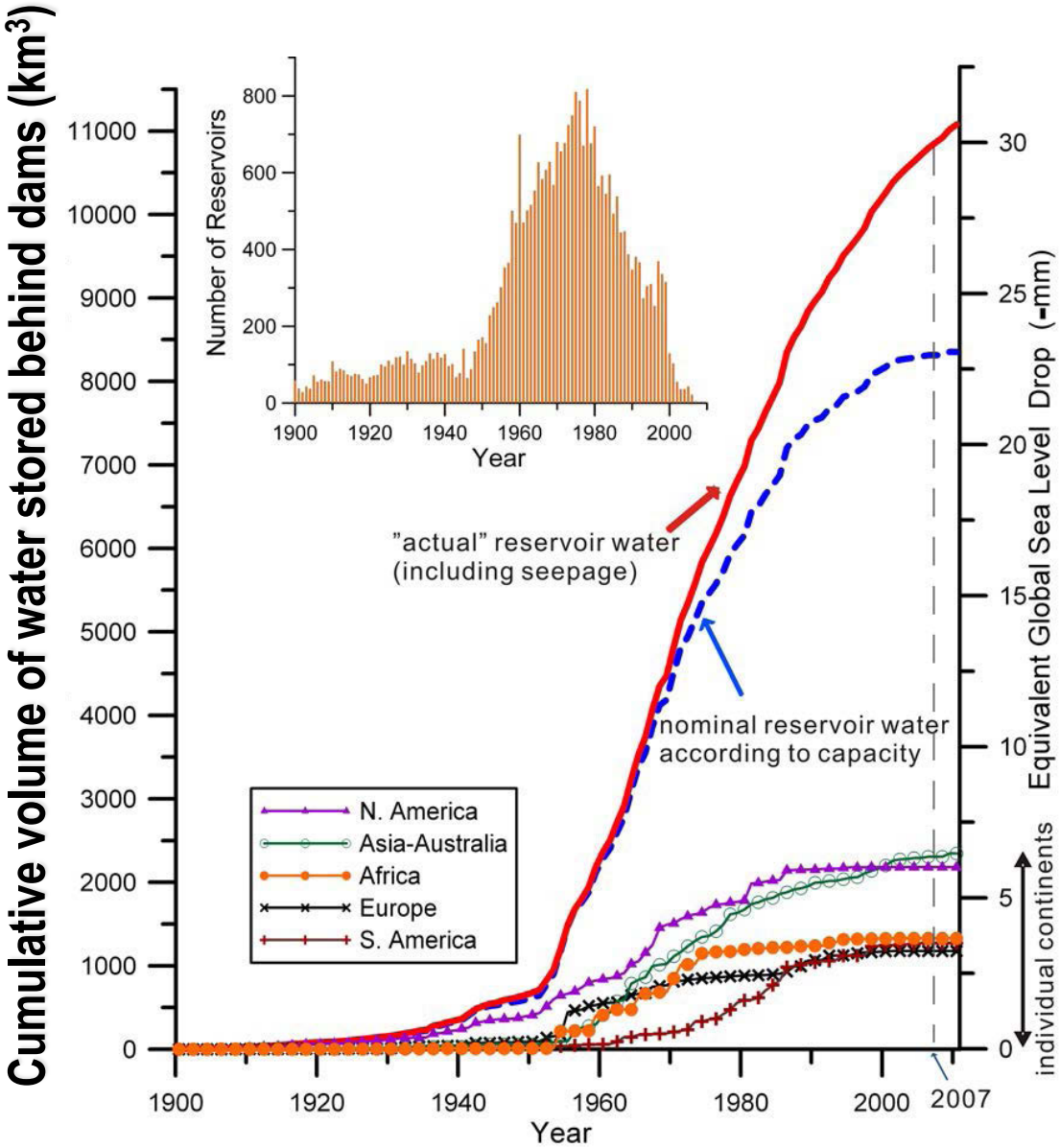
IPCC AR5


Land water storage change
2 contributions:
-Natural climate variability
-Anthropogenic changes
(dam building & groundwater extraction)

