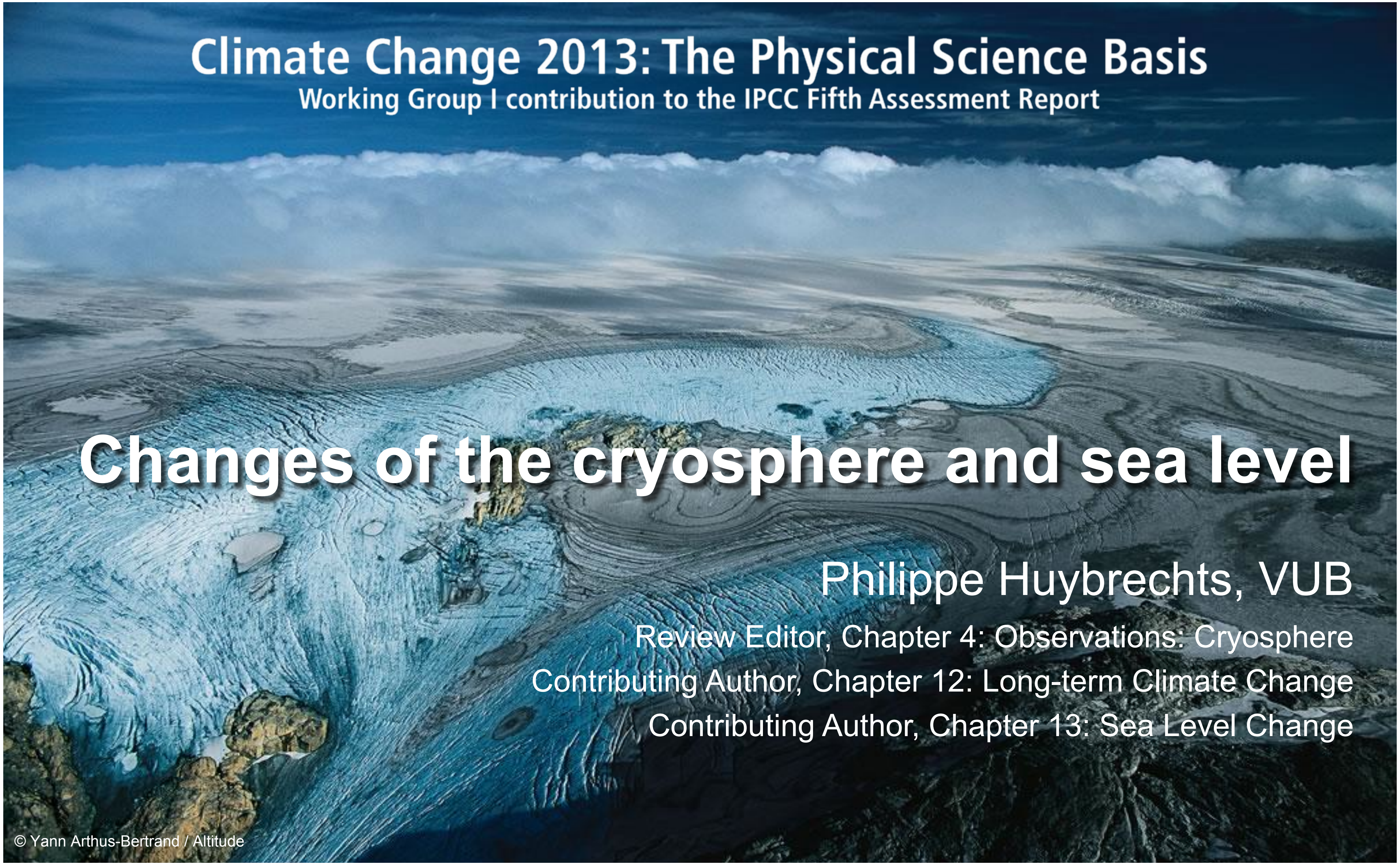

Climate Change 2013: The Physical Science Basis

Working Group I contribution to the IPCC Fifth Assessment Report

Changes of the cryosphere and sea level

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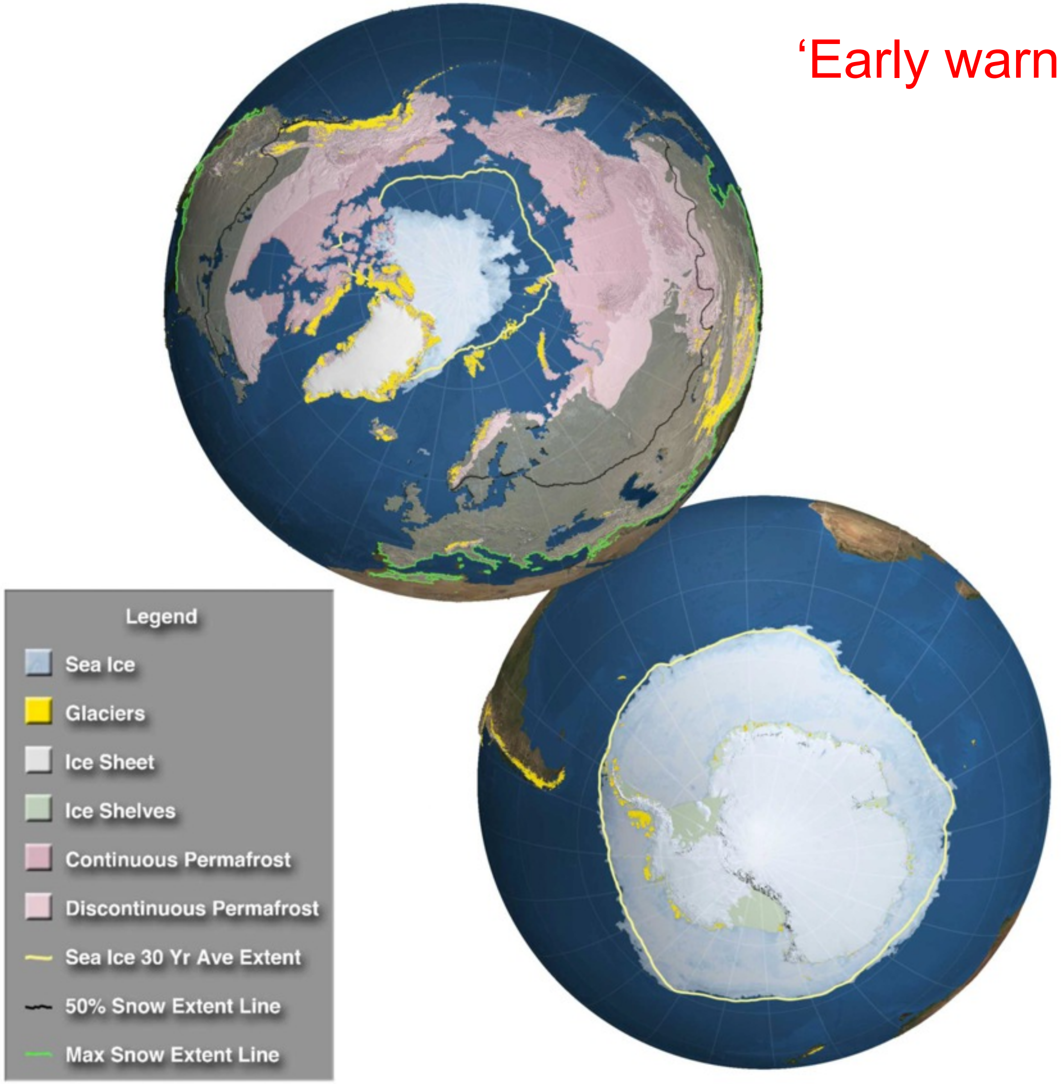
Review Editor, Chapter 4: Observations: Cryosphere

Contributing Author, Chapter 12: Long-term Climate Change

Contributing Author, Chapter 13: Sea Level Change

Components of the cryosphere

'Part of the Earth's surface which contains frozen water'



