

Sea level projections beyond 2100

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Outline

- Sea level rise with warming of 1.5 and 2 °C (Paris agreement)
- Geoengineering and sea level
- Sea level projections beyond 2100
- Conclusion

Climate Change

1712 – Steam engine by Thomas Newcomen (industrial use of coal)

1938 - Using records from 147 weather stations around the world, British engineer Guy Callendar shows that temperatures had risen over the previous century, link to the CO2 concentrations, suggesting that increase in CO2 caused the warming

1972 - First UN environment conference (chemical pollution, atomic bomb testing - **no climate change**), in Stockholm

1975 - US scientist Wallace Broecker puts the term "**global warming**" into the public domain in the title of a scientific paper

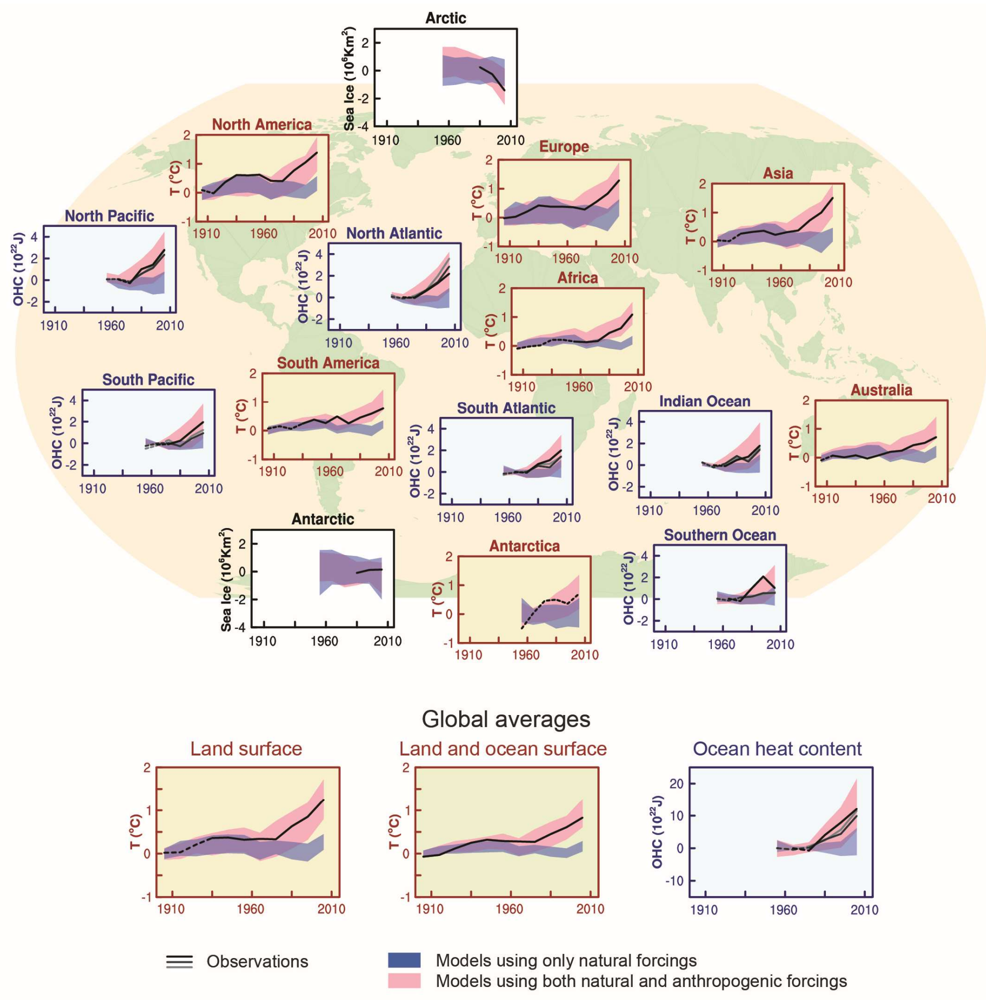
12 Dec 2015 – Paris Agreement on climate change (195 nations)

Paris agreement (key elements)

Governments agreed:

- a long-term goal of keeping the increase in global average temperature to **well below 2°C** above pre-industrial levels;
- to aim to limit the increase to **1.5°C**, since this would significantly reduce risks and the impacts of climate change;
- on the need for **global emissions to peak as soon as possible**, recognising that this will take longer for developing countries;
- to undertake **rapid reductions thereafter** in accordance with the best available science.

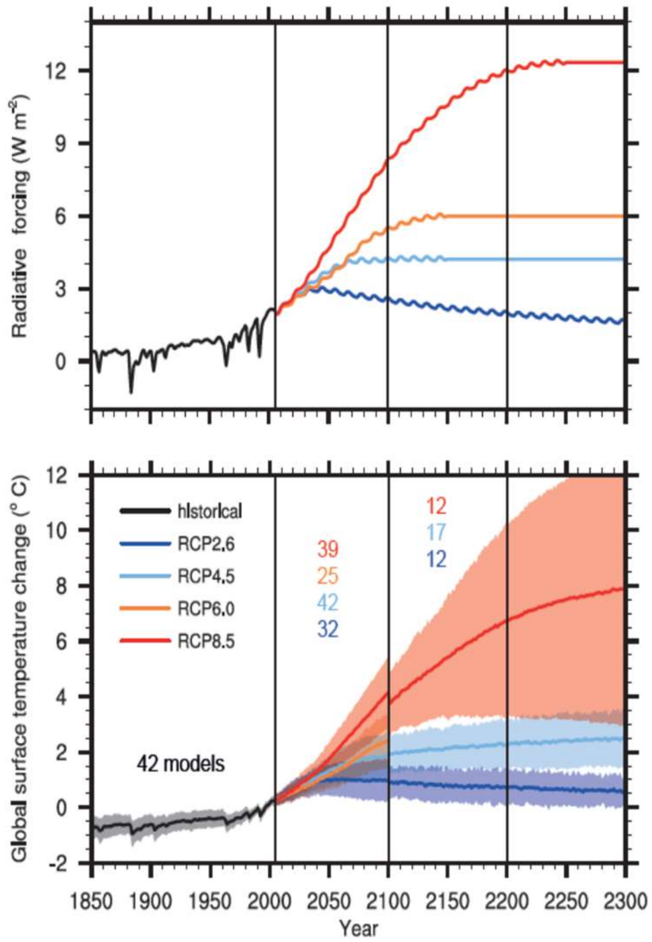
It is extremely likely (95-100% probability) that human influence was the dominant cause of global warming between 1951-2010



AR5 IPCC, SPM.6

Observed changes

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



RCP8.5 (Representative Concentration Pathways)

GHG emissions continue to grow at current level

RCP2.6

Substantial reductions in emissions

(2081-2100)

3.7 °C

[2.6 4.8]

(2081-2100)

1 °C

[**0.3** 1.7]

Future outlook

Climate change and society

Stern review, 2006

Future outlook

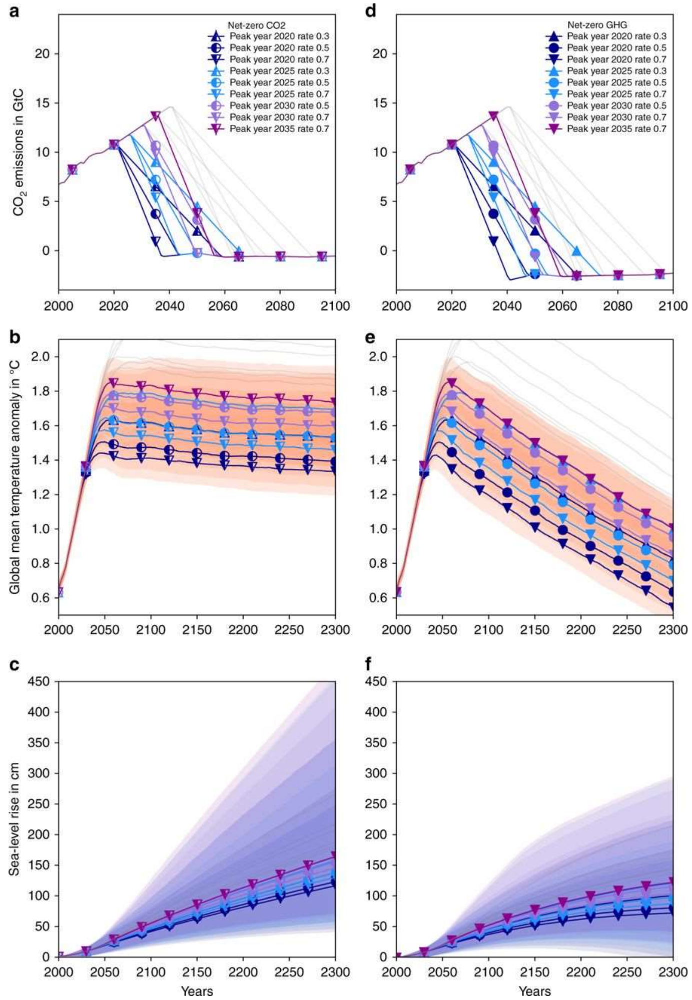
Future of our planet (1)

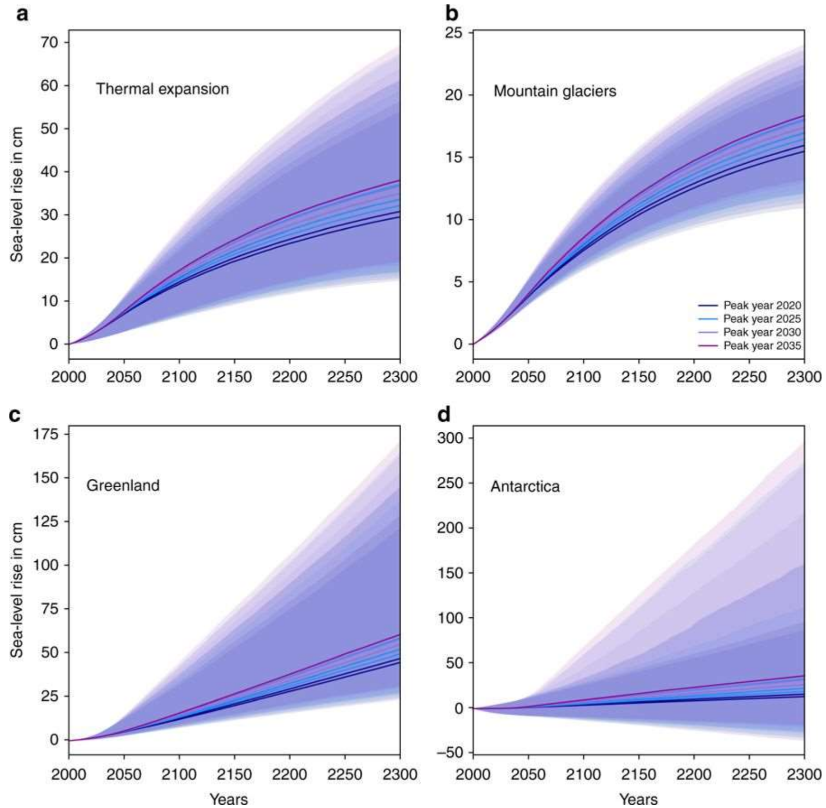
- highly-unlikely poorly-understood threshold-crossing disasters associated with abrupt large-scale irreversible changes in the climate system:
- sudden collapse of the Greenland and West Antarctica ice sheets,
- weakening or even reversal of thermohaline circulations that might radically affect such things as the Gulf Stream and European climate,
- changes in monsoon,
- runaway climate-sensitivity amplification of global warming due to positive-reinforcing multiplier feedbacks (including, but not limited to, loss of polar albedo, weakened carbon sinks, and rapid releases of methane from the thawing of arctic permafrost

Future of our planet (2)

- sea-level dynamics, drowned coastlines of unknown magnitude,
- very different extreme weather patterns including droughts and floods,
- coastal ecosystem destruction, mass species extinctions,
- large-scale migrations of human populations,
- contagious diseases