Land water storage change due to natural climate variability

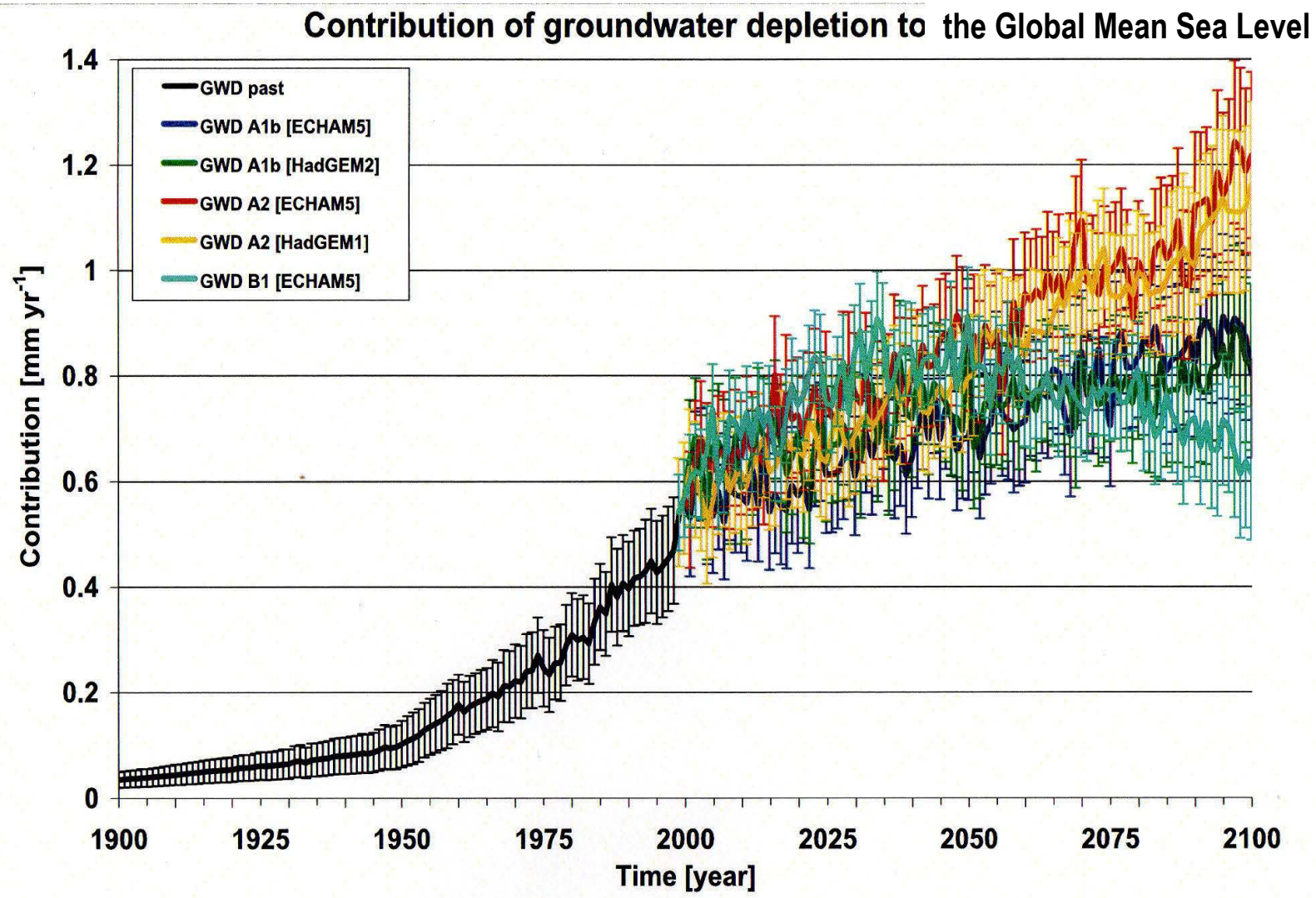


Dam building along rivers : Sea level drop

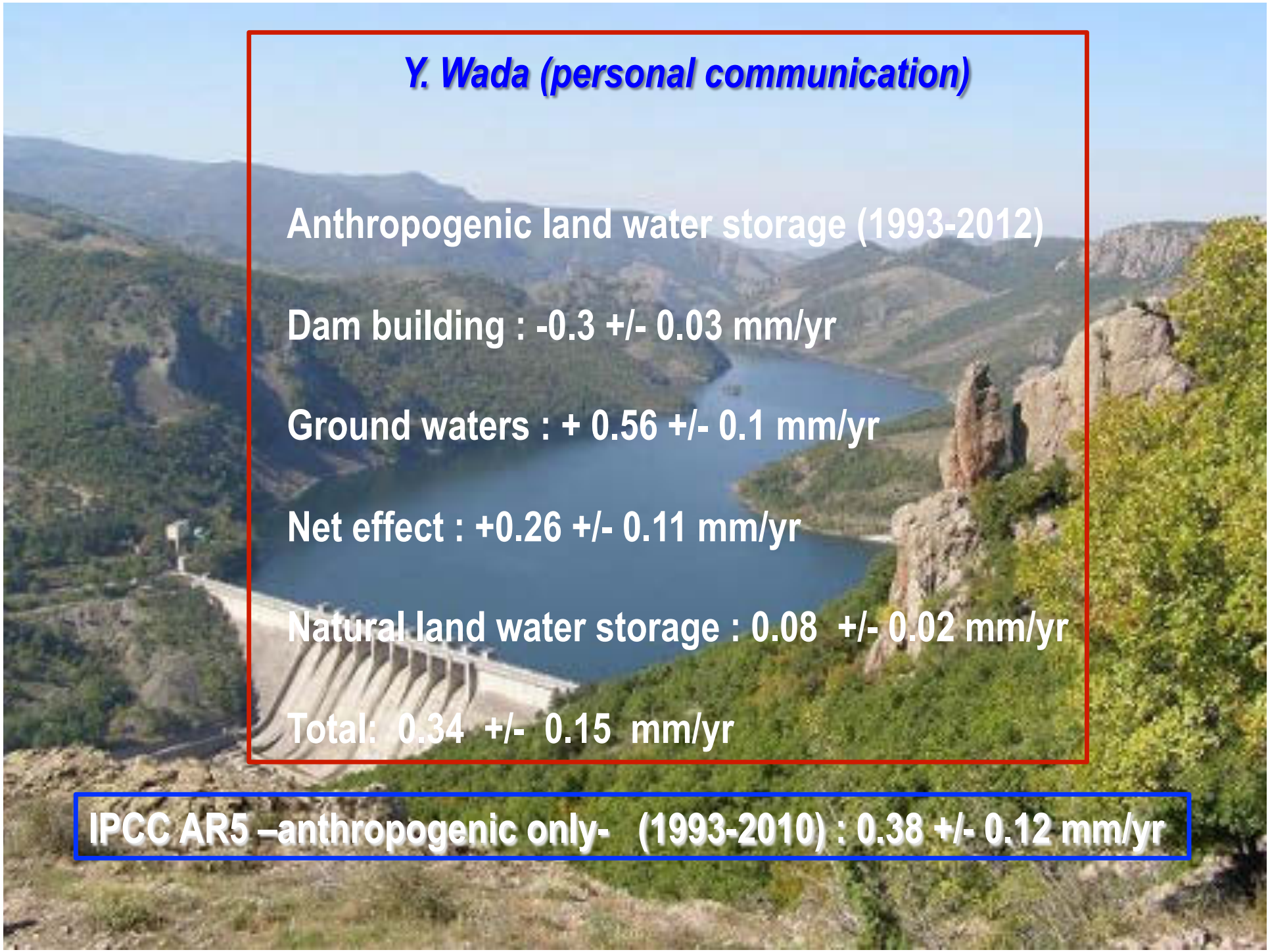


Chao et al., 2008

Past and future ground water depletion → Sea level rise



Wada et al., 2012



Y. Wada (personal communication)

Anthropogenic land water storage (1993-2012)

Dam building : -0.3 +/- 0.03 mm/yr

Ground waters : + 0.56 +/- 0.1 mm/yr

Net effect : +0.26 +/- 0.11 mm/yr

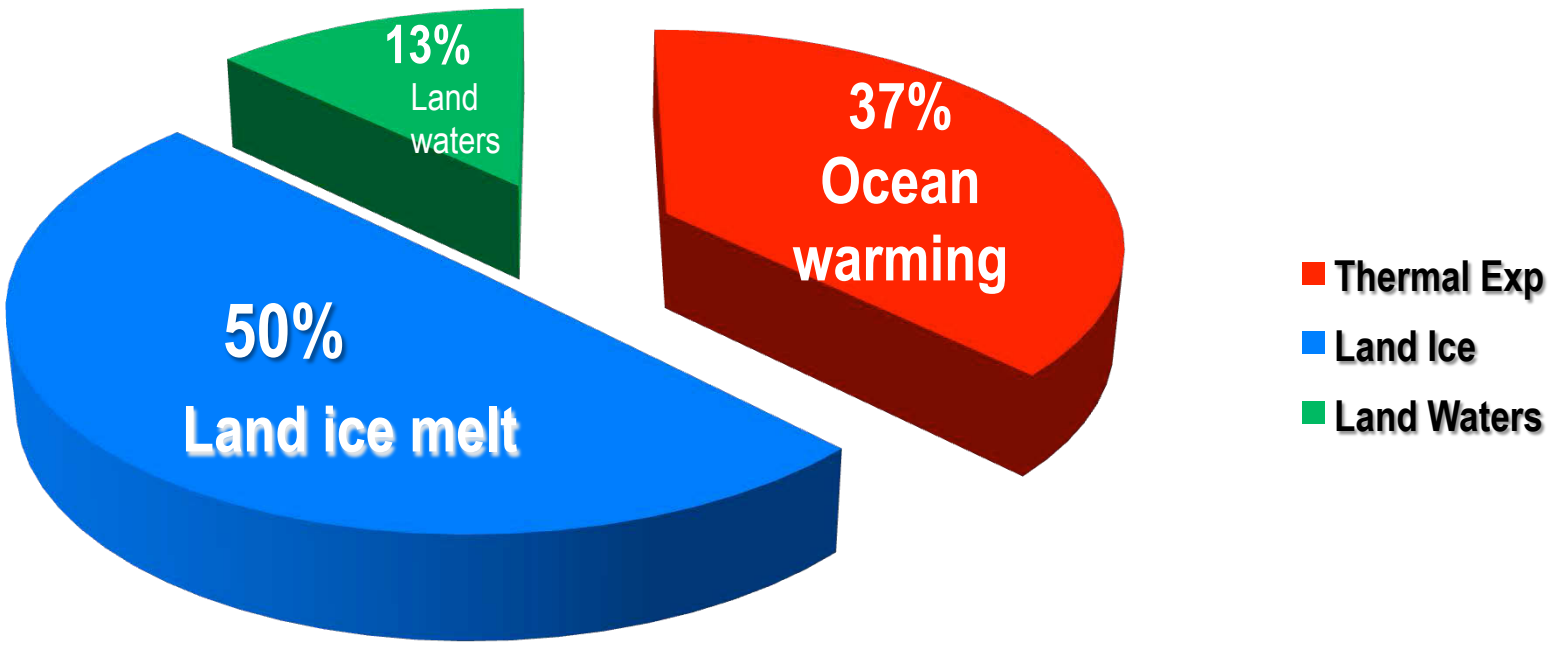
Natural land water storage : 0.08 +/- 0.02 mm/yr