Sea ice extent of 13 September 2012

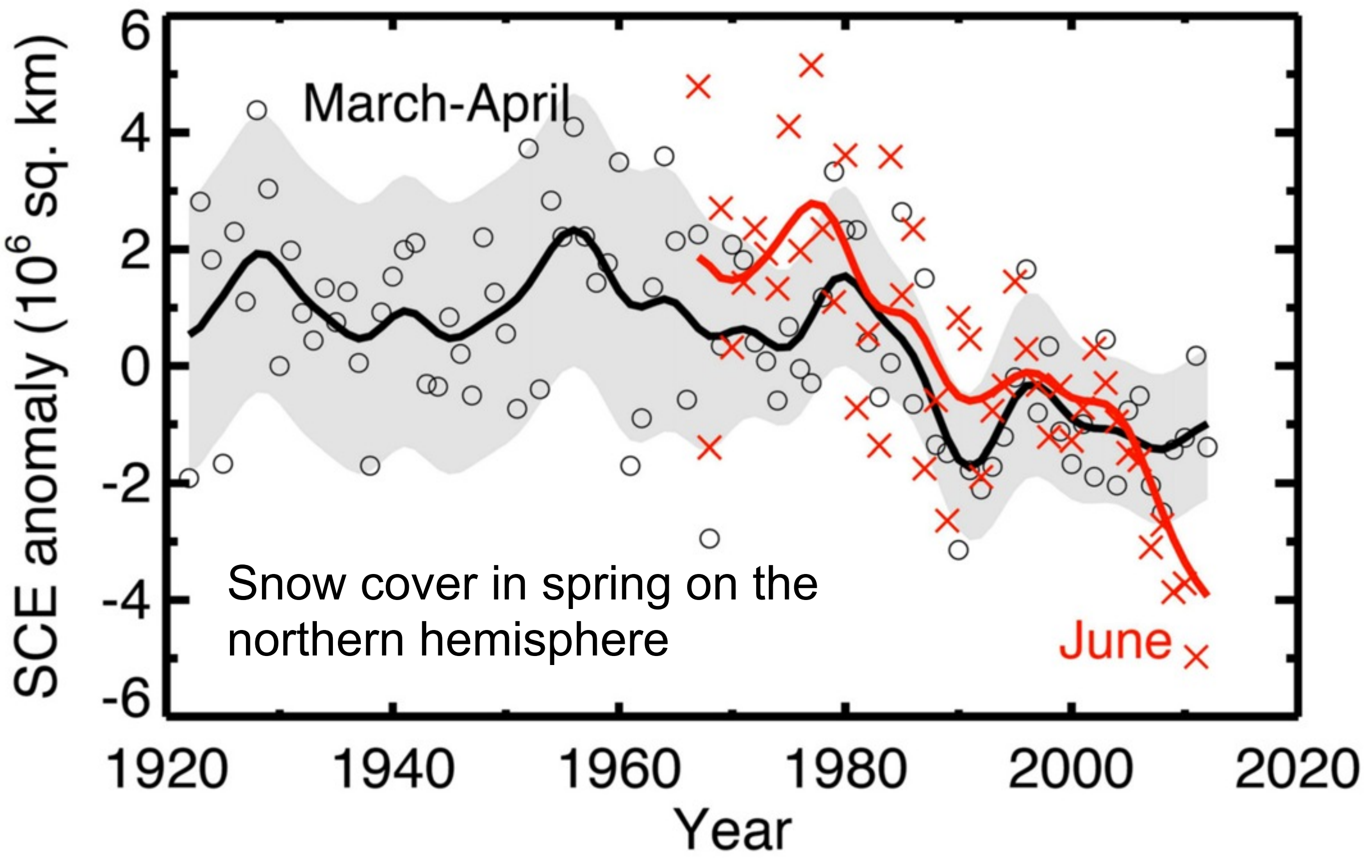
'Early warning system'

The cryosphere is mostly located in remote places but its changes have global consequences:

- Changes in sea ice and snow cover affect the global radiation balance and affect weather and climate elsewhere, including in Europe

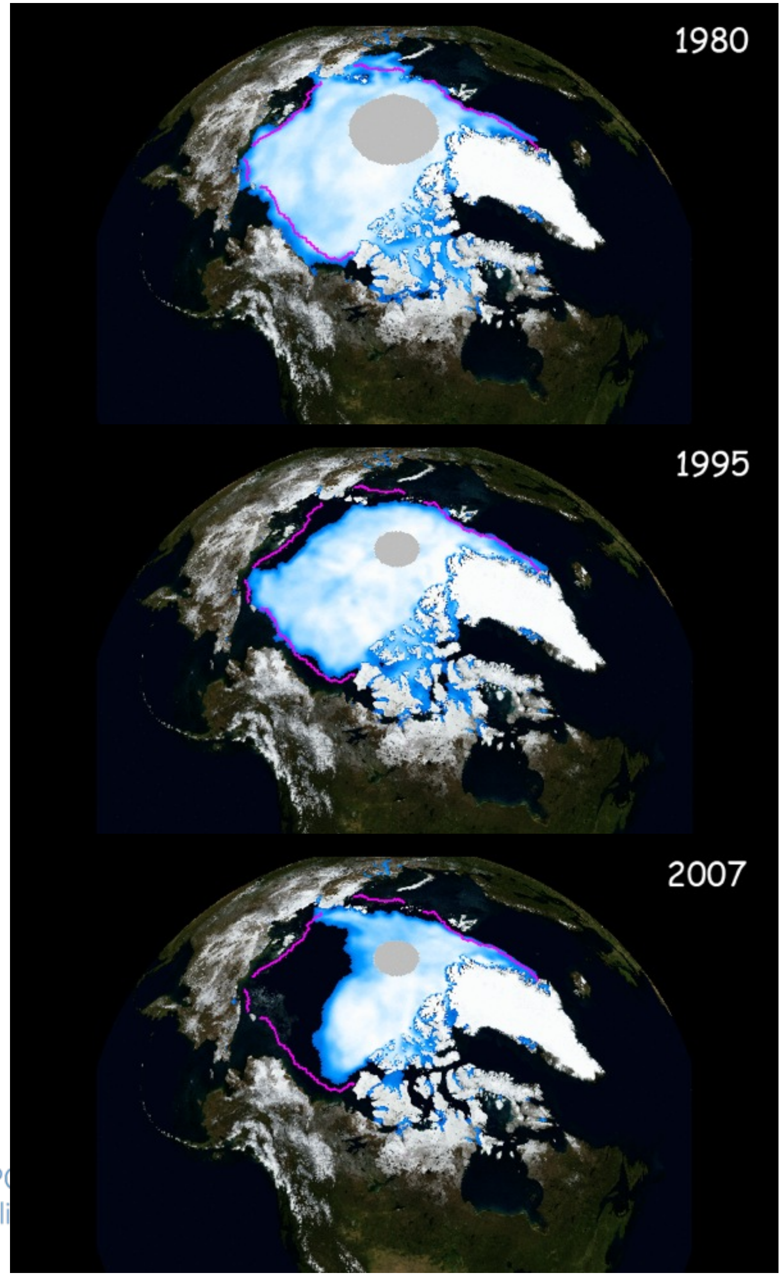
- Melting of ice sheets and glaciers raises global sea level

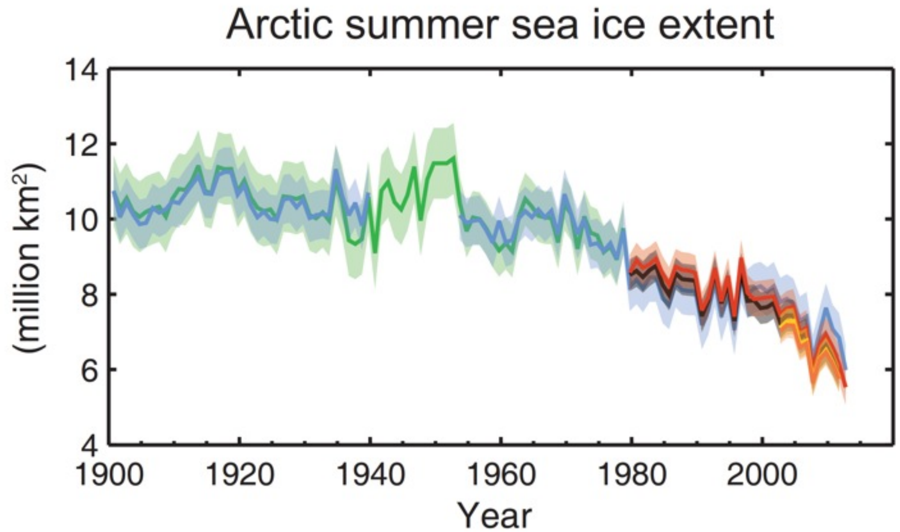
Decrease of seasonal snow cover



Northern Hemisphere snow cover extent decreased 1.6 % per decade for March and April, and 11.7 % per decade for June, over the 1967 to 2012 period