Sea level rise with warming of 1.5 °C

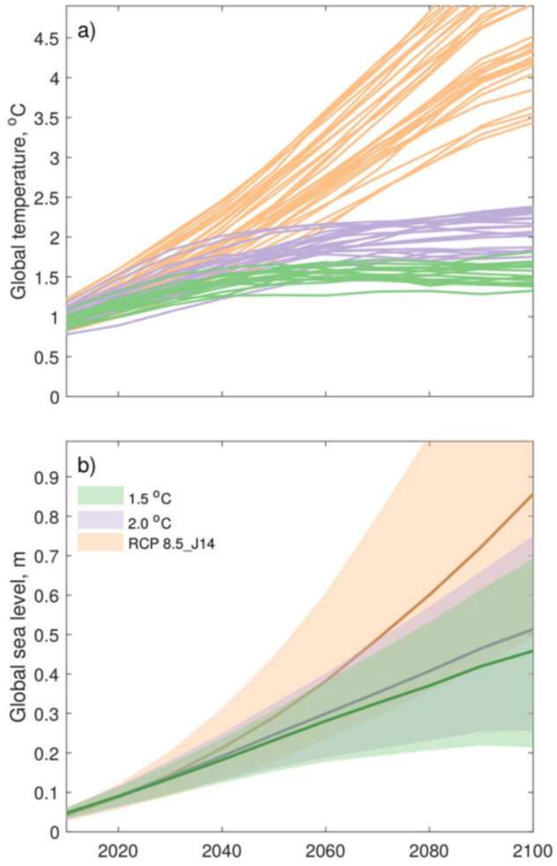




Semi-empirical approach by Mengel et al., 2018

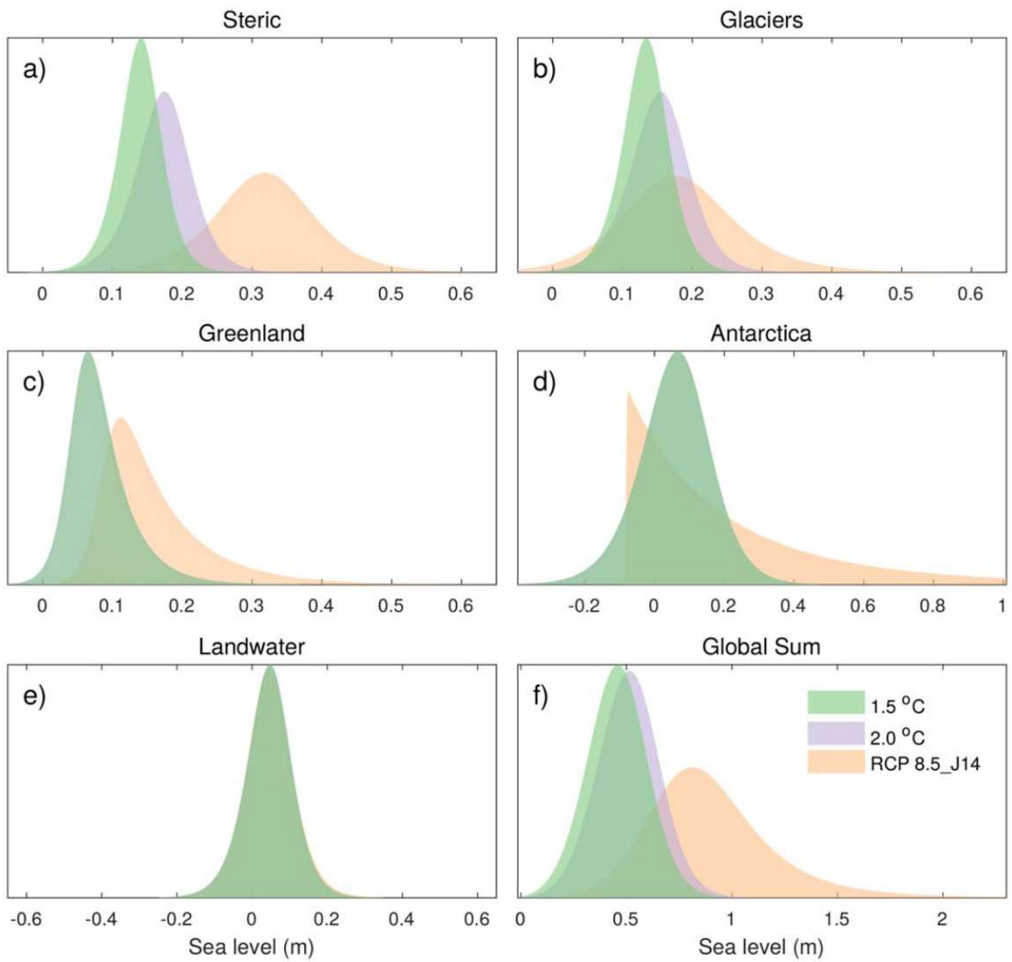
Process based approach

Model	1.5 °C		2 °C	
	RCP2.6	RCP4.5	RCP2.6	RCP4.5
BCC-CSM1-1	1.44			2.2
BCC-CSM1-1-m	1.43			2.12
BNU-ESM			1.75	
CanESM2			2.19	
CCSM4	1.48			2.25
CESM1-BGC				2.22
CESM1-CAM5			2.11	
CNRM-CM5	1.66			
CSIRO-Mk3-6-0				2.02
EC-EARTH	1.54			
FIO-ESM		1.64		
GFDL-ESM2M	1.28			1.79
GFDL-ESM2G		1.61		
GISS-E2-H	1.4			2.3
GISS-E2-H-CC				1.99
GISS-E2-R				2.03
GISS-E2-R-CC				1.79
HadGEM2-AO	1.75			
HadGEM2-ES			2.06	
inmcm4				1.86
IPSL-CM5A-LR			1.83	
IPSL-CM5A-MR			1.73	
IPSL-CM5B-LR				2.25
MIROC5	1.64			2.32
MIROC-ESM			2.26	
MPI-ESM-LR	1.41			
MPI-ESM-MR	1.4			2.3
MRI-CGCM3	1.59			2.29
NorESM1-M	1.49			2.24
NorESM1-ME	1.6			



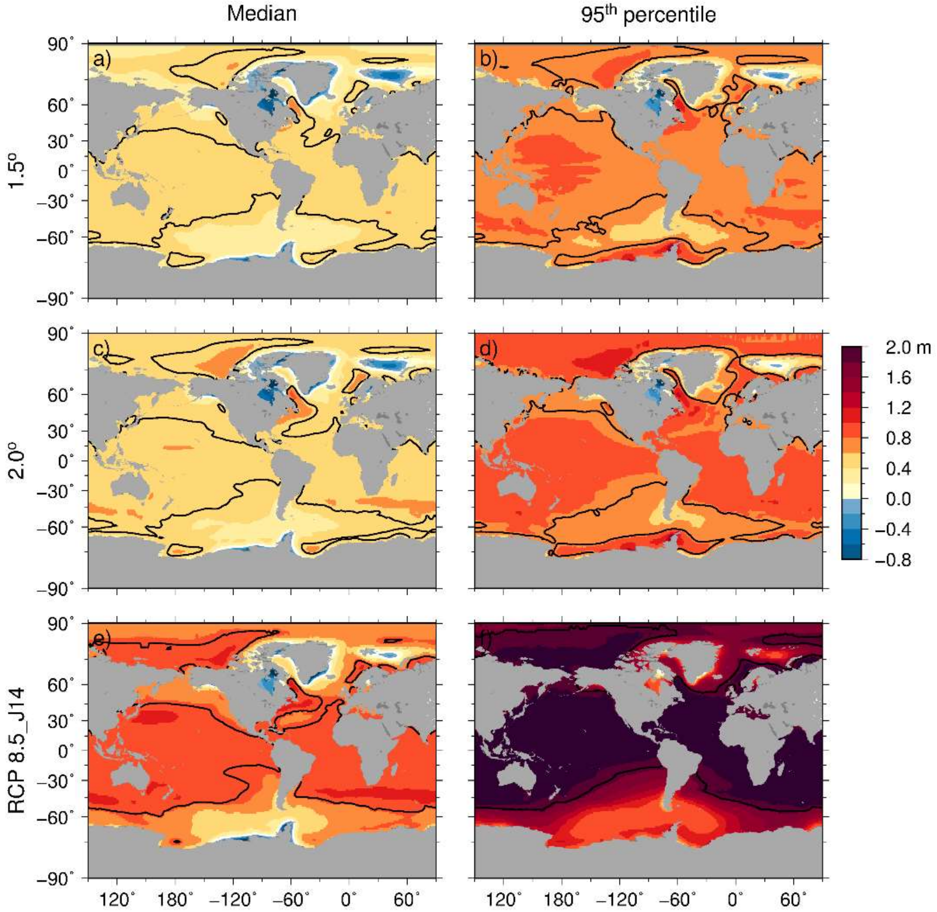
Jevrejeva et al., 2018

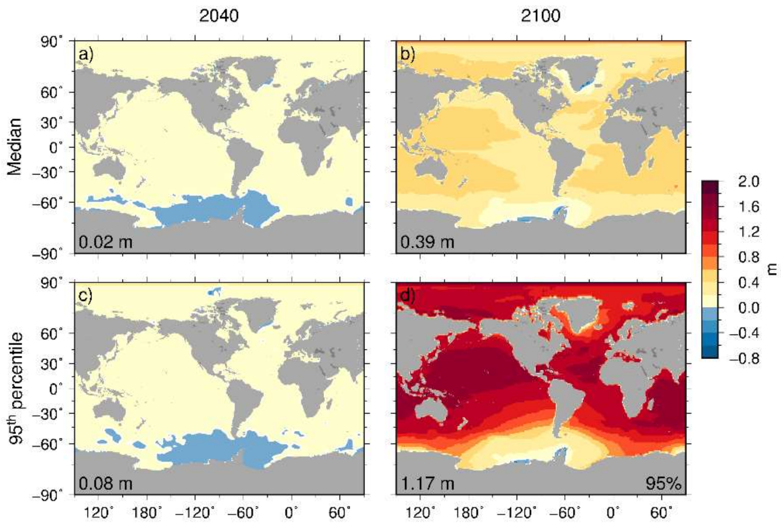
PDFs for sea level components and total sea level (1.5 and 2 °C)



Jevrejeva et al., 2018

Sea level projections with warming of 1.5 and 2 °C
Process based approach





Difference between RCP8.5 and 1.5 degree

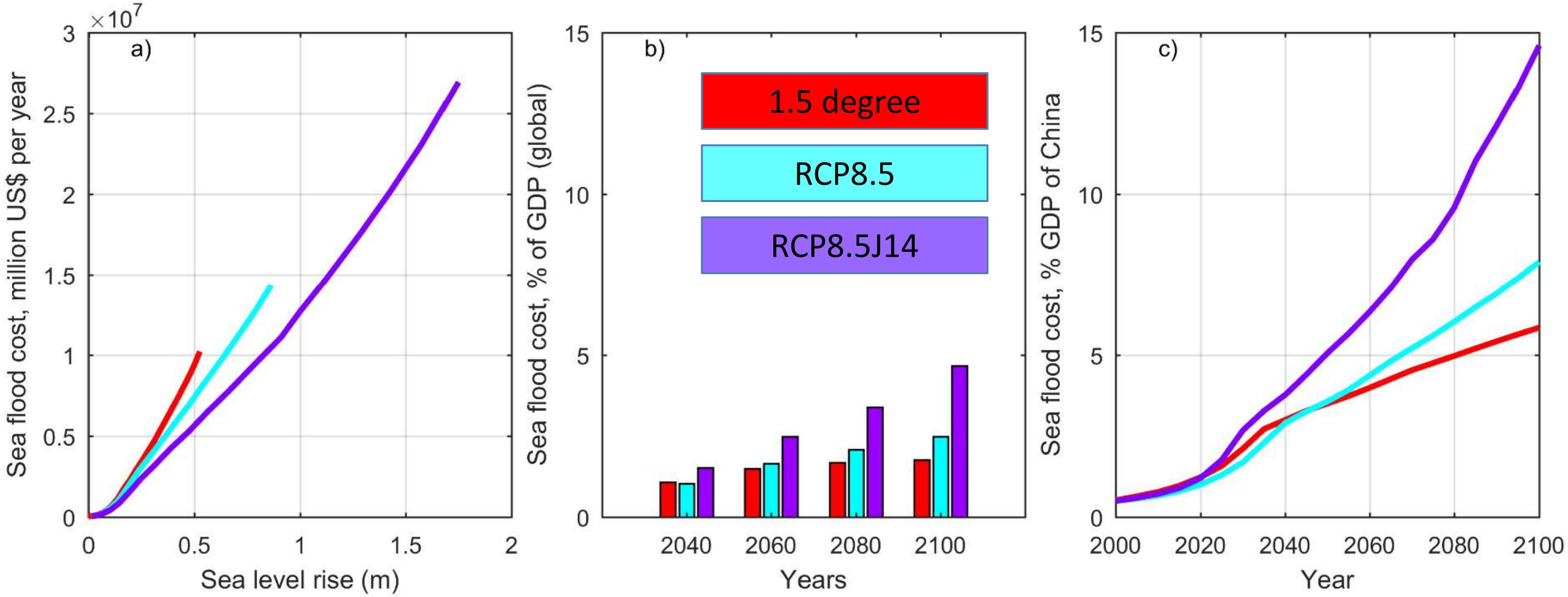
Jevrejeva et al., 2018

Sea flood damage costs with the sea level rise by 2100

Global sea floods cost, Million US$ per year

Global sea floods cost, % of GDP (global)