Total: 0.34 +/- 0.15 mm/yr

IPCC AR5 –anthropogenic only- (1993-2010) : 0.38 +/- 0.12 mm/yr

Causes of sea level rise (altimetry era: last 2 decades)

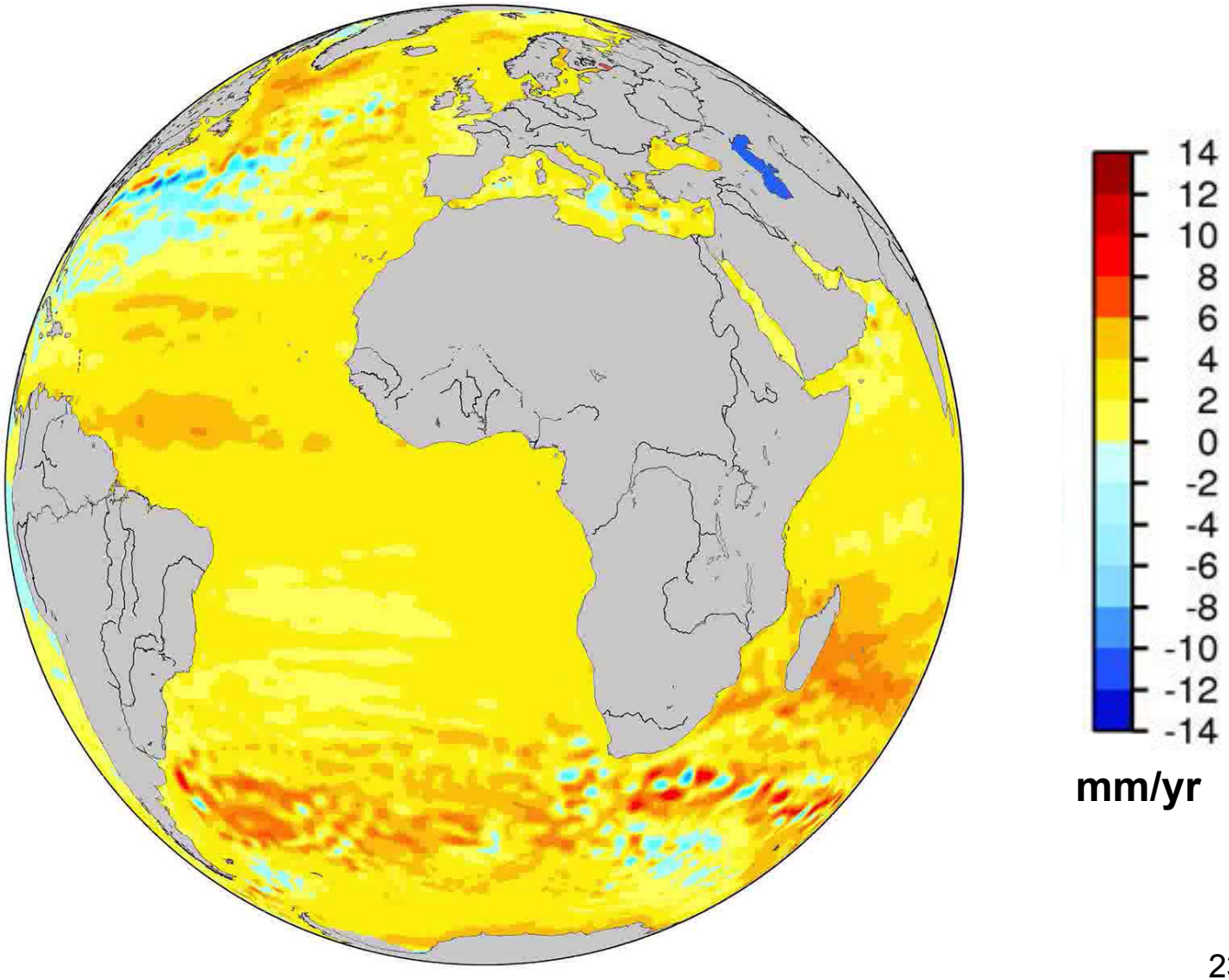
Individual contributions (in % of the observed rate of rise)