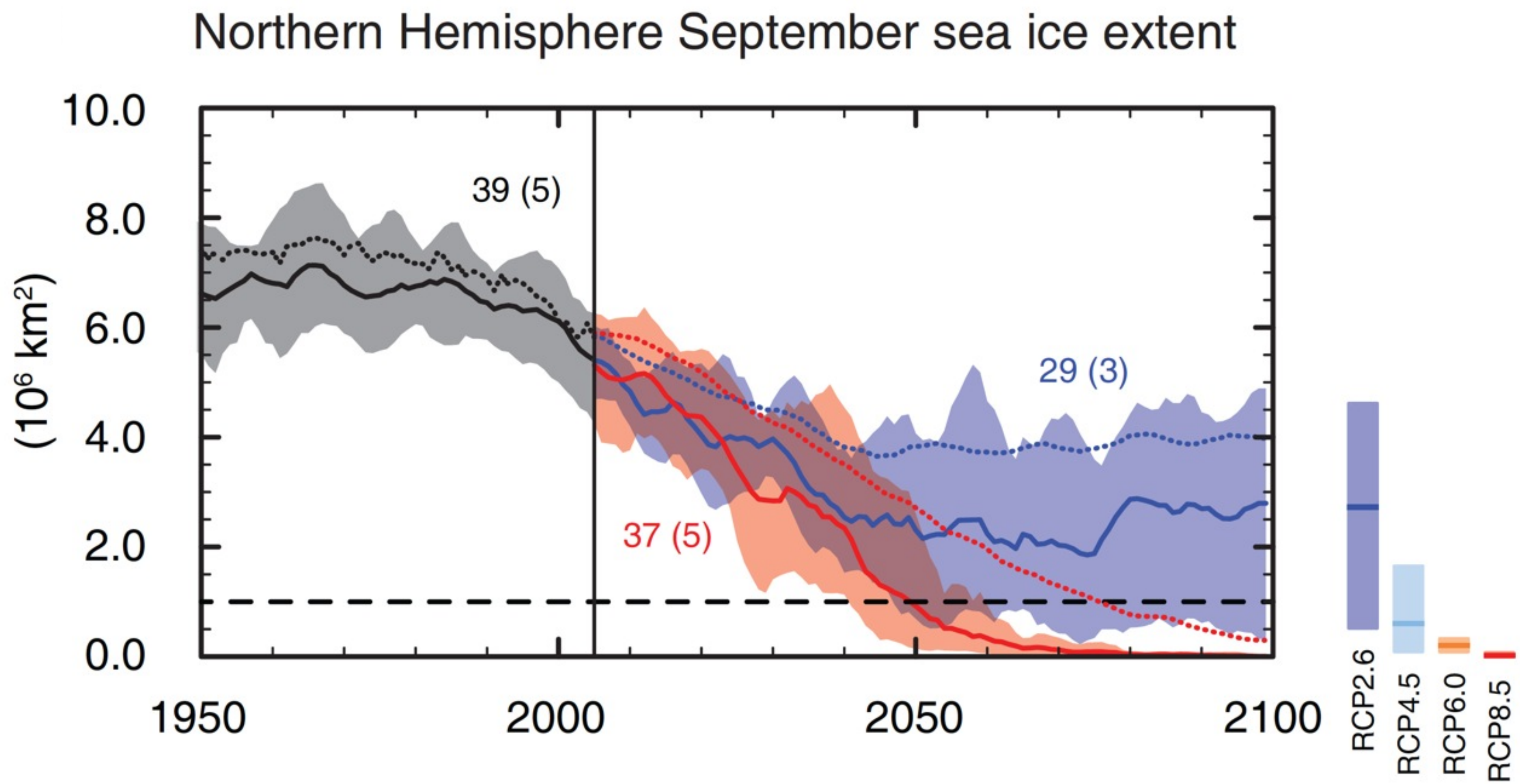
Decline of Arctic sea ice





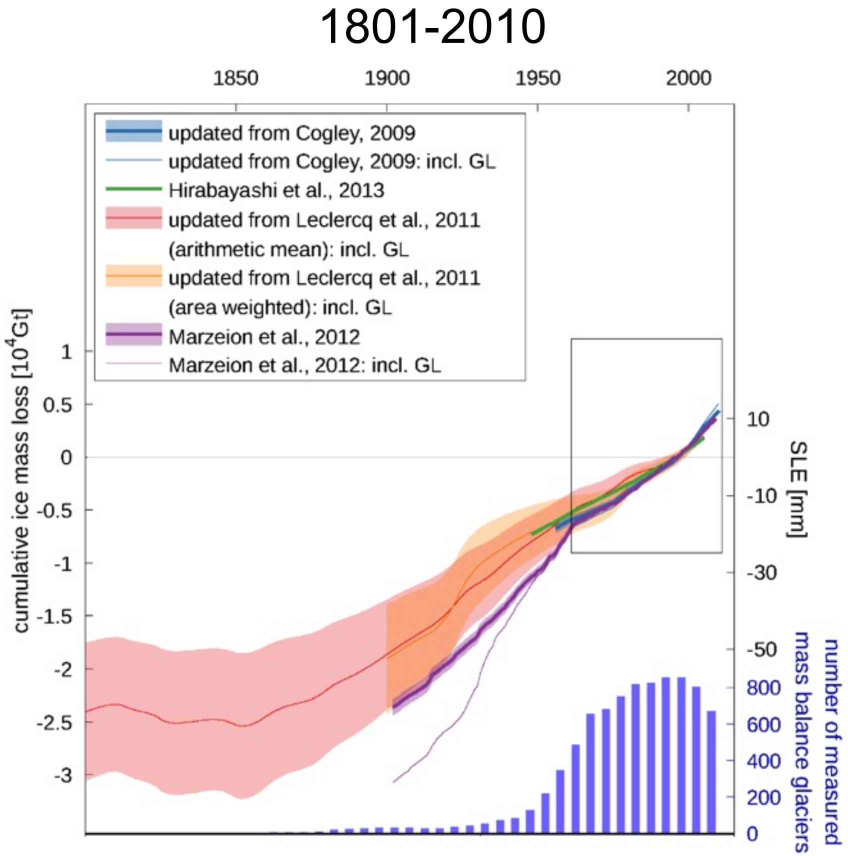
Summer minimum extent decreased by 9.4-13.6% per decade in 1979-2012

Projections of Arctic sea ice



A nearly ice-free Arctic Ocean is *likely* in September before mid-century for the highest RCP8.5 scenario in those models that most closely reproduce the observed trend 1979-2012

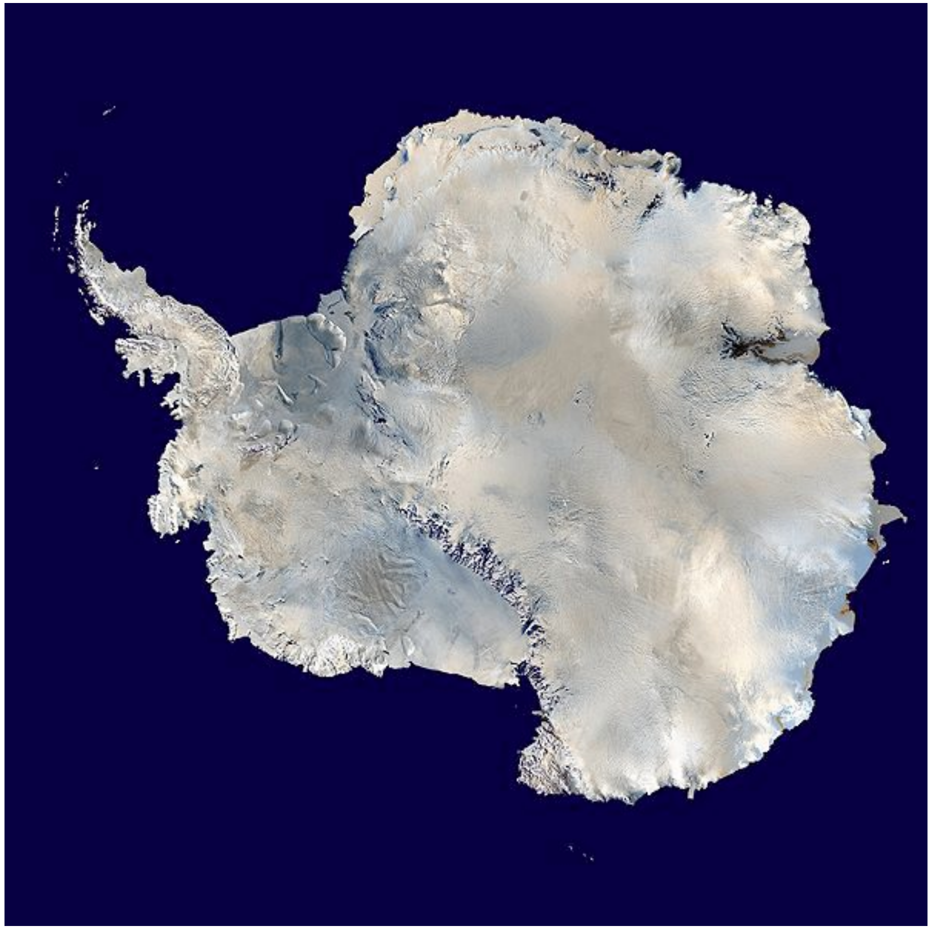
Worldwide retreat of glaciers since the end of 19th century



- 1900-2000: 5.4 ± 1.8 cm of sea-level rise
- Rate of glacier shrinkage has increased since ~1990 to 0.8 mm yr^{-1}
- 27 cm sea-level equivalent remaining