Sea flood cost for China, % of GDP (China)

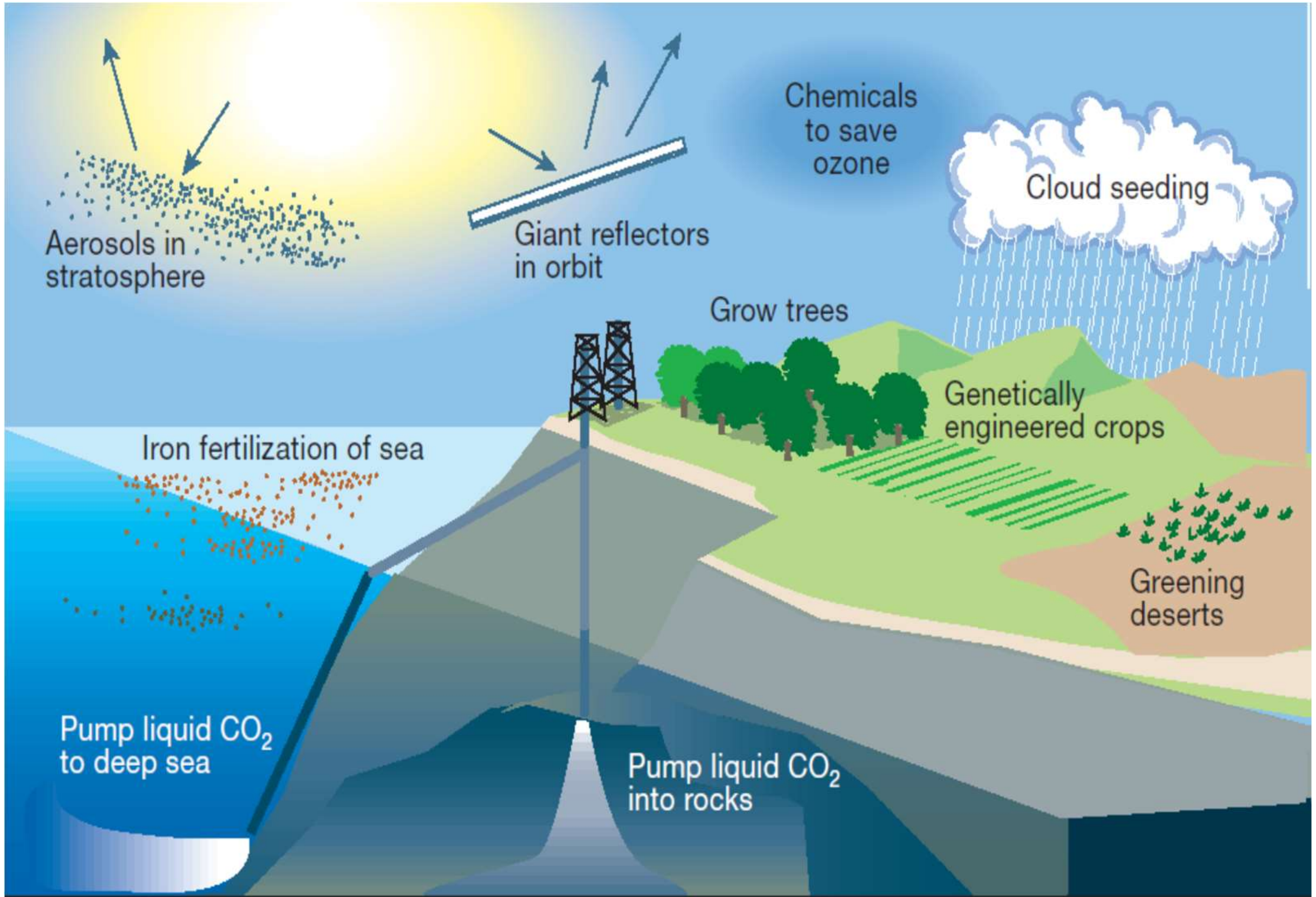


China, flood cost in 2100

US$ 3.4 trillion per year (5.8 % GDP) with warming of 1.5 degree (0. 5 m sea level rise)
US$ 4.6 trillion per year (7.8% GDP) with RCP8.5 (0. 8 m sea level rise)
US$ 8.5 trillion per year (14 % GDP) with RCP8.5J14 (1.8 m sea level rise)

Jevrejeva et al., 2018

Geoengineering and sea level



Schematic representation of various climate-engineering proposals (courtesy B. Matthews).

Aerosols in stratosphere / Volcanic forcing

Radiative forcing (W/m^2) is "the rate of energy change per unit area of the globe as measured at the top of the atmosphere"

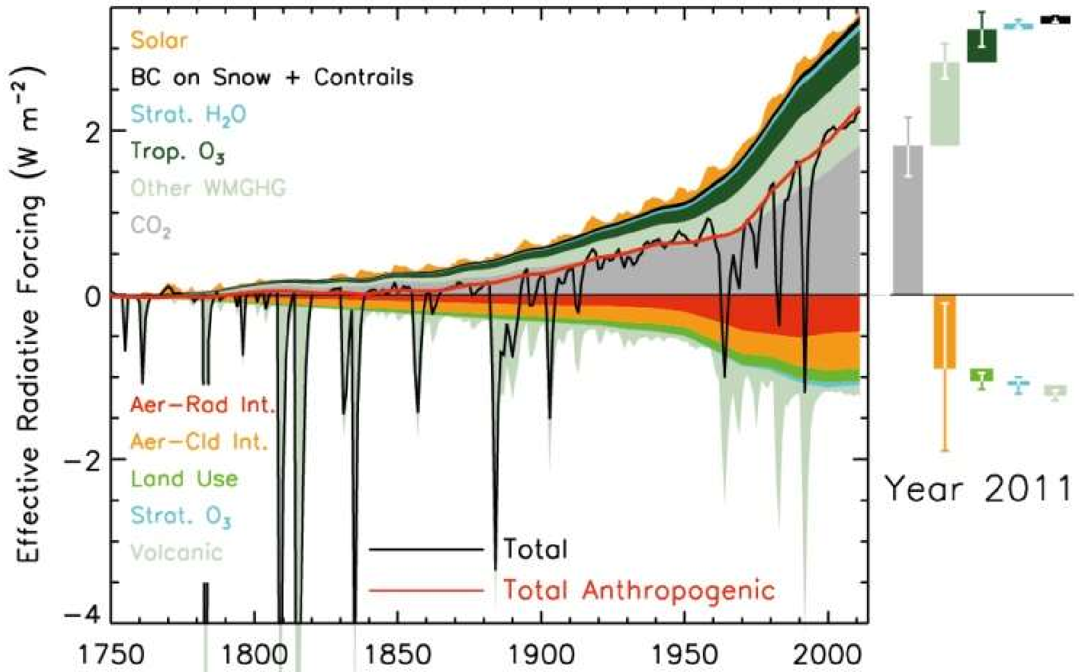


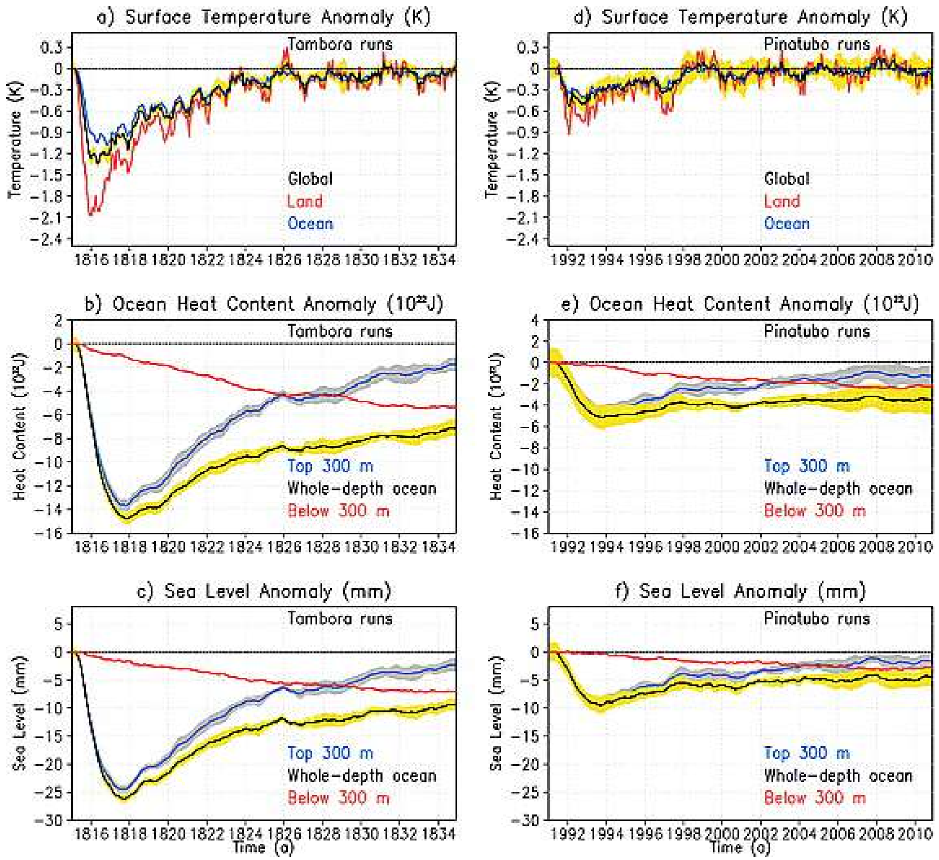
Figure 8.18, AR5 IPCC

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, D16104, doi:10.1029/2008JD011673, 2009

Volcanic signals in oceans

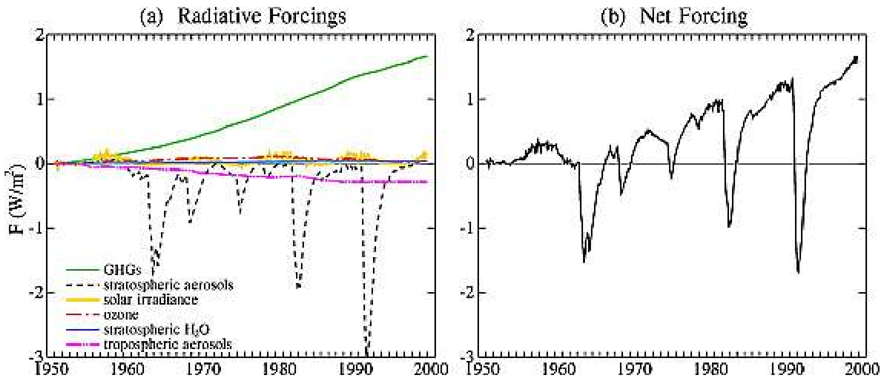
Georgiy Stenchikov,[1,2] Thomas L. Delworth,[3] V. Ramaswamy,[3] Ronald J. Stouffer,[3]
Andrew Wittenberg,[3] and Fanrong Zeng[3]