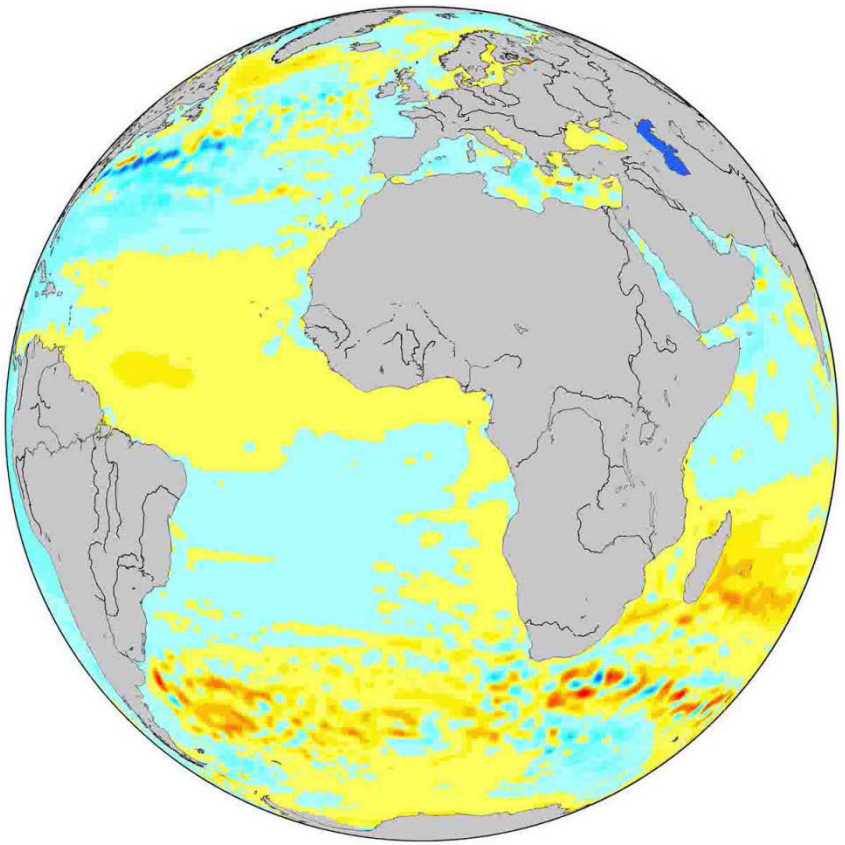
IPCC AR5

Regional variability

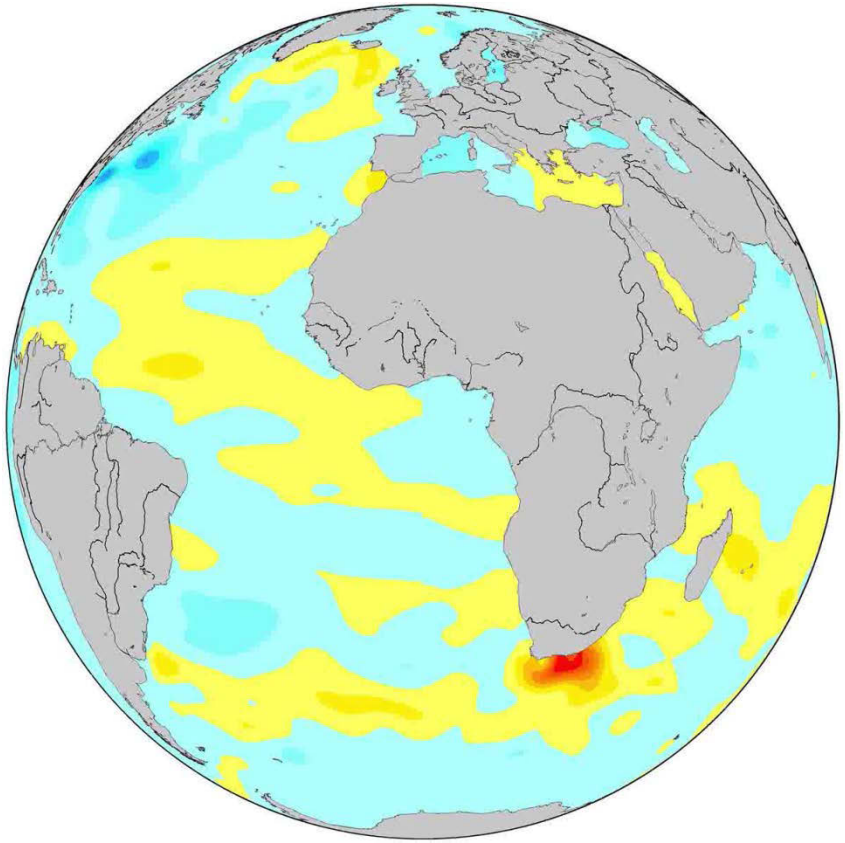
Sea level trend patterns from satellite altimetry (1993-2012)



Regional variability of the rates of sea level change over 1993-2012 (*global mean rise removed*)



Observed sea level by satellite altimetry



Observed thermal expansion + salinity changes

Future sea level rise

Warming scenarios considered by IPCC AR5

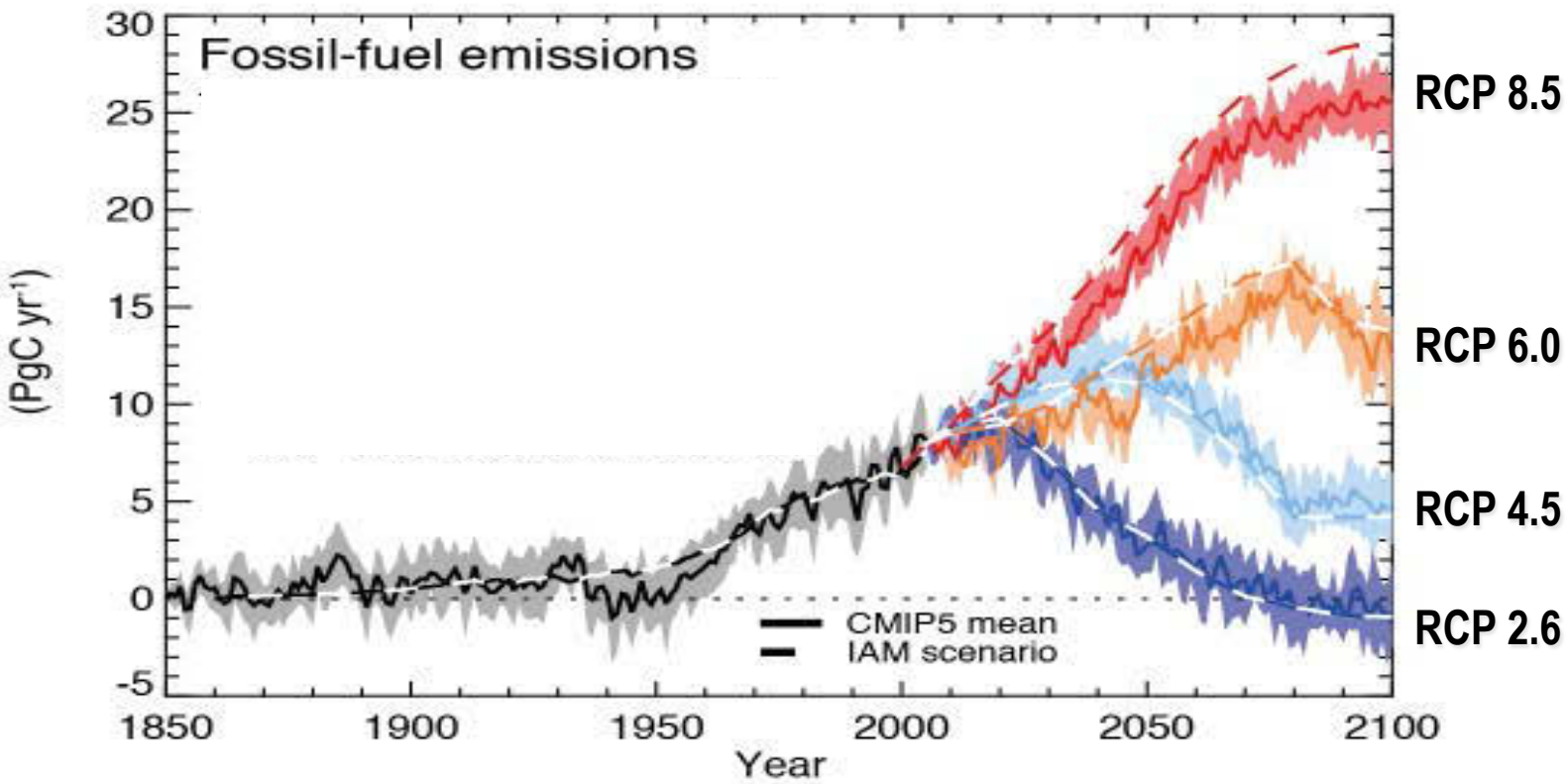
→ Representative Concentration Pathways (RCPs)

→ 4 RCP scenarios defined by their total radiative forcing by 2100:

- RCP2.6 (2.6 Wm^{-2})
- RCP4.5 (4.5 Wm^{-2})
- RCP6.0 (6.0 Wm^{-2})
- RCP8.5 (8.5 Wm^{-2})