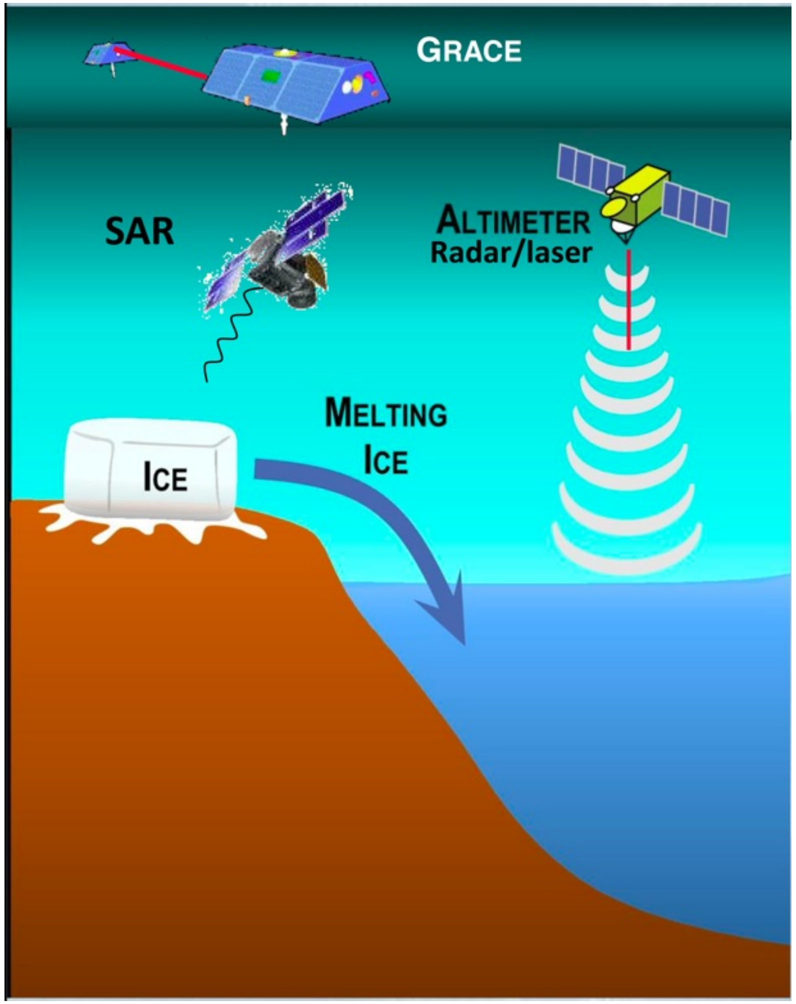
The polar ice sheets have the largest potential for sea-level rise

Greenland ice sheet
Sea-level equivalent: 7.4 m



Antarctic ice sheet
Sea-level equivalent: 57 m

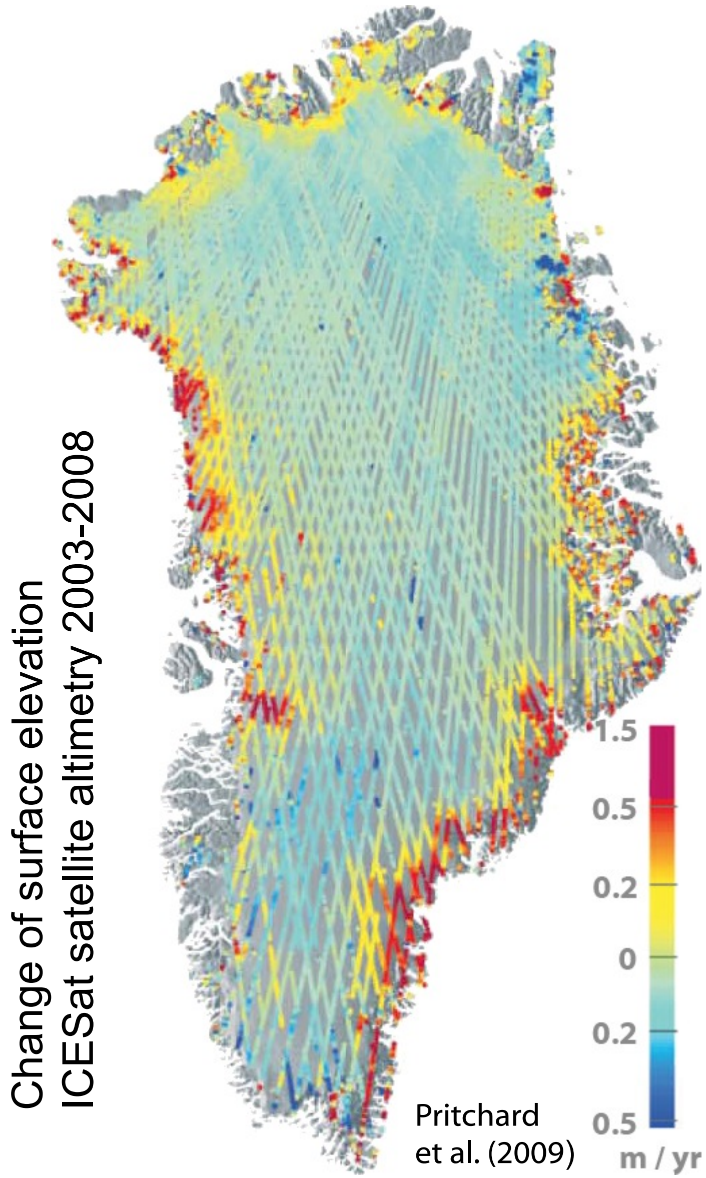
Ice-sheet mass balance: major advances from remote sensing platforms over the last decade

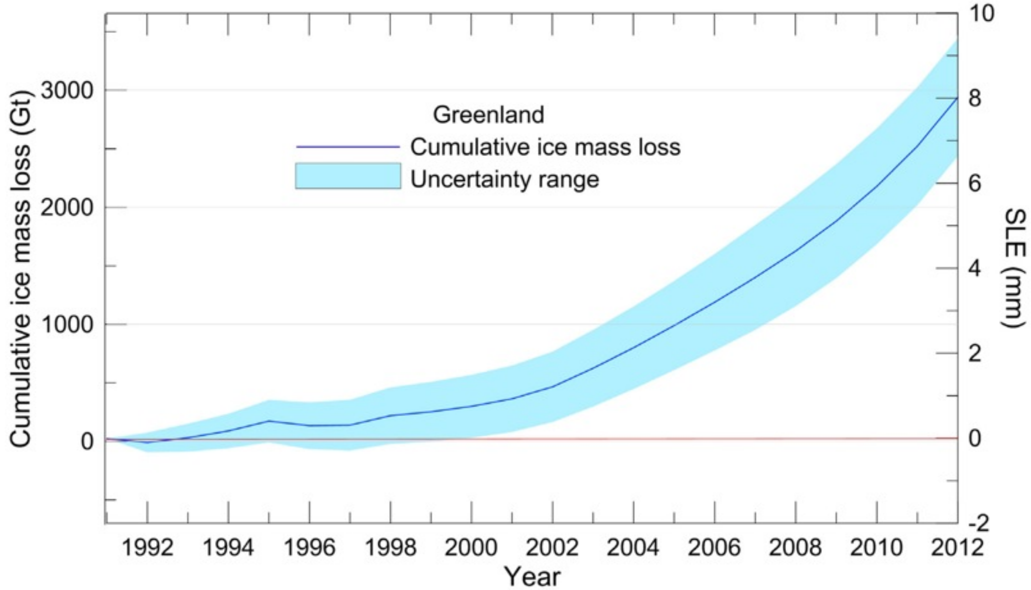


Methods to measure ice-sheet mass balance:

- Repeated laser/ radar altimetry
  - *Measures surface elevation from airplanes or satellites*
- Temporal changes in Earth gravity
  - *Measures mass changes directly from satellites*
- Mass budget method
  - *Comparison of outflow velocities with mass input from climate modeling*