Tambora
1815

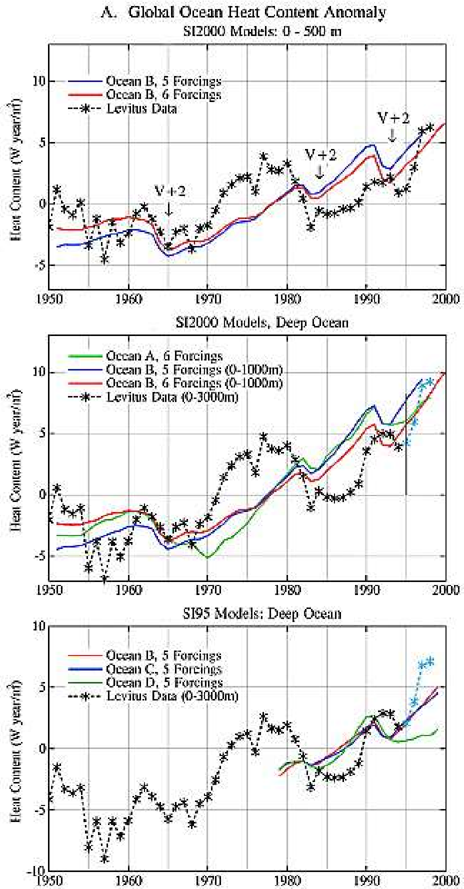


Pinatubo
1991

Ocean response to volcanic forcing

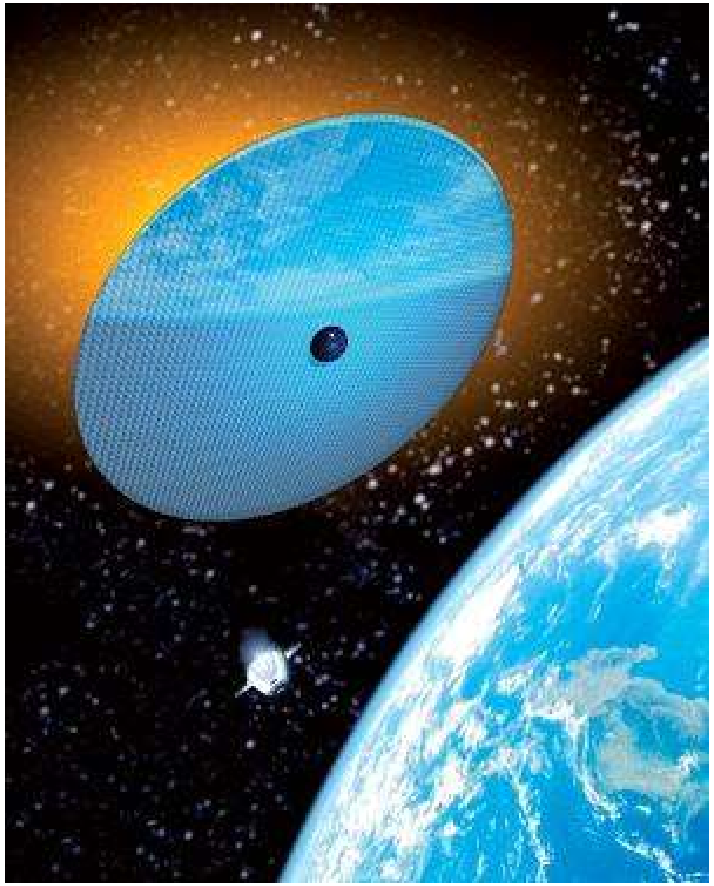


Agung 1963 (Bali)
El Chichon 1982 (Mexico)
Pinatubo 1991 (Philippines)



Hansen et al., 2002

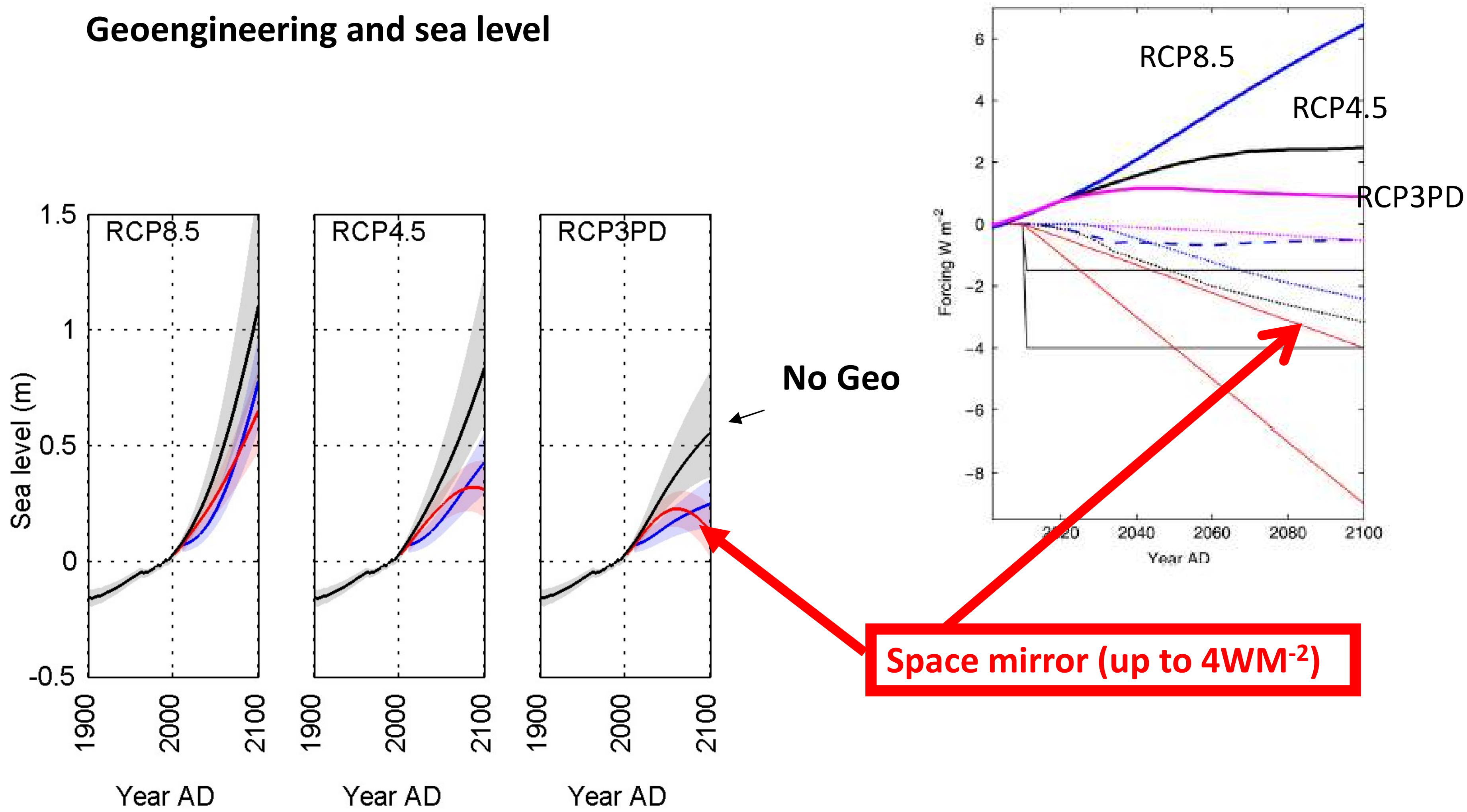
Mirrors in Space



- Another way to reduce the solar heat flux reaching Earth's surface is to put deflectors in space
- A cloud of trillions of 0.6-meter-diameter, thin refractive screens to deflect sunlight
- To offset a doubling of CO_2 over preindustrial levels would require a total mass of 20 million tons to block 1.8% of the solar radiation

Computer artwork of a large mirror (circular) in Earth orbit with a spacecraft (lower left). The mirror is designed to shield the Earth (lower right) from the sun (behind mirror), in an attempt to control changes in the climate of the Earth. (Image: Victor Habbick Visions/SPL)

Geoengineering and sea level



Moore et al., 2010

Ocean response to geonegineering

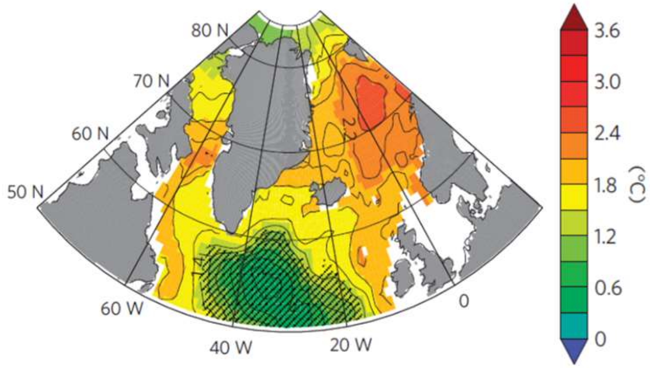
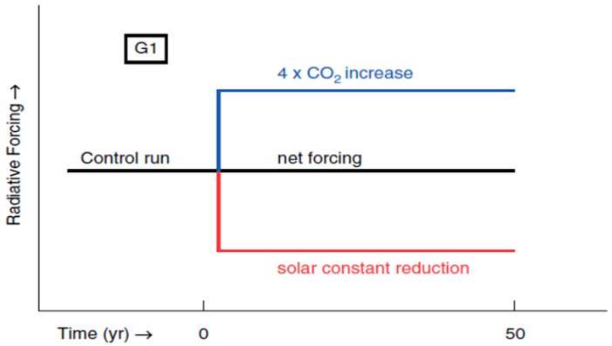


Figure 3: Projected anomalies of subsurface (200-500m) ocean temperatures by 19 CMIP3 models during 2091-2100, A1B scenario [from *Yin et al*, 2011], suggesting that warming around Greenland (1.7-2.0 ˚C) will be almost double the global mean.