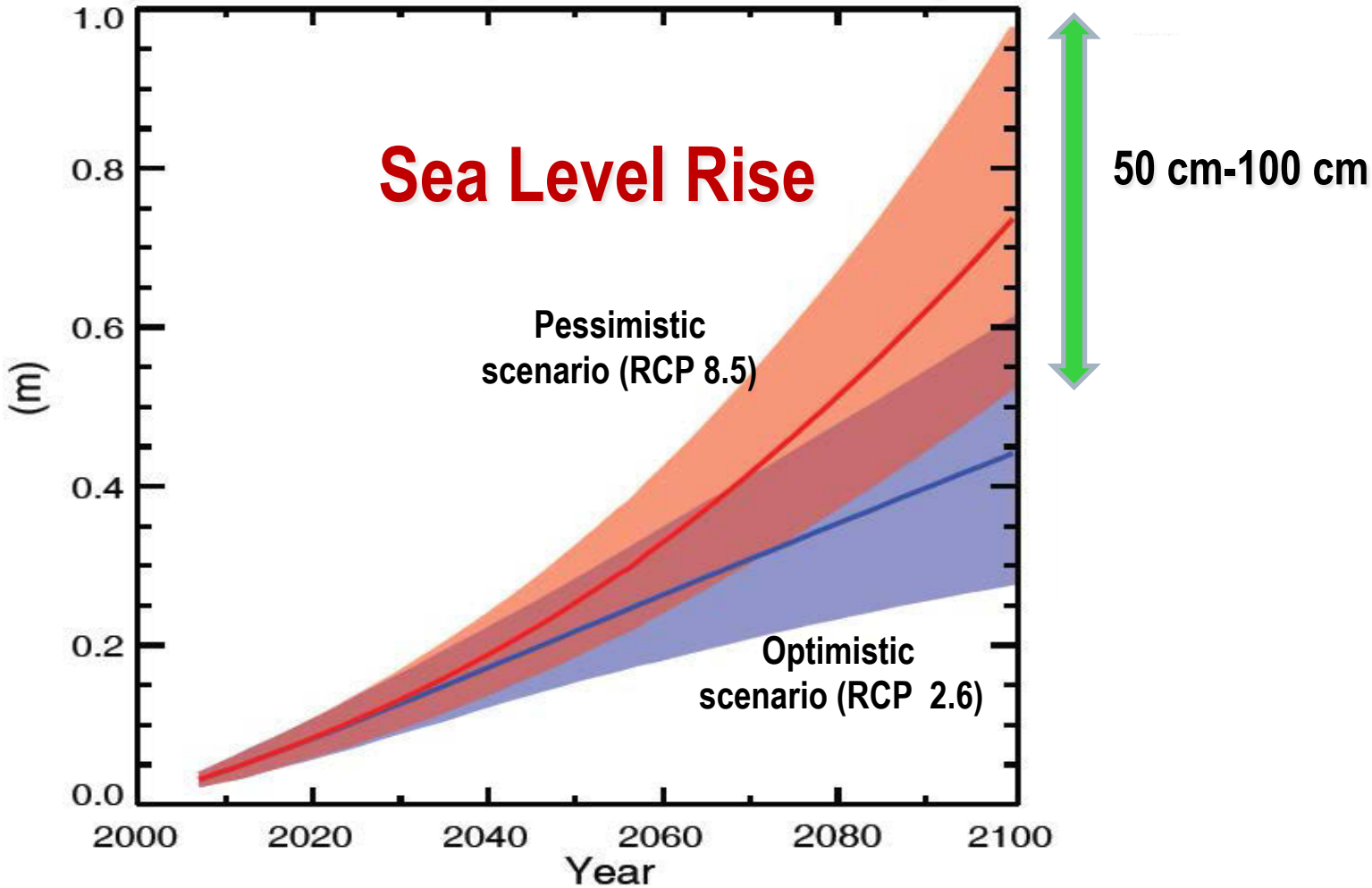
Radiative forcing *: an energy imbalance imposed on the climate system either externally or by human activities; ususally reported as a change in energy flux at the top of the atmosphere and expressed in units of watts per square meters (Wm^{-2})*

4 scenarios for future greenhouse gas emissions considered by IPCC AR5 for the 21st century

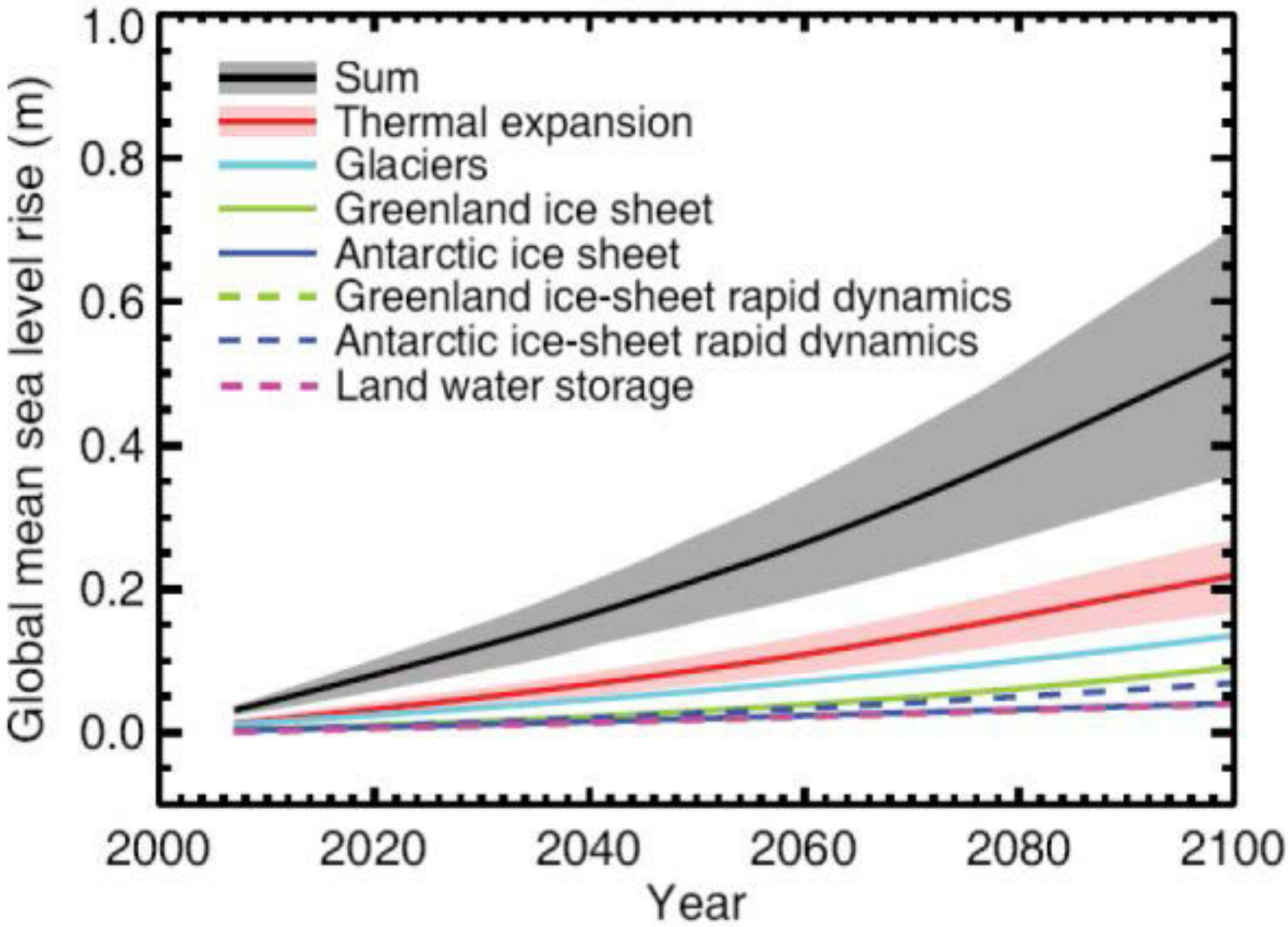


IPCC AR5

IPCC-AR5 projections of Global Mean Sea Level Rise during the 21st century under two warming scenarios