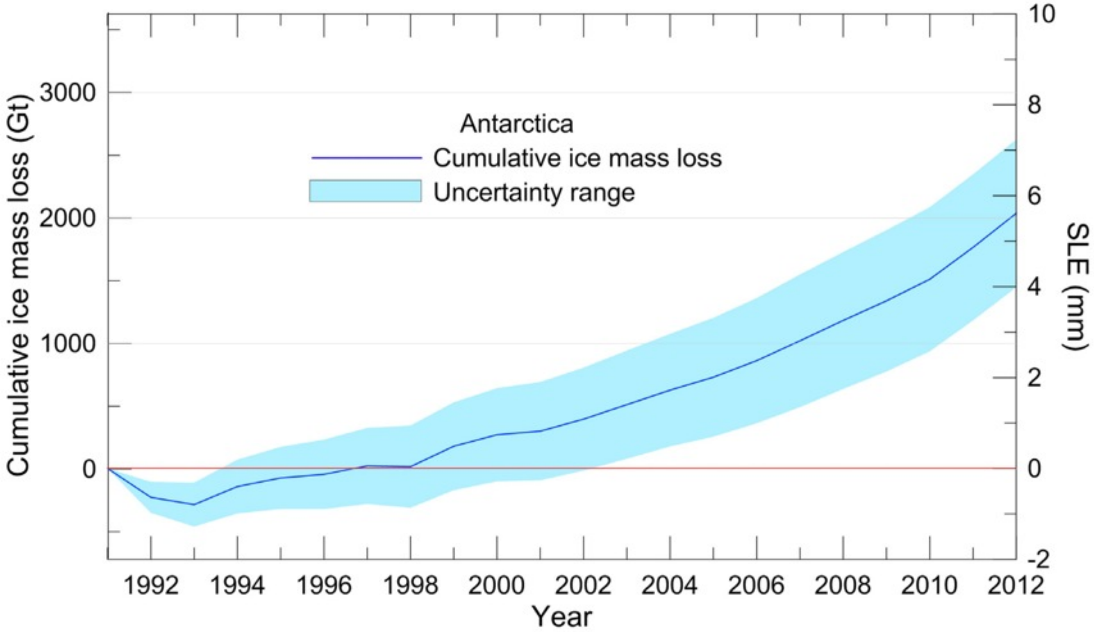
Evolution of the Greenland ice sheet: 1990 to 2012



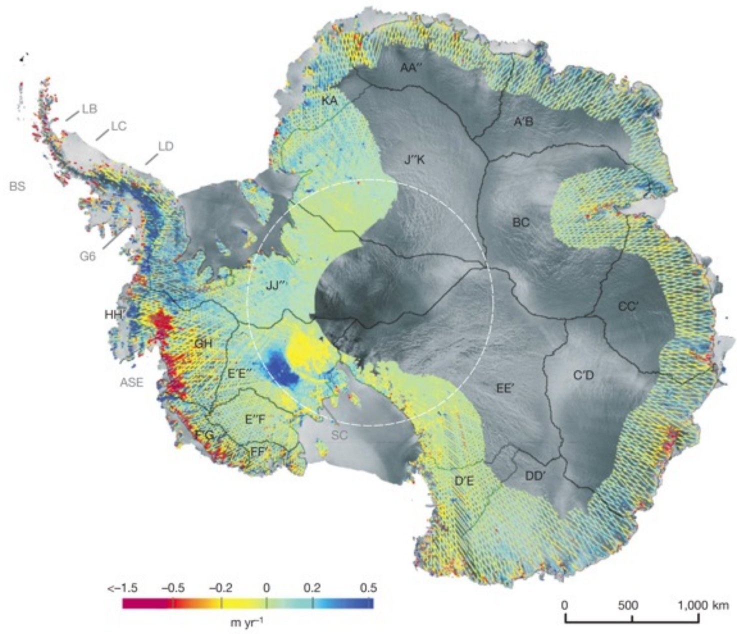


- Significant volume decrease over last 20 years linked to global warming *(very high confidence)*
- Rate of mass loss has increased since ~2000
- Mass loss equally split between increased runoff and increased discharge
- 2002-2011 rate: +0.6 mm yr^{-1} s.l.e.

Evolution of the Antarctic ice sheet: 1992-2012

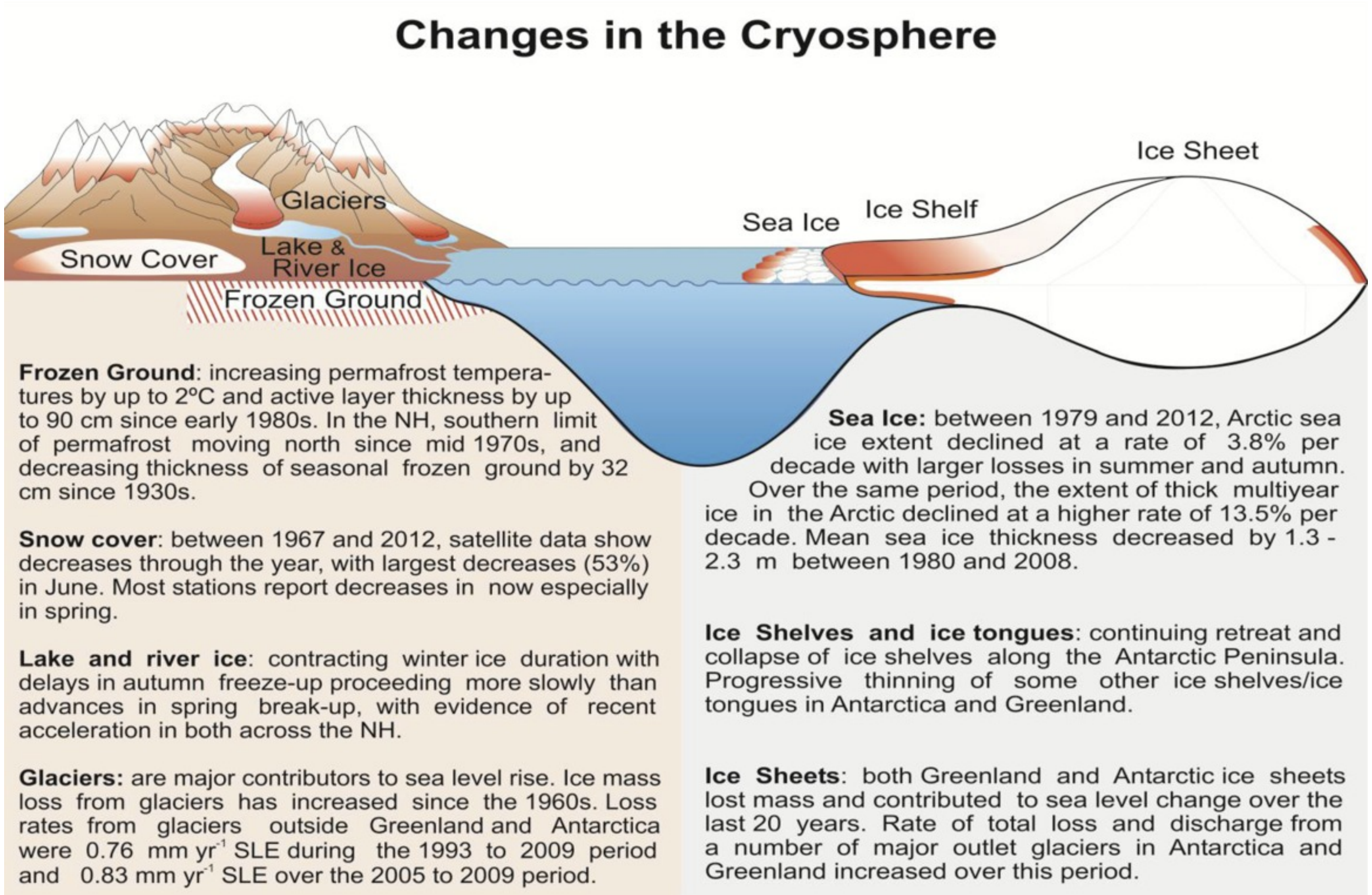


ICESat laser altimetry 2003-2007



Pritchard et al. (2009)