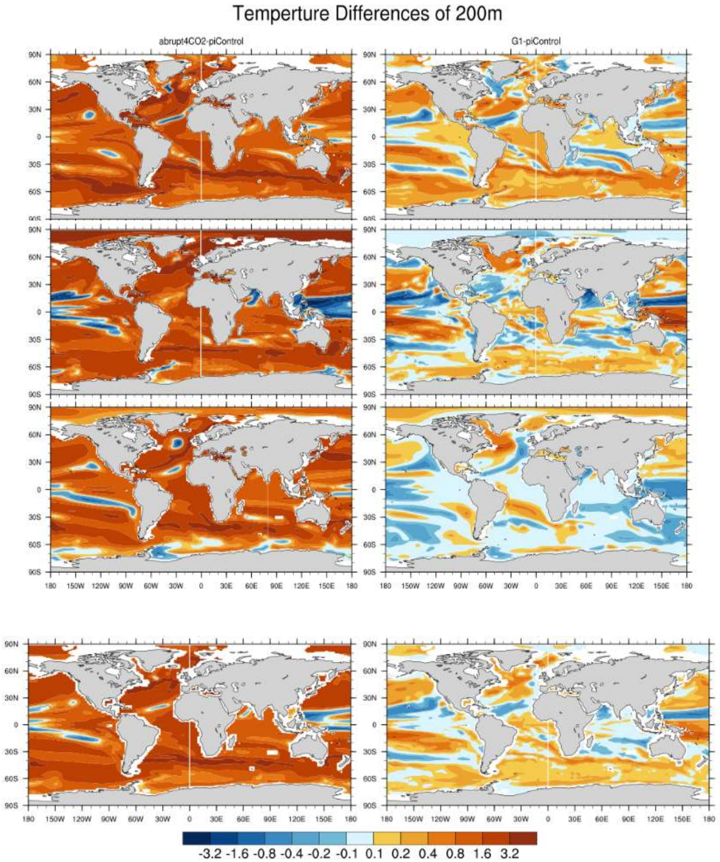


BNU-ESM

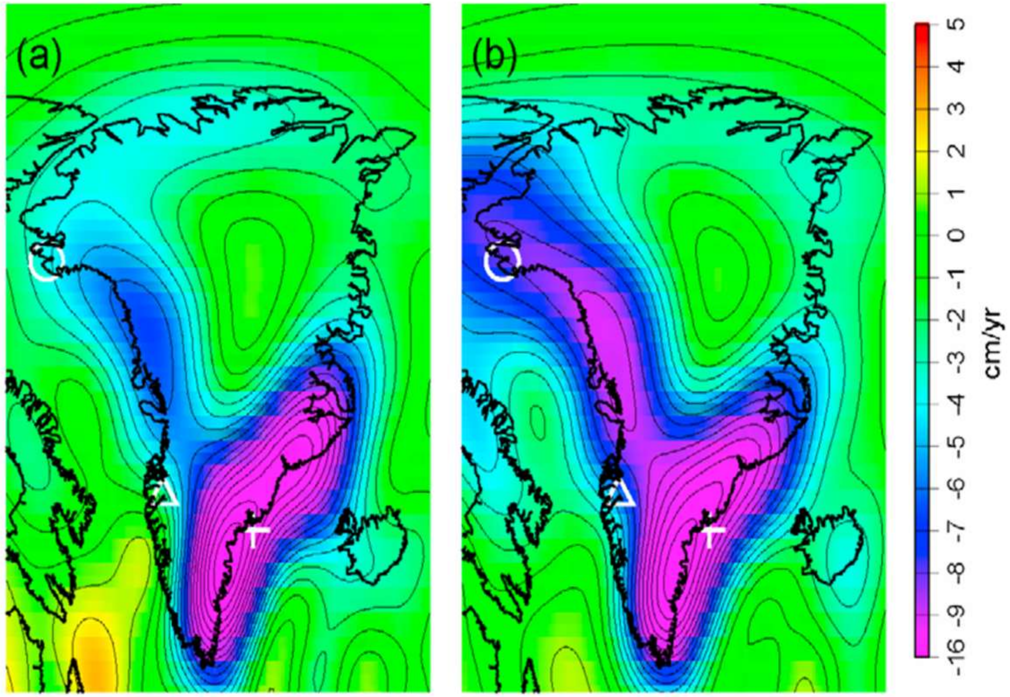
HadGEM2-ES

IPSL-CM5A-LR

Ensemble



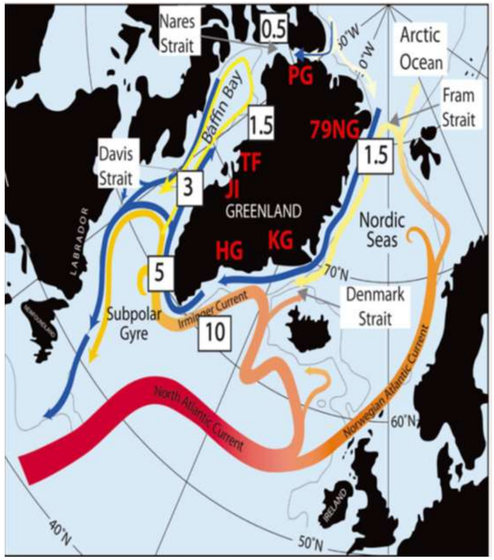
Ice loss in Greenland



2003-2007

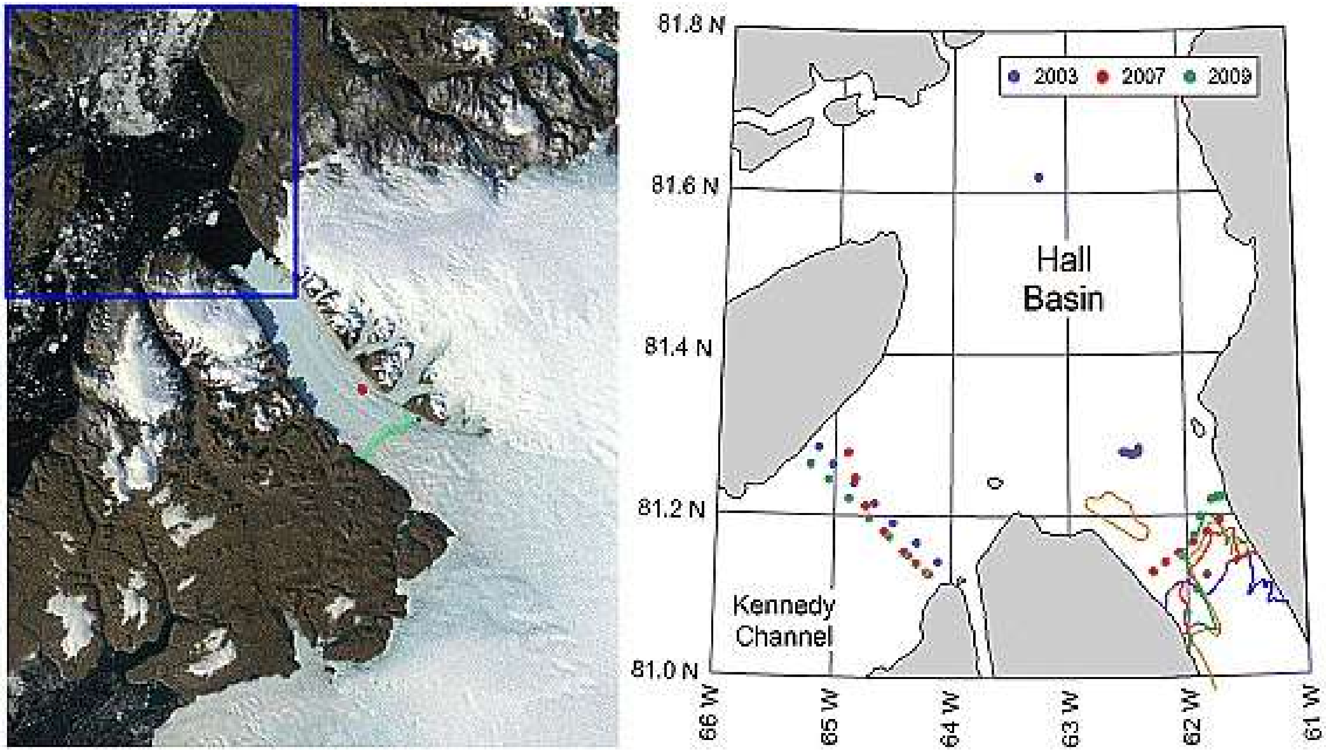
2003-2009

The rate of mass loss, in cm/yr water equivalent thickness, determined from monthly GRACE gravity field solutions, from Khan et al, 2010.



Straneo et al. 2012

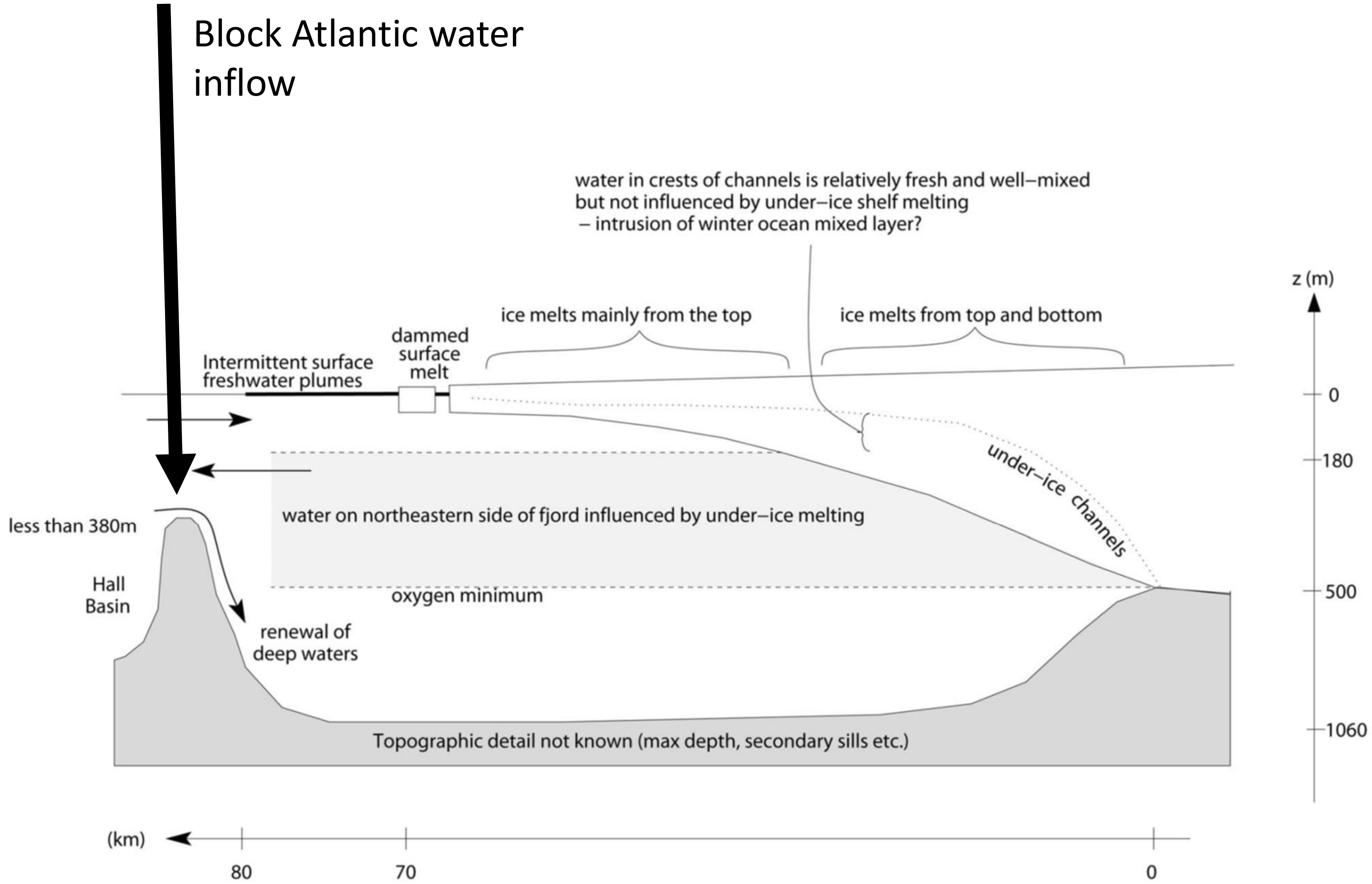
Ocean circulation and properties in Petermann Fjord, Greenland