Climate related contributions to future sea level rise (RCP6.0)

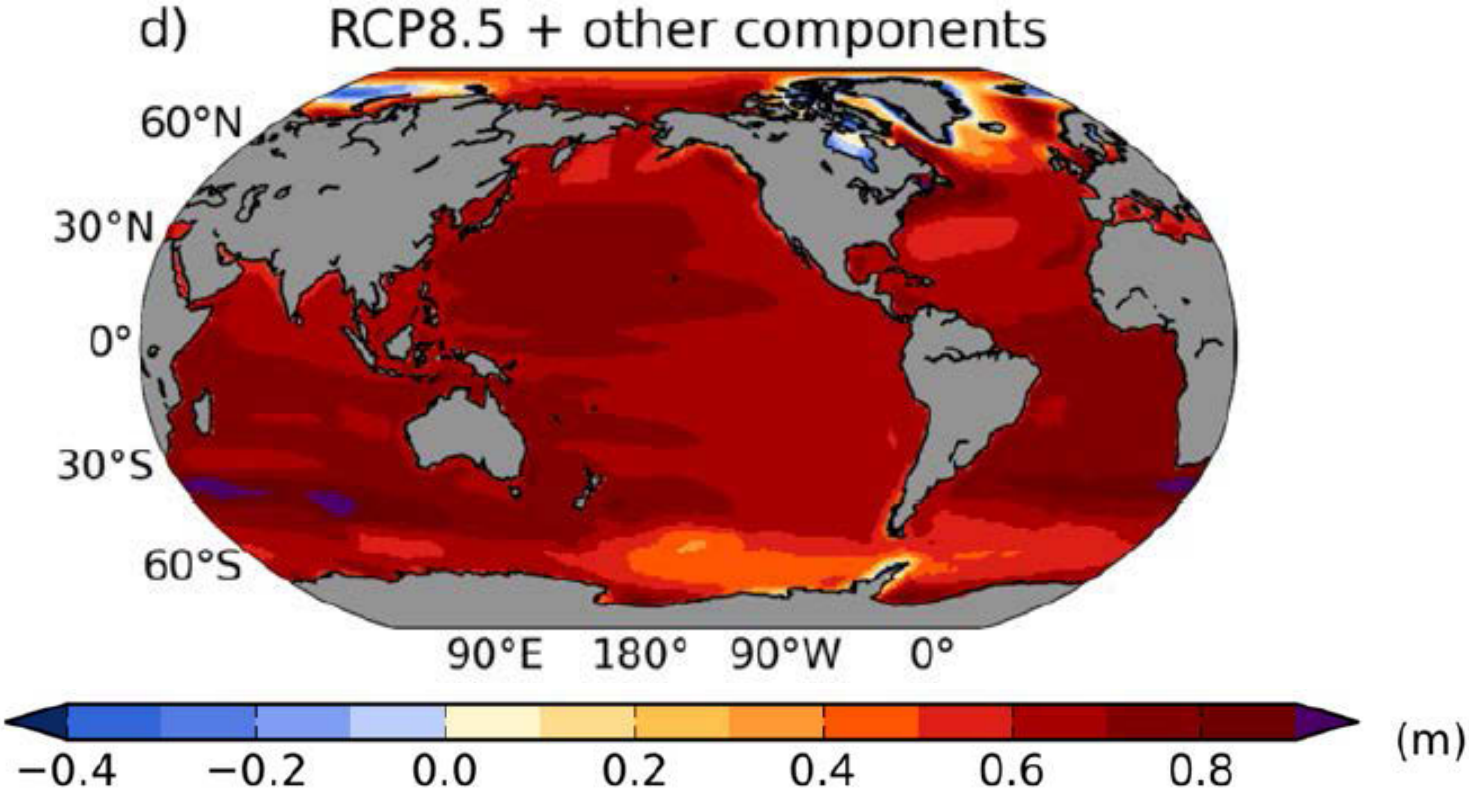


IPCC AR5

Ensemble mean projections of regional sea level rise by the end of the 21st century

(regional variability due to non uniform thermal expansion & salinity

+ solid Earth effects)



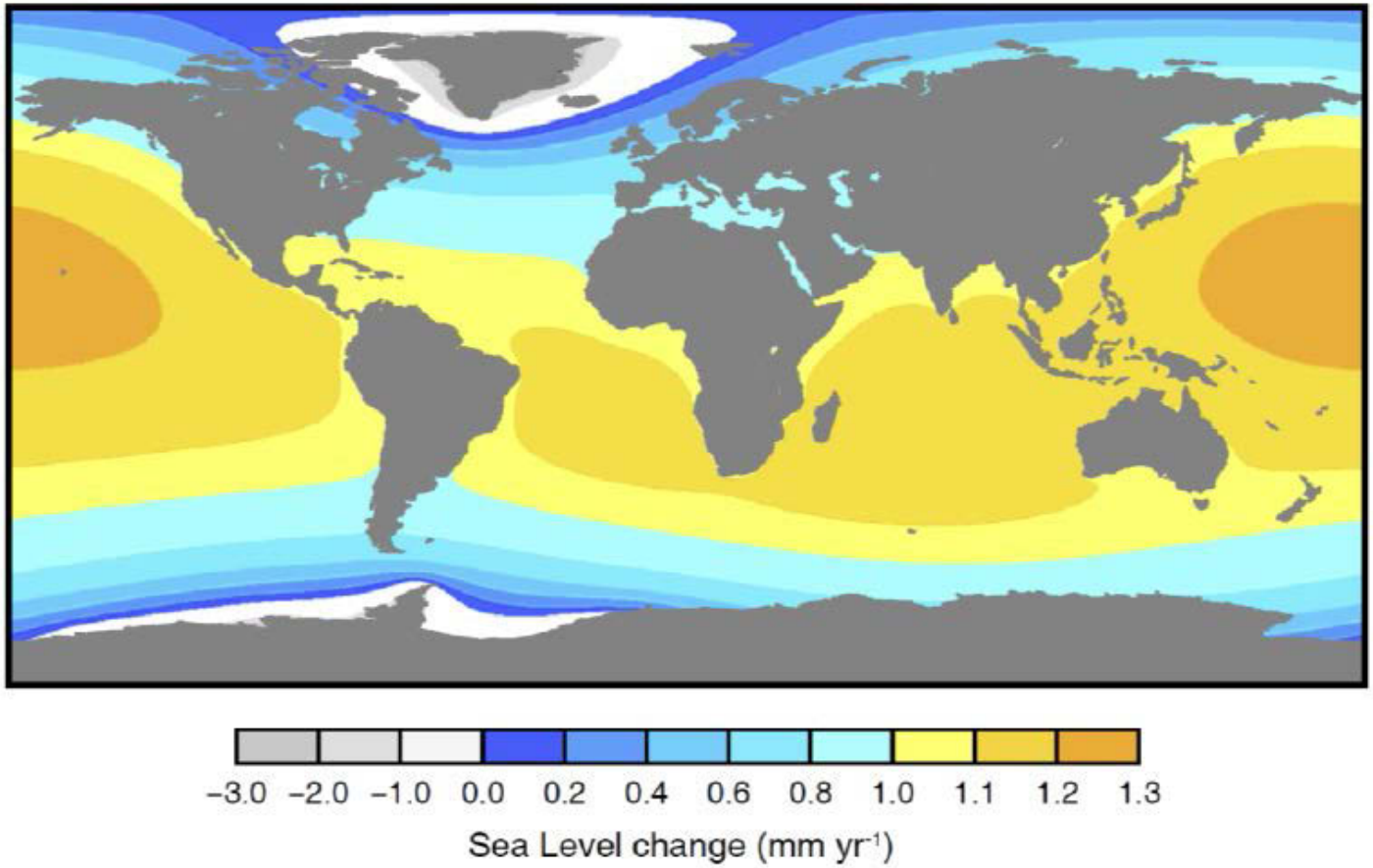
Global mean sea level rise
of 75 cm
(high warming scenario)