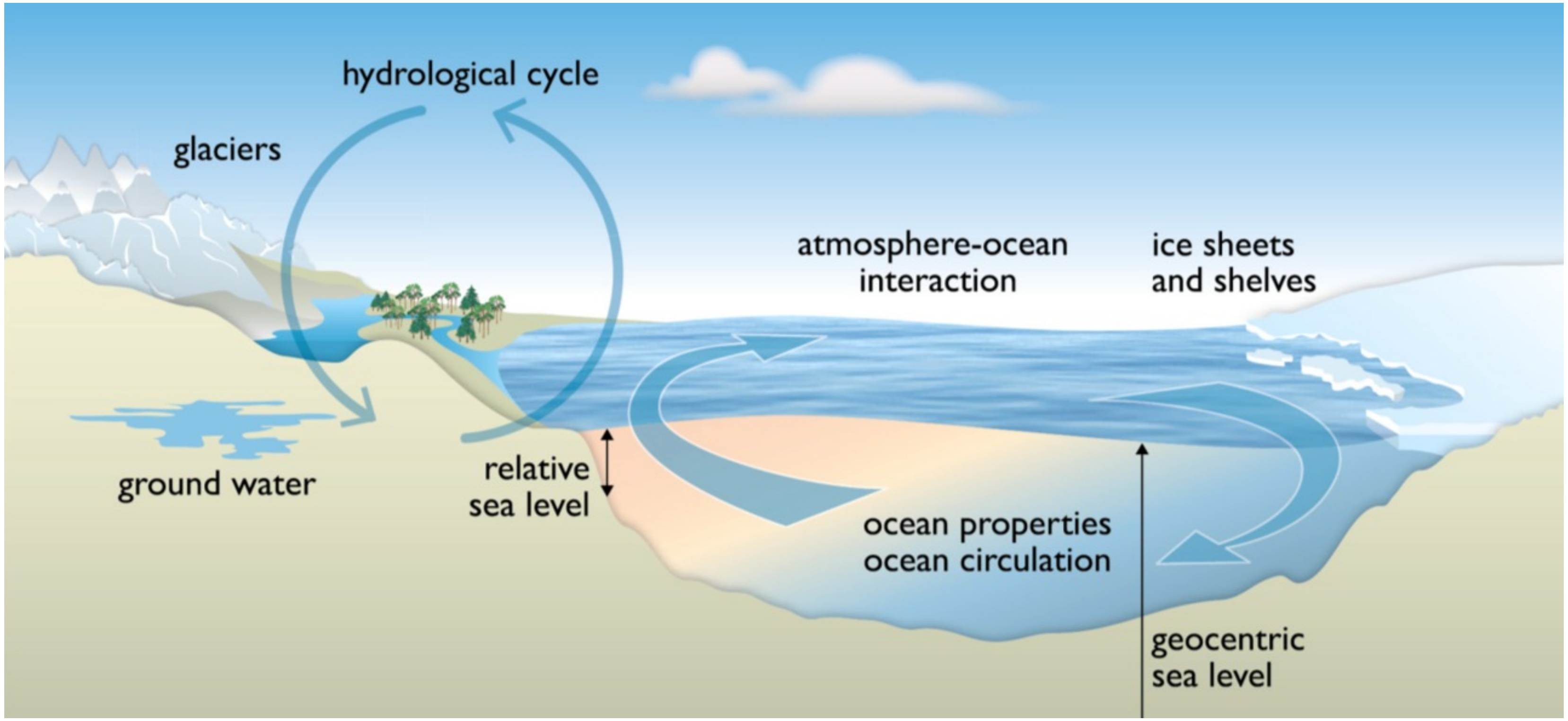
- Ice sheet loss *likely* increased from 1992-2001 to 2002-2011
- 2002-2011 rate: +0.4 mm yr^{-1} s.l.e.
- Mass loss mainly from increased discharge from the West Antarctic ice sheet *(high confidence)*



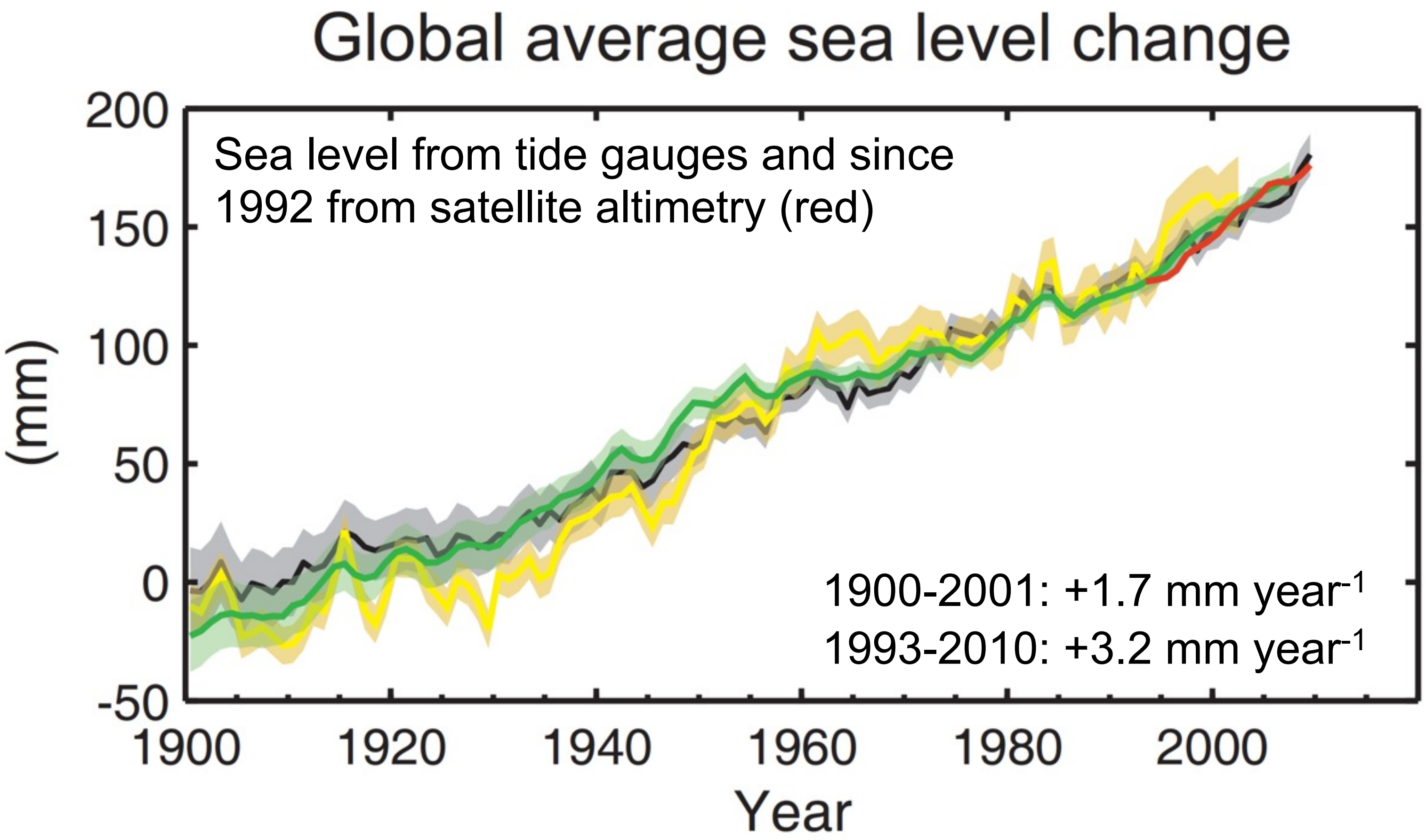
The observed changes of the Earth's cryosphere (with the exception of Antarctica) are consistent with a warming world. They therefore bear a significant influence from anthropogenic forcing.

Causes of mean global sea level rise

Warming the ocean (thermal expansion)
Loss of ice from glaciers and ice sheets
Reduction of liquid water storage on land



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



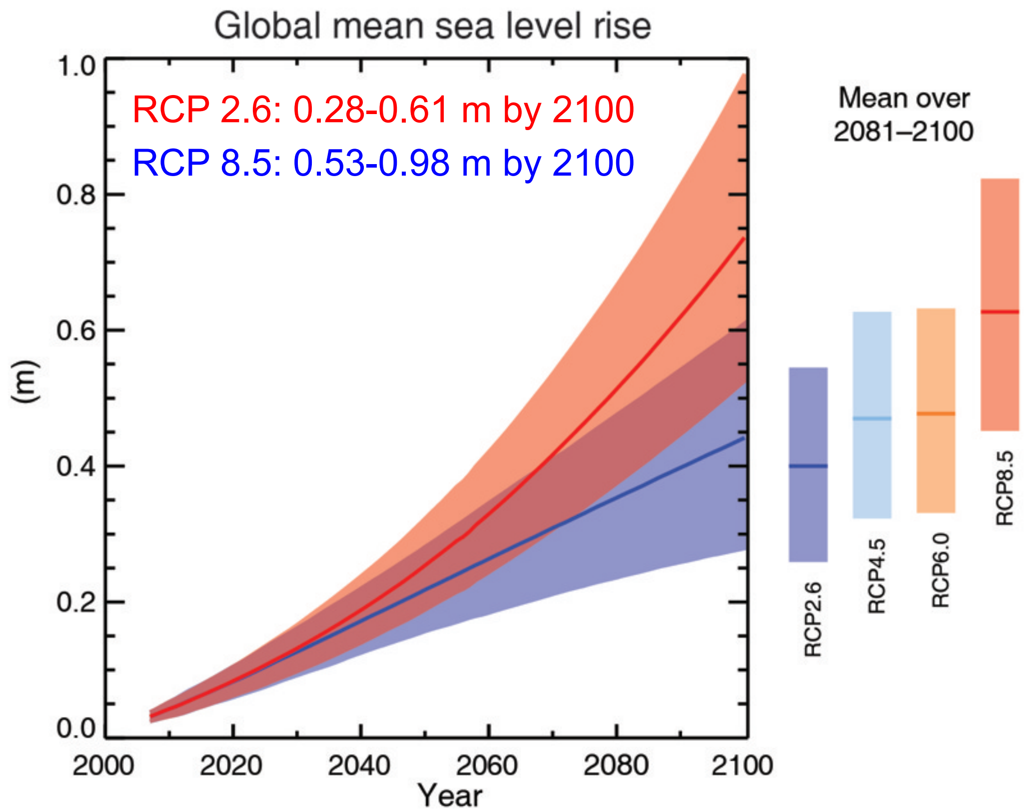
Contributions to sea level rise for the period 1993-2010