Johnson et al., 2011

How to stop sea level rise

Block Atlantic water
inflow

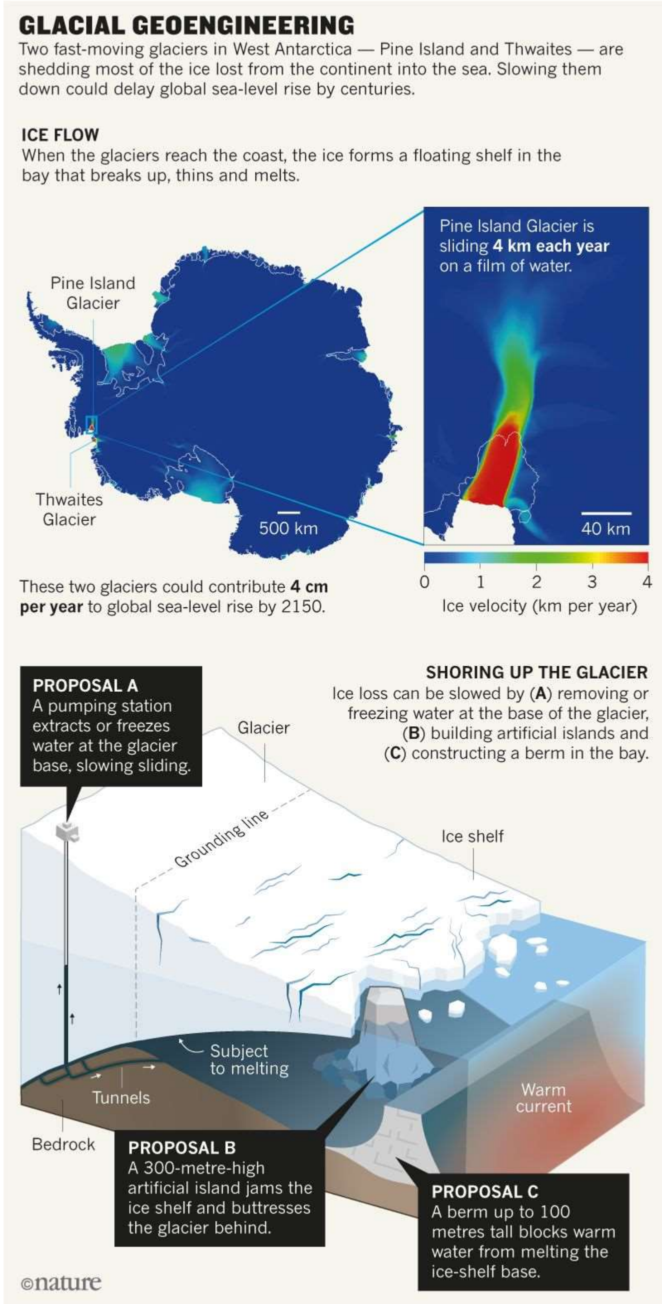


Johnson et al., 2011


JOE RAEDLE/GETTY

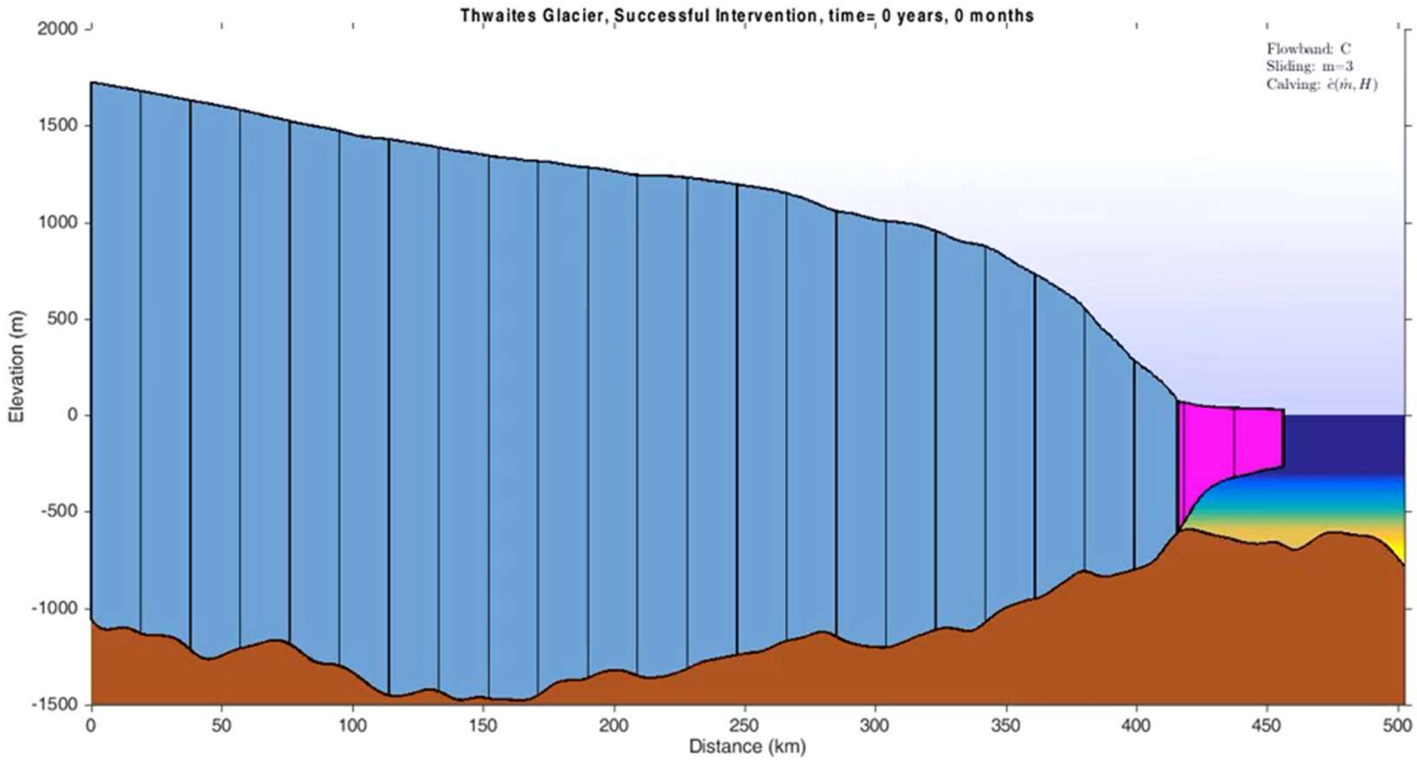
The village of Ilulissat in western Greenland is surrounded by icebergs that have calved from the Jakobshavn Glacier.