In addition to steric effects, there are other causes of regional variability

→Large-scale water mass redistributions due to land ice melt

→Deformations of ocean basins (because the Earth mantle is viscous and the crust is elastic) + changes in mutual gravitational attraction between water & ice masses

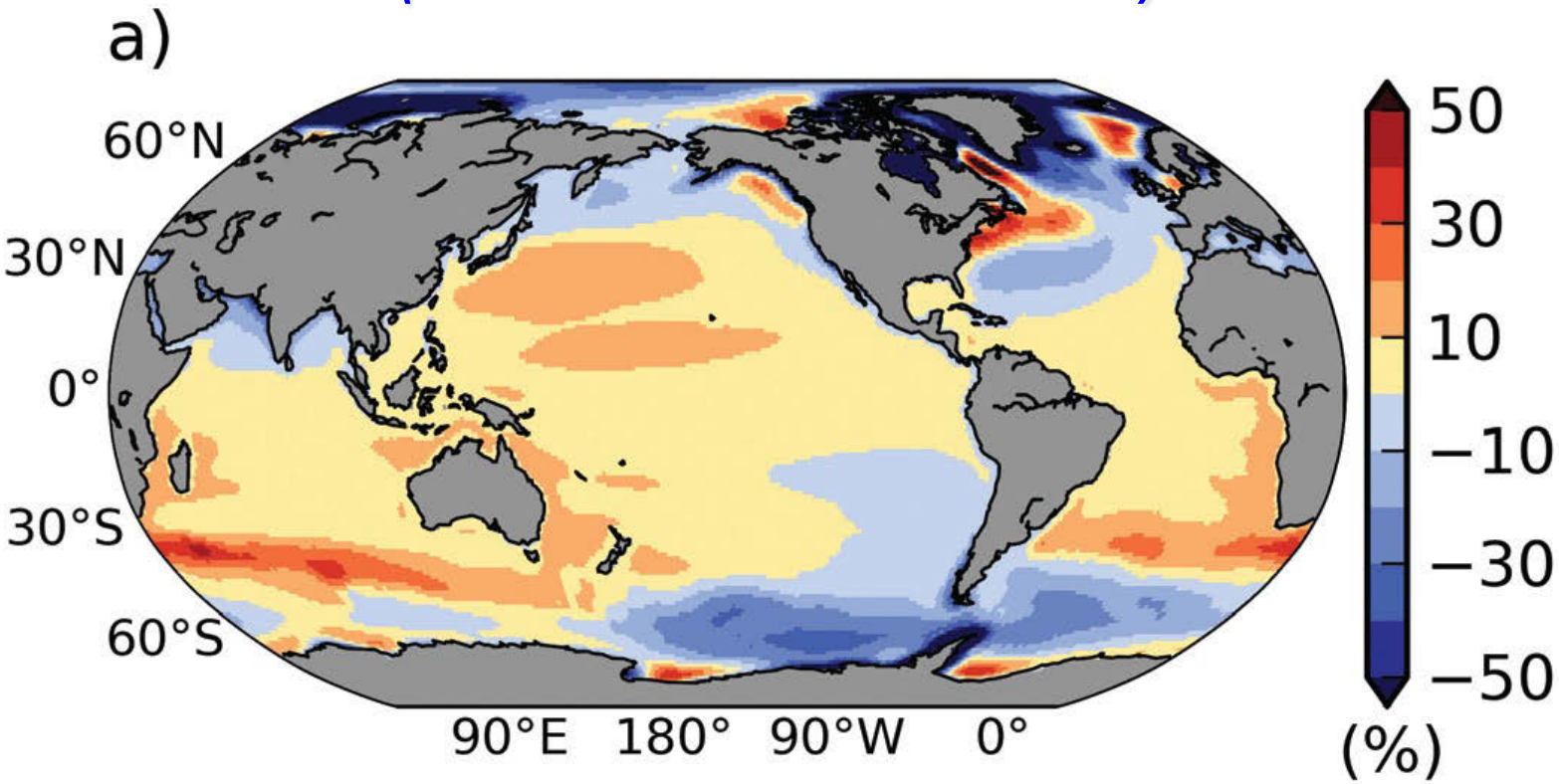
Regional sea level change due to solid Earth's deformations in response to ongoing & future ice sheet melting (Greenland : 0.5 mm/yr; west Antarctica : 0.5 mm/yr)



Amplification of the rate of sea level rise in the tropics by 20%-30%

IPCC AR5

Regional variability by 2100
Percentage of deviation from the global mean rise
(same values for all scenarios)



Long-term climate change

Many aspects of climate change will persist for many centuries even if emissions of greenhouse gases are stopped!

- 20% of emitted CO_2 will remain in the atmosphere more than 1000 years

- Sea level will continue to rise for many centuries in response to deep ocean warming and associated thermal expansion

- Ice sheet mass loss may become irreversible (Greenland) → sustained warming above a certain threshold may lead to near-complete loss of the Greenland ice sheet over a time scale of 1000 years (→ 7 m of sea level rise)

IPCC AR5

Conclusions

- Current global mean sea level rise is likely accelerating
- The sea level budget (altimetry era) almost closed
- Global mean sea level rise: very likely a consequence of anthropogenic global warming
- Regional variability (spatial trend patterns) : still dominated by natural (internal) modes of climate variability
- The global mean sea level will continue to rise during the 21st century in response to global warming (values by 2100 in the range 50 cm-1 m NOT unlikely)
- The regional variability will amplify the global mean rise by 30%-40% in the tropics
- Even if GHG emissions stop tomorrow, sea level will continue to rise during several centuries

Grand challenges for the coming years

-Insure continuity of space-based & in situ observing systems (+ new observations)

→ *satellite altimetry (sea level & ice sheets)*

→ *space gravimetry (GRACE Follow On)*
(ice sheet mass balance, glaciers, land waters)