Ocean warming: ***38%***
Land water storage: 14%

Changes in glaciers: 28%
Greenland ice sheet: 10%
Antarctic ice sheet: 10%

AR5 projections of global mean sea level rise

Process-based models



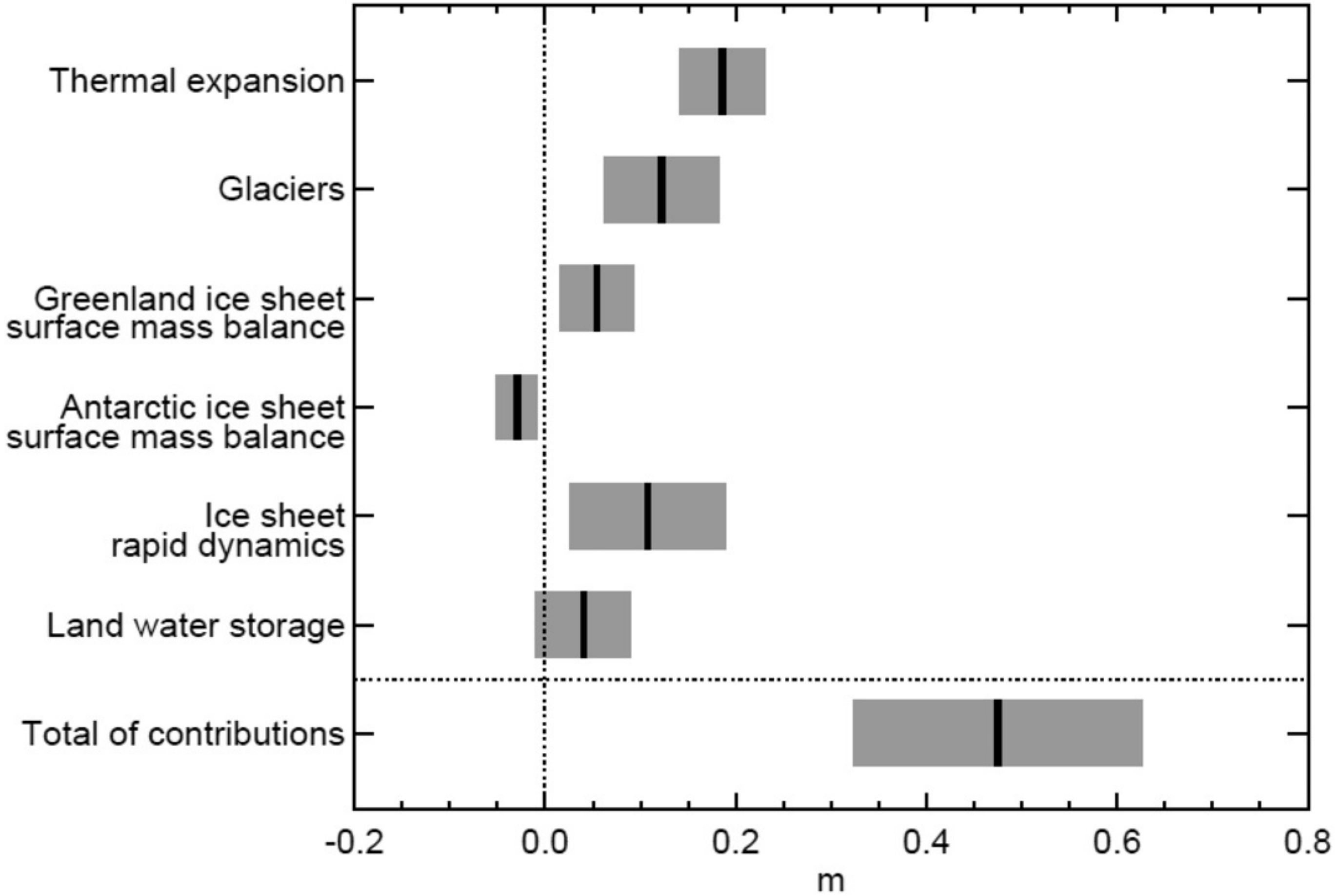
Likely range for 2081-2100 relative to 1986-2005 for all RCPs

0.26-0.82 m

These projections are higher than AR4 because rapid ice sheet dynamical changes are now included in the main projections (0.03 – 0.20 m)

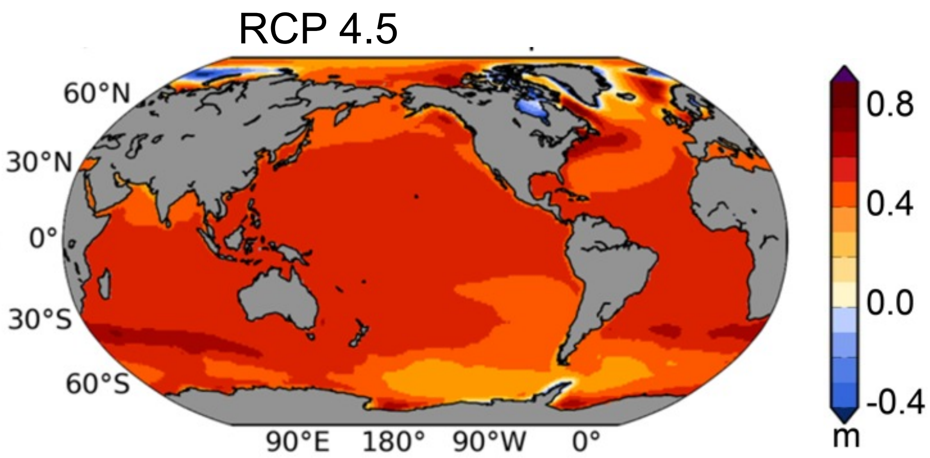
AR4: -0.01 – 0.17 m from rapid ice dynamics, but considered separately

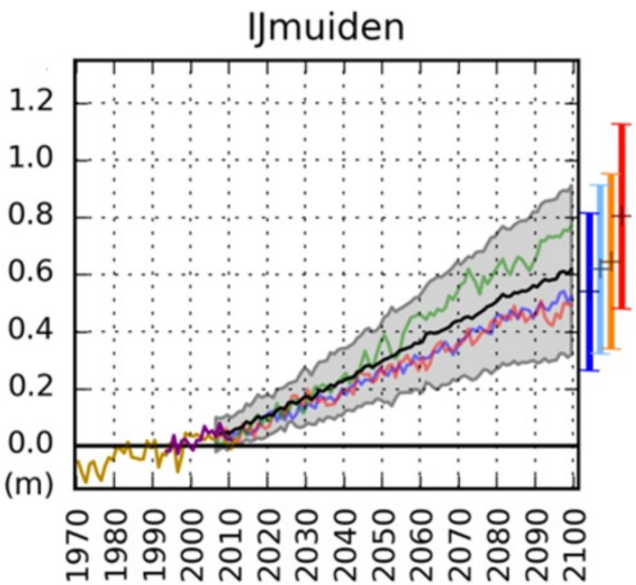
Projection for 2081-2100 under RCP4.5



For any given scenario, the largest contributor is thermal expansion, followed by glaciers, the Greenland ice sheet and the Antarctic ice sheet