Geoengineer polar glaciers to slow sea-level rise



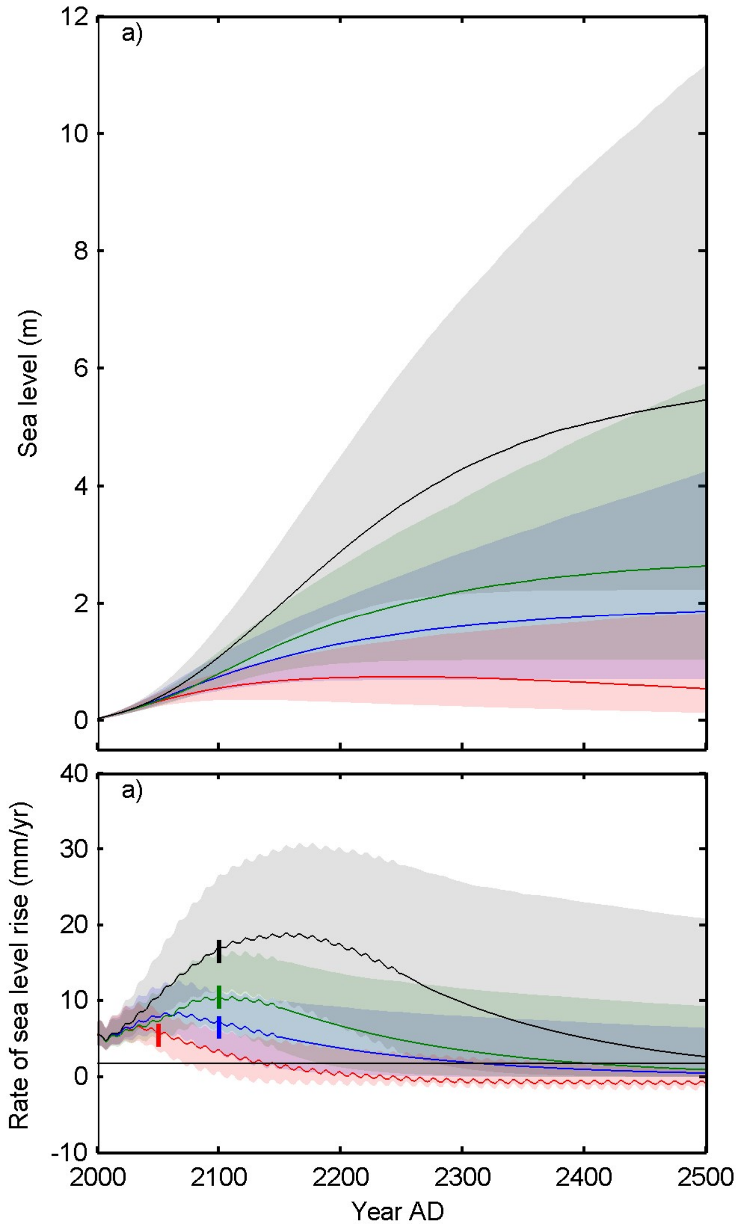
Moore et al, 2018

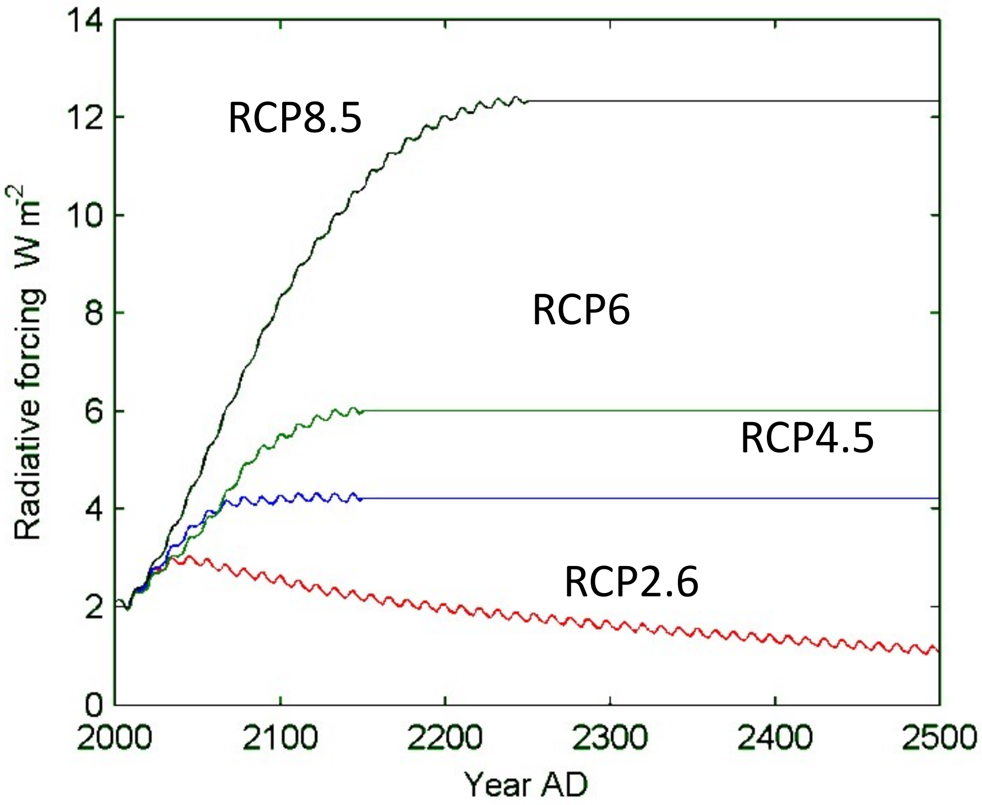
Targeted Geoengineering



Moore et al, 2018

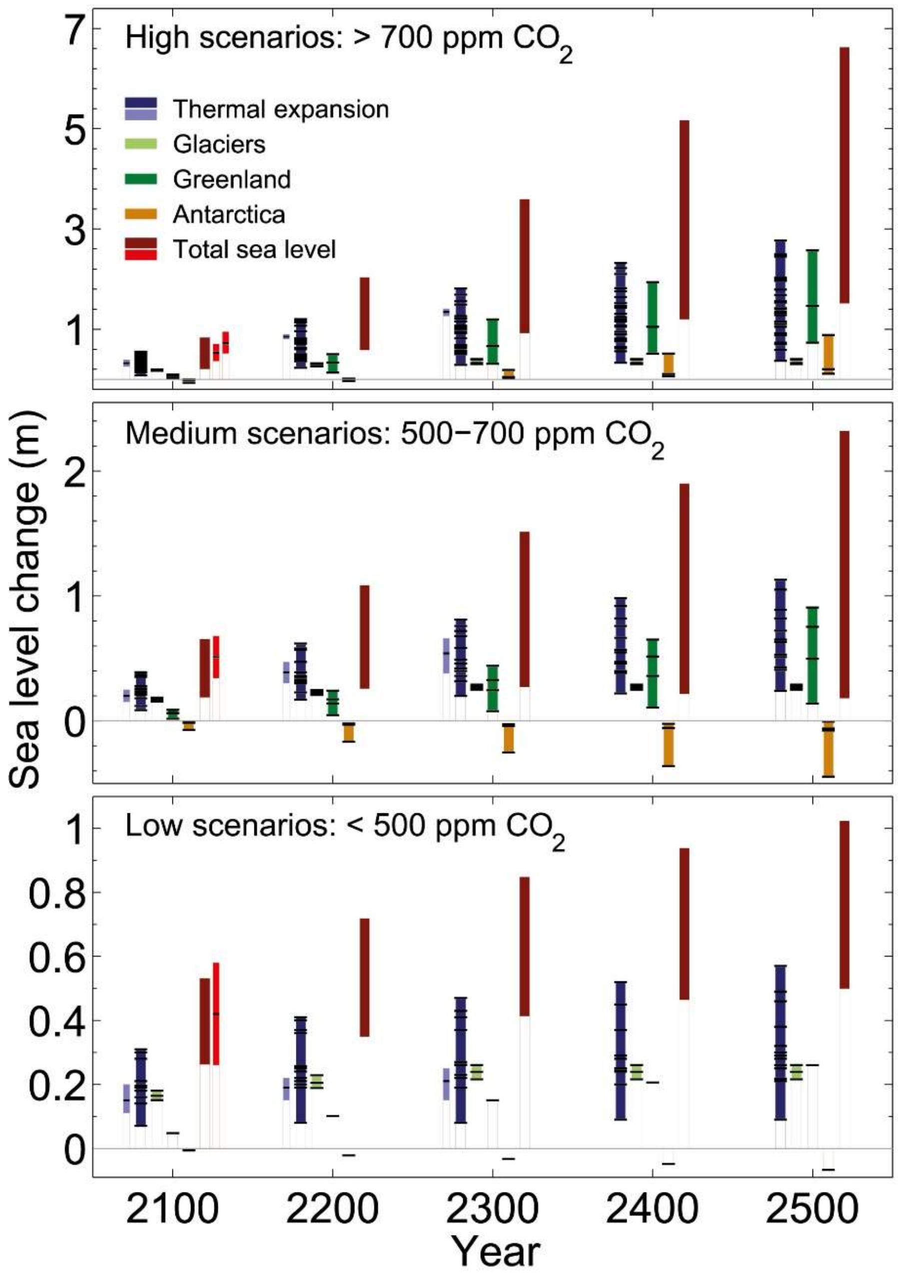
Sea level rise by 2500





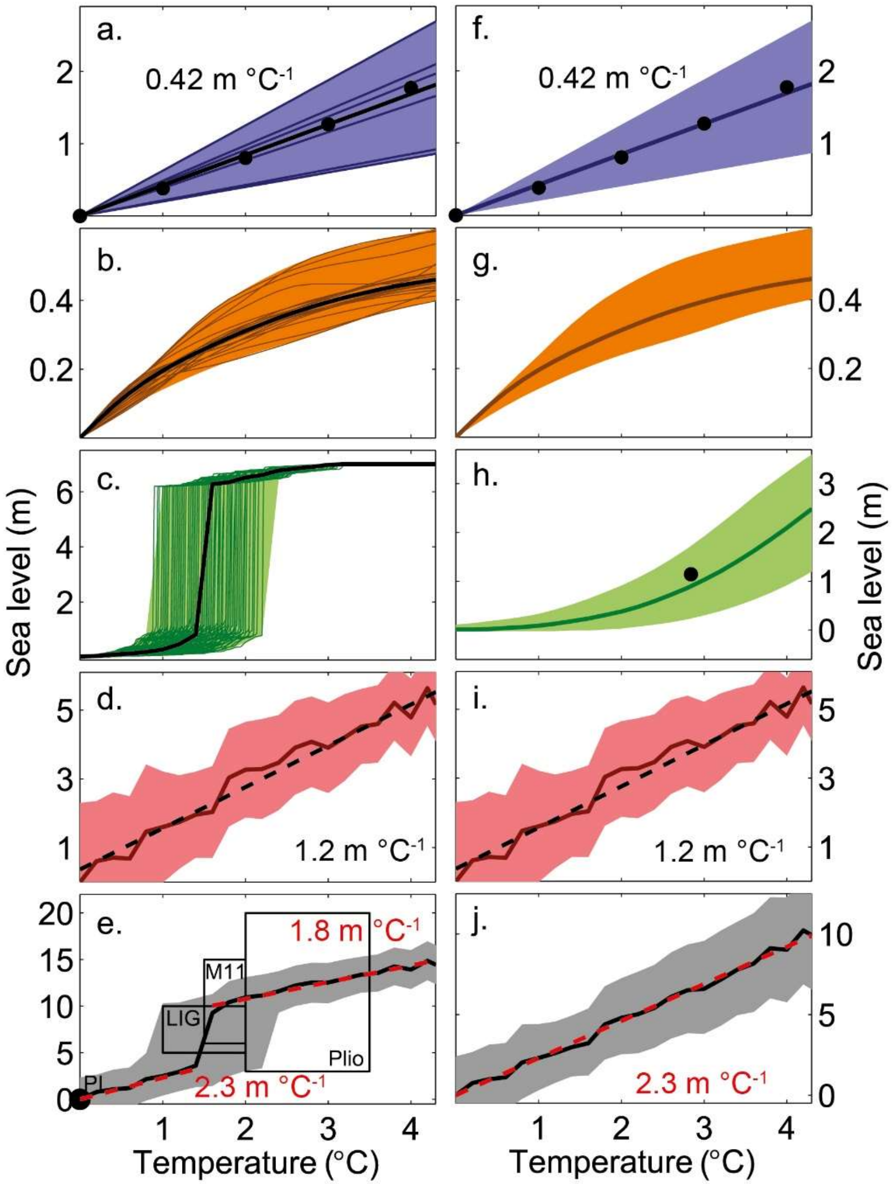
Jevrejeva et al, 2012

Sea level rise by 2500



AR5 IPCC

Multi-millennial sea level commitment per degree of warming



Thermal expansion

Glaciers

Greenland

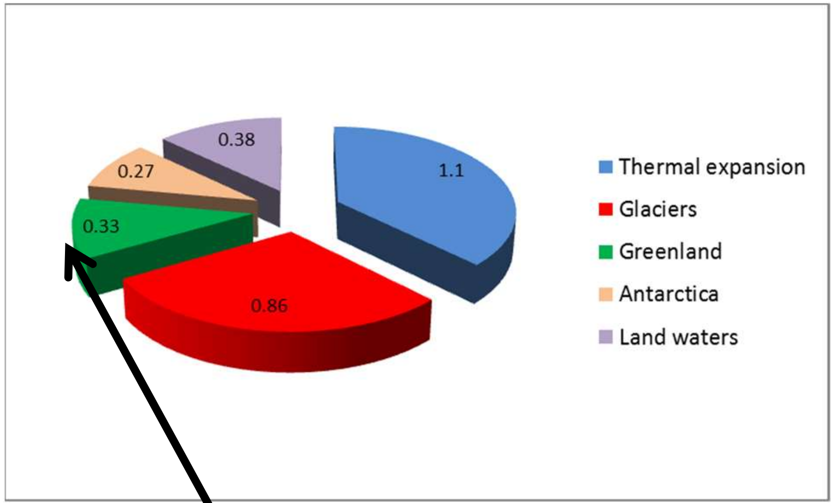
Antarctica

Total

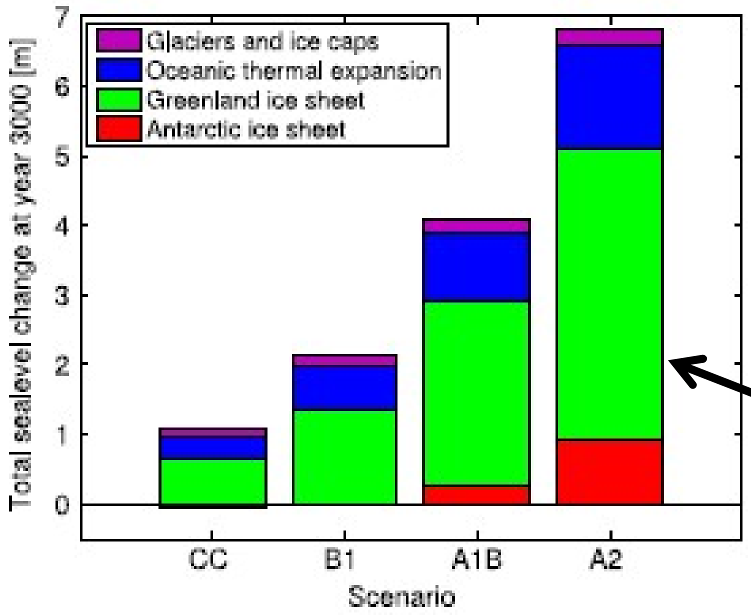
AR5 IPCC

Future Sea level budget

1993-2010, 11%



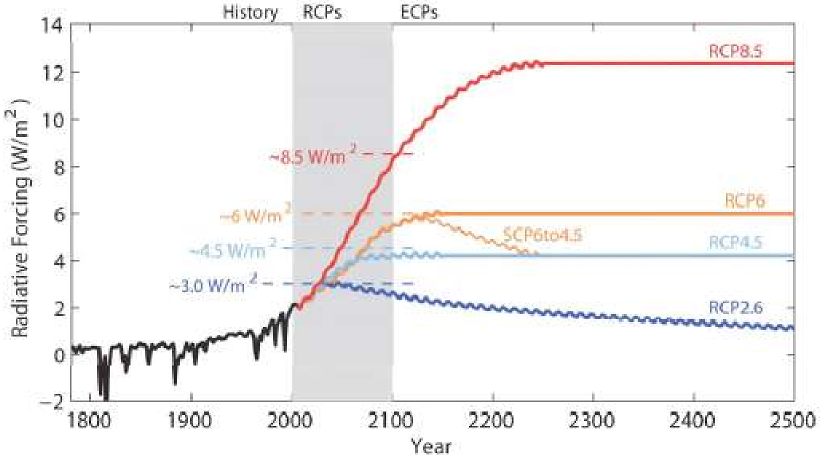
By year 3000, 60%

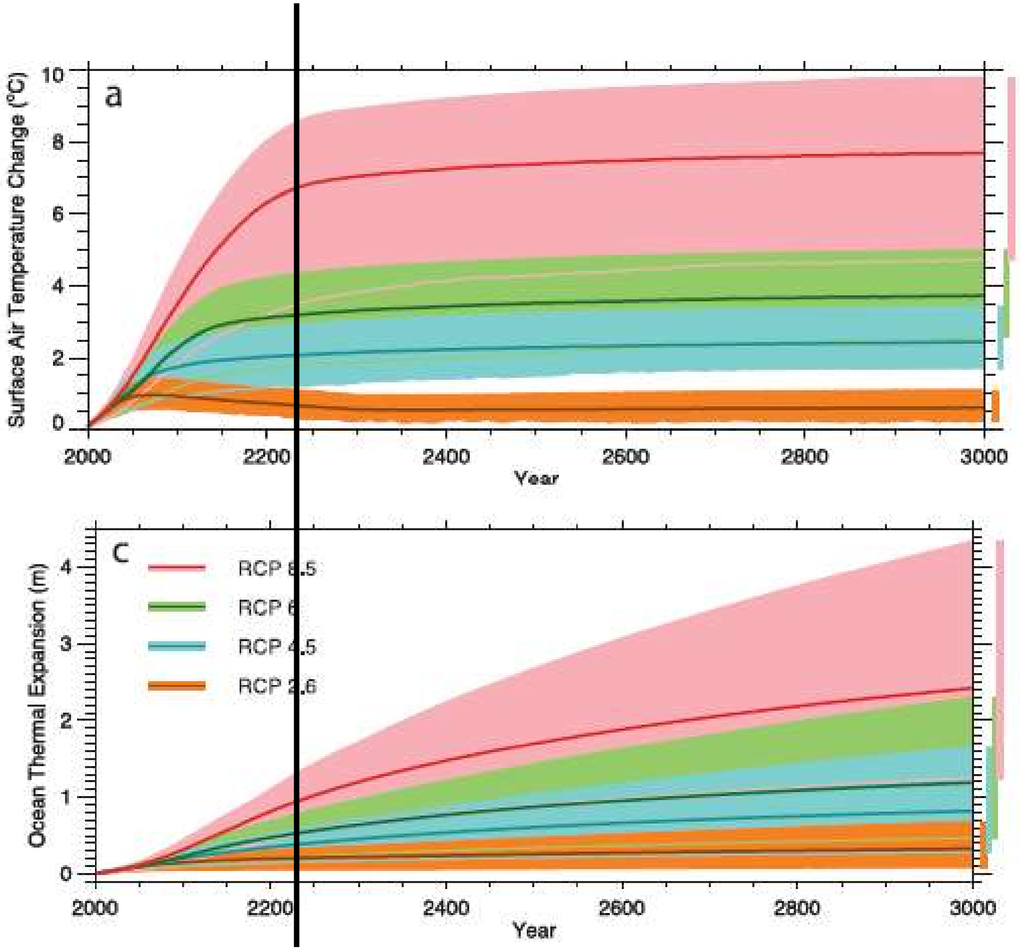


Greenland

Goelzer et al, 2012

Ocean contribution by 3000





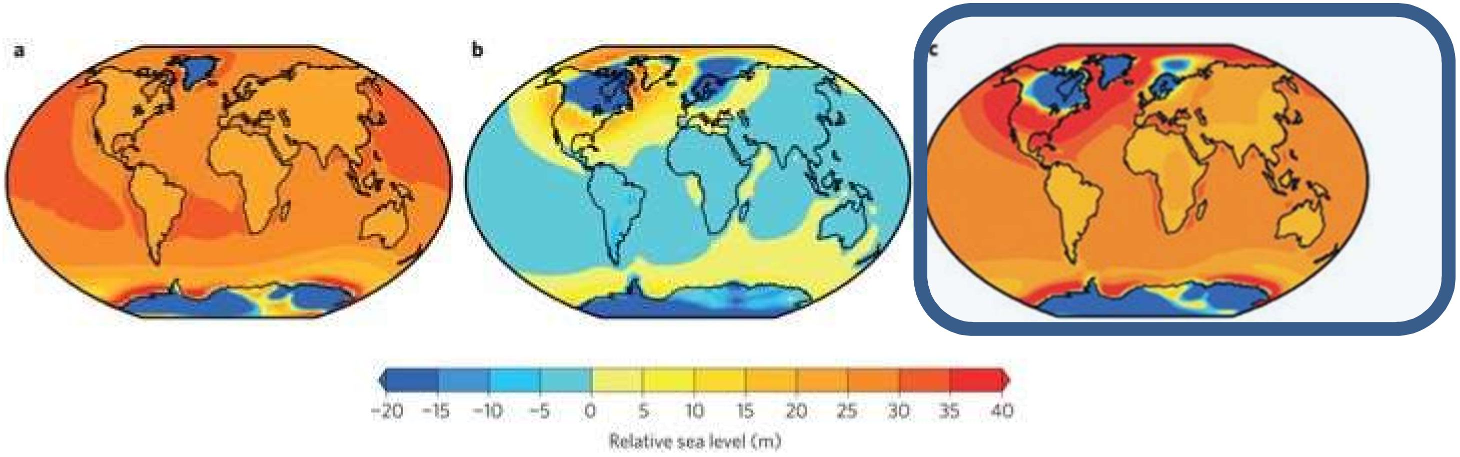
Zickfeld et al, 2013

Sea level rise after 10 000 yrs

Greenland and Antarctic ice sheets

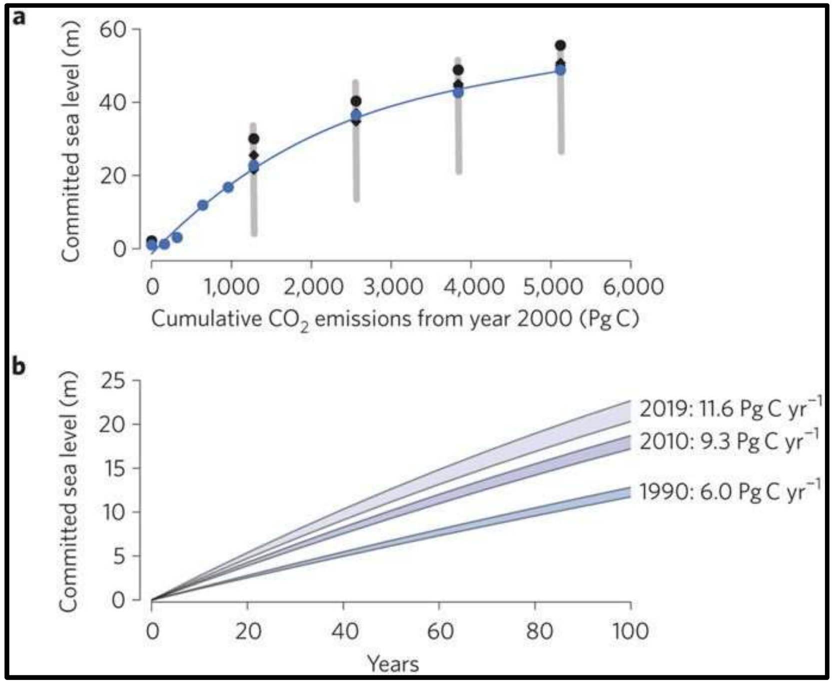
Deformation of Earth

a+b



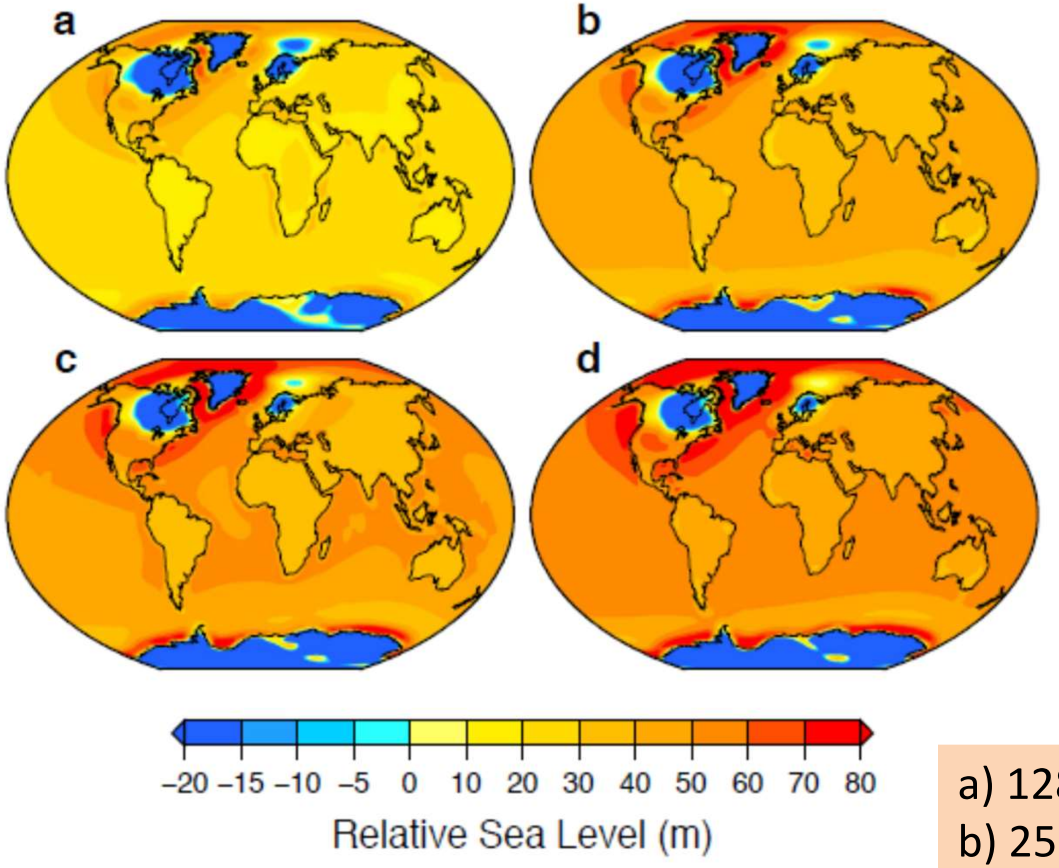
Clark et al. 2016

Relation between future cumulative emissions and committed sea-level rise



Clark et al. 2016

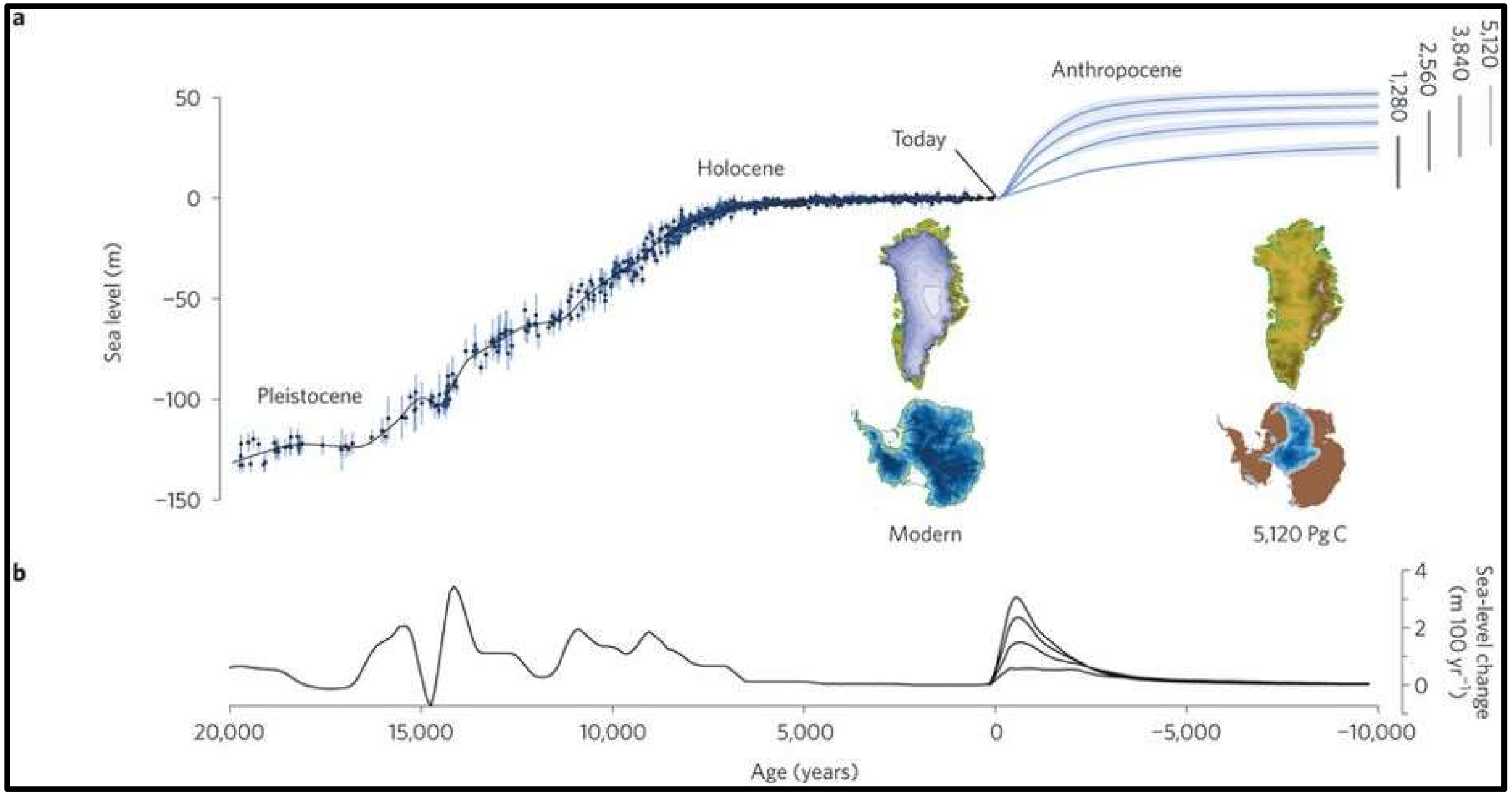
Sea level rise after 10 000 yrs



a) 1280 PgC,
b) 2560 PgC,
c) 3840 PgC,
d) 5120 PgC

Clark et al. 2016

Past and future changes in global mean sea level



a, Long-term global mean sea-level change for the past 20,000 years (black line) based on palaeo sea level records and projections for the next 10,000 years for four emission scenarios (1,280, 2,560, 3,840, and 5,120 Pg C).
b, The rates of change in global mean sea level (using a 500-year smoothing window)

Clark et al., 2016

Conclusion (Paris agreement)