→ *Argo + Argo deep ocean*

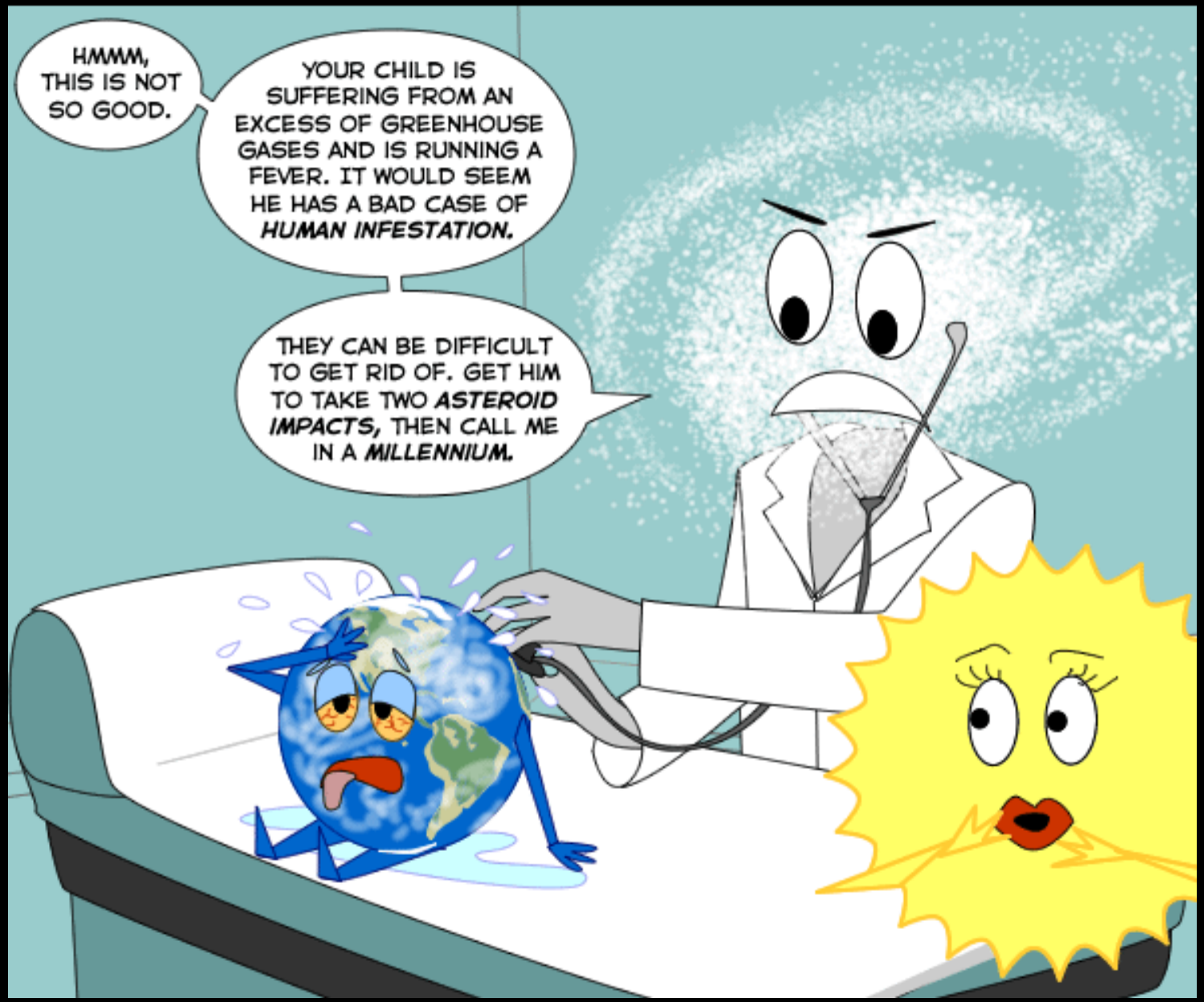
→ *Tide gauges + GPS*

-Improve past sea level reconstructions & OGCMs

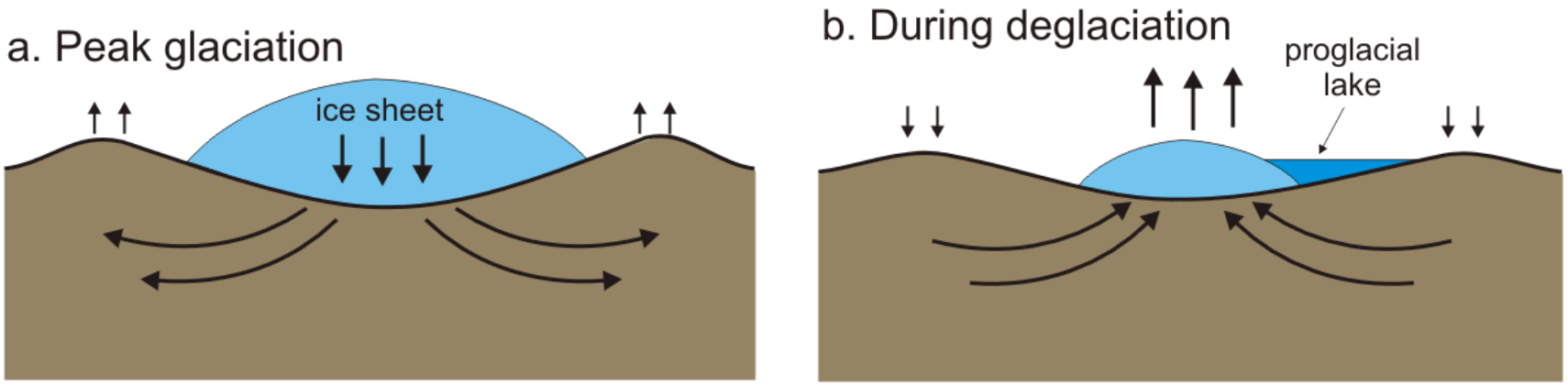
-Reprocess long time climatic time series (e.g., ESA CCI for 'Essential Climate Variables') → climate services

-Perform systematic comparisons between observations and climate model hindcasts…….

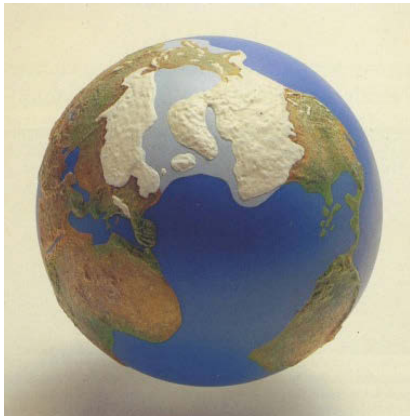
Thanks for your attention



Post Glacial Rebound

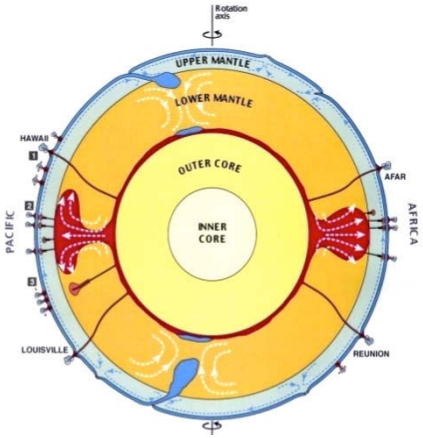


Models of
Post Glacial Rebound
(also called
Glacial Isostatic Adjustment
or GIA)



Deglaciation history

+



Models of
Earth's viscosity structure