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



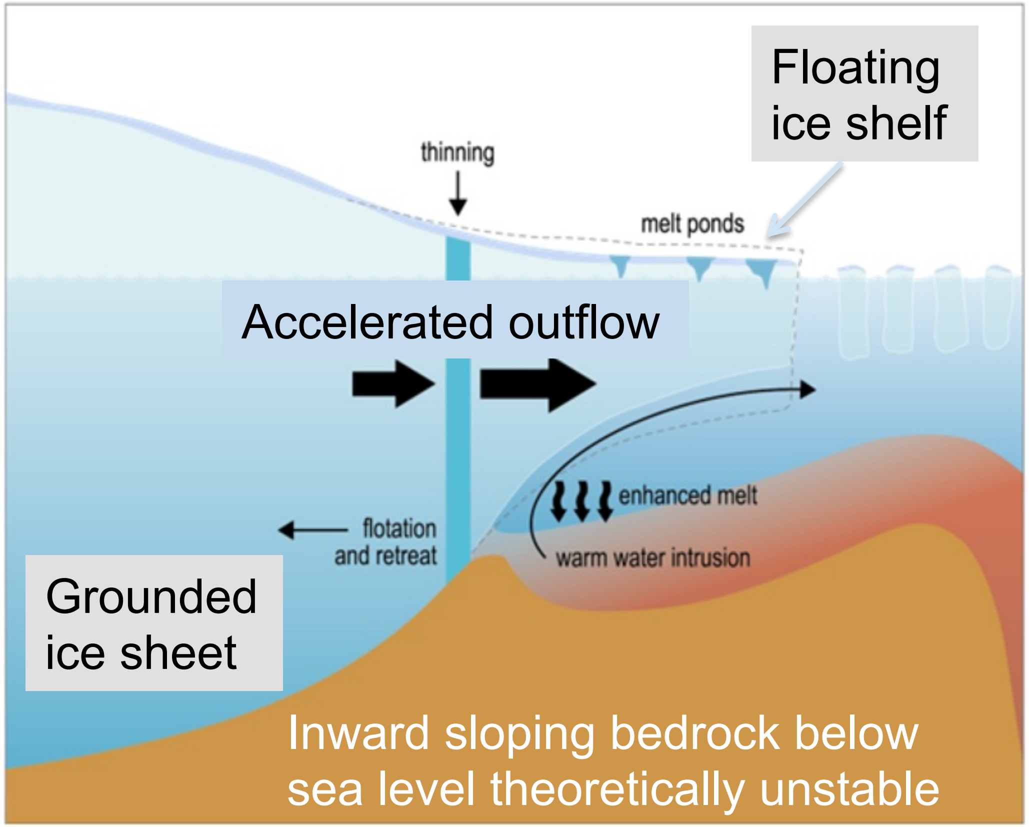


It is *very likely* that sea level will rise in more than 95% of the ocean area

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

For the southern North Sea (Ijmuiden) the upper end of the likely range of sea-level rise is ~15 cm higher than the global mean

Rapid increase in ice sheet outflow



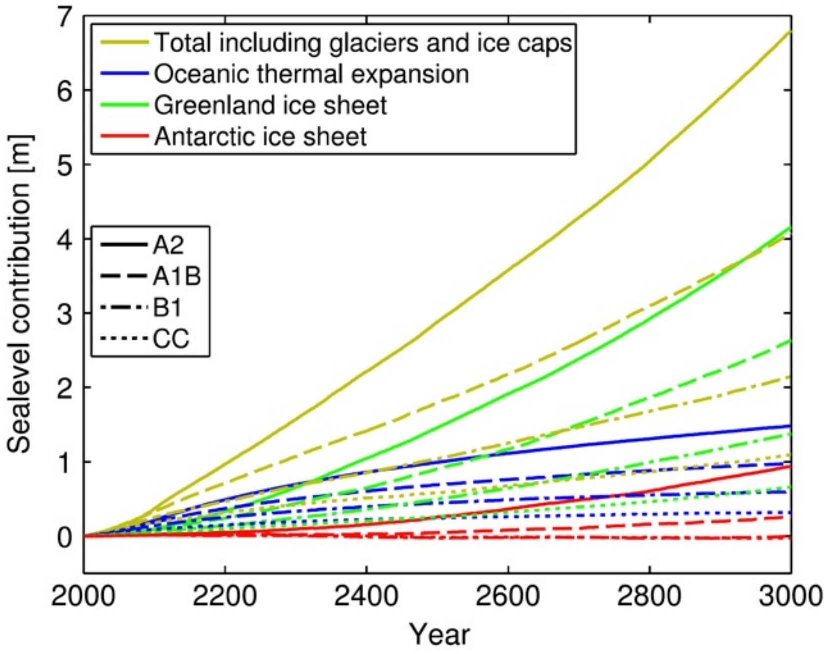
Only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea to rise substantially above the *likely* range during the 21st century

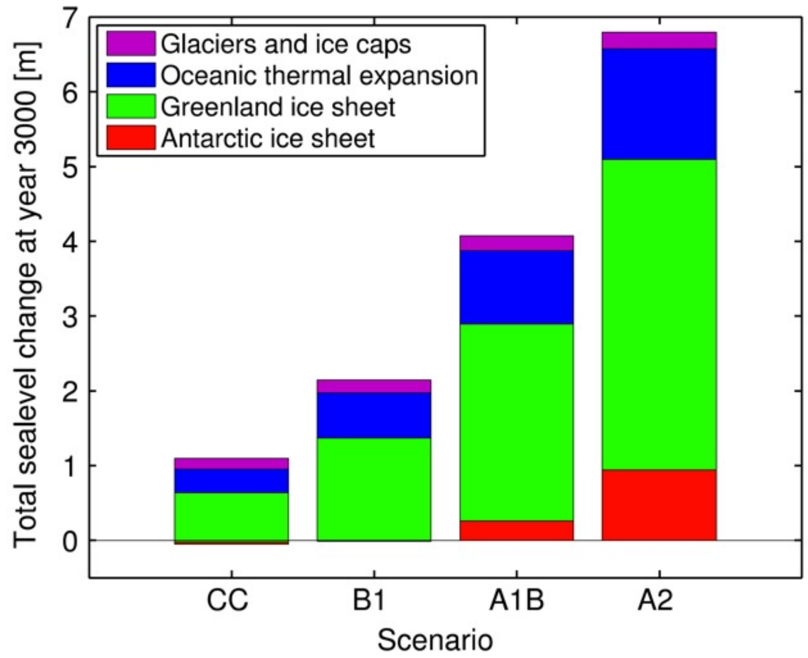
Medium confidence that this additional contribution would not exceed several tenths of a meter

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

Commitment to sea level rise and irreversibility

Due to the long time scales of the climate system, it is *virtually certain* that sea level rise will continue for many centuries beyond 2100 from both thermal expansion and land ice melt

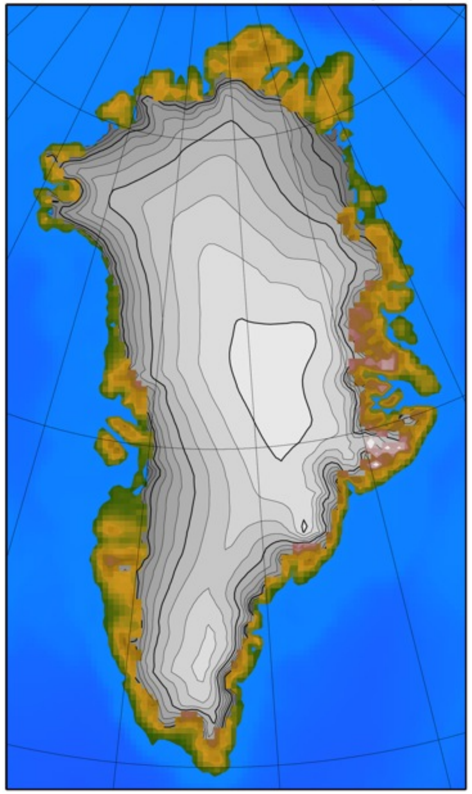




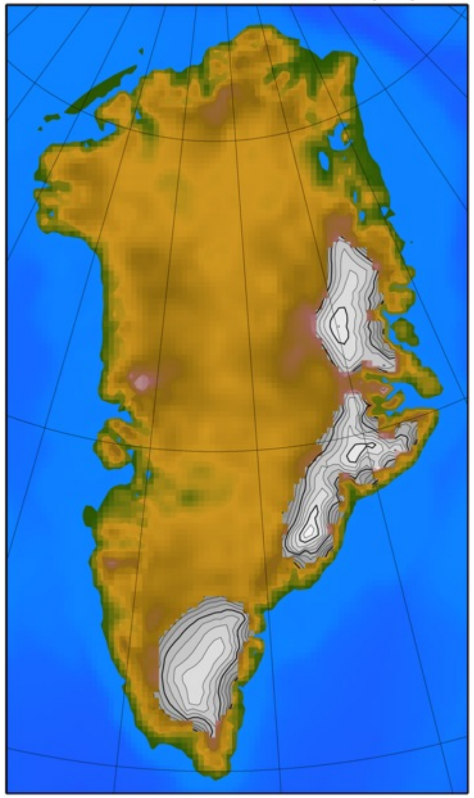
Calculations with ***LOVECLIM*** (Goelzer et al., 2012)

Year 2000 concentrations (CC): 1 m of committed sea level rise by year 3000
Constant forcing after 2100 A.D.: 2 – 7 m of committed sea level rise by year 3000

Vulnerability of the Greenland ice sheet



Current ice sheet



4 x CO_2 climate
After 2000 years

The Greenland ice sheet is a relict ice mass left over over from the Ice Ages that sustains itself because of its elevation

The ice sheet is close to a **threshold of sustainability** that is greater than 1°C global warming *(low confidence)* but less than 4°C *(medium confidence)*

Sustained warming above this threshold would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global sea level rise of up to 7 m *(high confidence)*

Thank you for your attention

INTERGOVERNMENTAL PANEL ON climate change