- With warming of 1.5 and 2 ºC global sea level rise is projected up to up to 52 cm [25-87 cm, 5th – 95th percentile] and up to 63 cm [27-112 cm, 5th – 95th percentile]
- Coastal sea level rise generally exceeds the global average, with exceptions of coastline in the areas close to Greenland and Antarctic ice sheets
- The largest differences between 1.5 ºC and 2 ºC scenarios along coastlines are ~15 cm for median projections (up to 20 cm at 95th percentile) and occur for the USA east coast and the small-island nations in the Pacific and Indian oceans
- By 2100 the difference between RCP8.5 and 1.5 ºC scenario for global sea level is 39 cm (median), with large areas along the coastline of South and South East Asia, US east coast, Africa and Australia reaching 50 cm
- This difference between scenarios for projected sea level rise leaps up in 2100 at the 95th percentile where it is 117 cm globally and up to 155 cm for small islands in the Western Pacific and 147 cm in the Indian Ocean

Conclusion (beyond 2100)

1. It is virtually certain that global mean sea level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions.

2. Due to long response time of climate system the most rise is expected after stabilization of forcing

3. 200-400 years will require dropping the rate of sea level rise to the 1.8 mm/yr- the 20th century average

4. This long-term perspective of sea level rise (1000- 10 000yrs) illustrates that policy decisions made in the next few years to decades will have profound impacts on global climate, ecosystems and human societies — not just for this century, but for the next ten millennia and beyond

5. Global sea level would respond with considerable delay to geoengineering options due to the huge inertia of the climate system.