Sea level in a changing climate: AR5 and recent scientific advances

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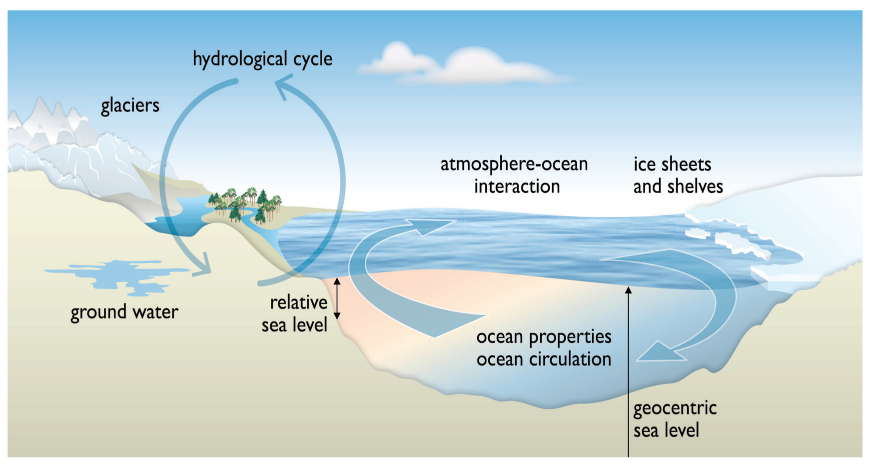
Introduction

- Change in sea level is a major concern for coastal managers and society at large, and occurs over a wide range of temporal and spatial scales – with many contributing factors making it an integral measure of climate change ;
- The IPCC 5th assessment report (AR5) stressed an increased confidence in projections of global mean sea level, owing to improved physical understanding of components of sea level, improved agreement of process-based models with observations, and the inclusion of ice-sheet dynamical changes ;
- The stability of marine sectors of the Antarctic ice sheet in a warming climate has been identified as the largest source of uncertainty in projections of future sea-level rise.

AR5 key findings

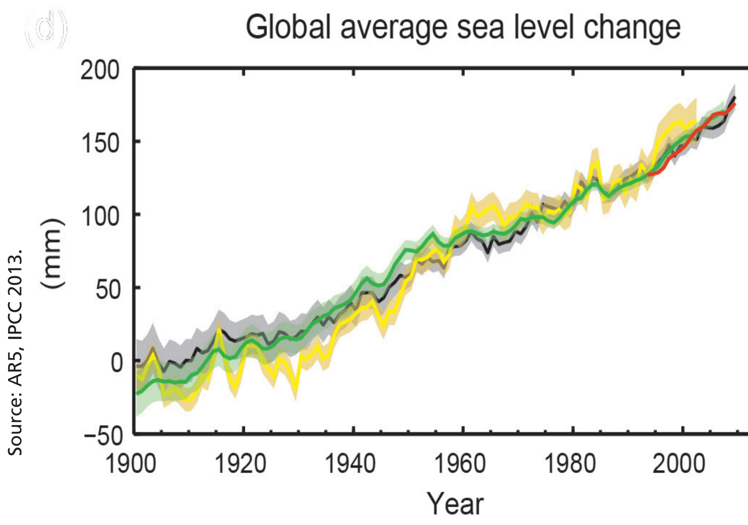
Drivers and relevance of sea level change

- Importance of sea level rise for coastal systems and low-lying areas: storm surge, coastal flooding, coastal erosion, salinization.



Source: AR5, IPCC 2013.

Observed global mean sea level (GMSL) change

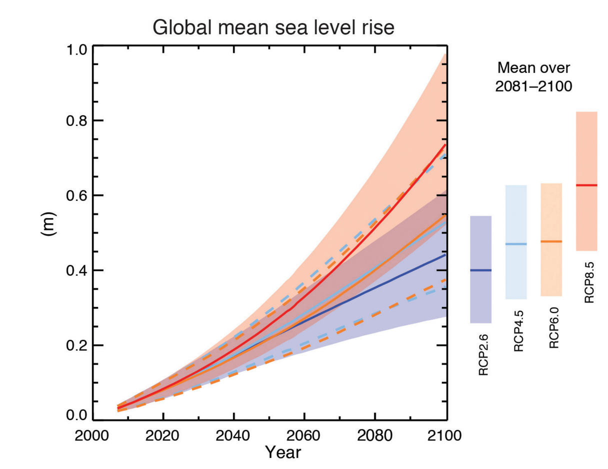


Source: AR5, IPCC 2013.

- The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia *(high confidence)*.
- Since the early 1970s, glacier mass loss and ocean thermal expansion from warming together explain about 75 % of the observed global mean sea level rise *(high confidence)* ;
- Over the period 1993 to 2010, GMSL rise is with *high confidence* consistent with the sum of the observed contributions from ocean thermal expansion, changes in glaciers, Greenland ice sheet, Antarctic ice sheet and land water storage.

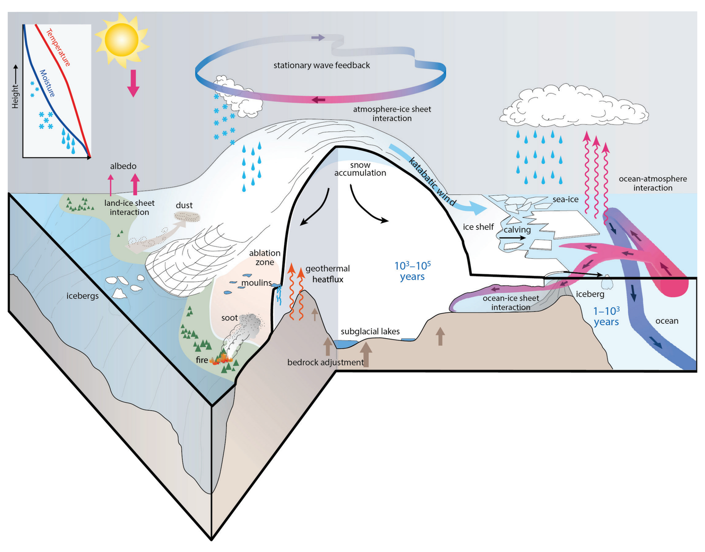
Projected future changes

- GMSL will continue to rise during the 21st century and beyond. Under all RCP scenarios, the rate of GMSL rise will *very likely* exceed that observed during 1971-2010, due to increased ocean warming and increased loss of mass from glaciers and ice sheets ;
- In projections, thermal expansion accounts for 30-55 % of 21st century GMSL rise and glaciers for 15-35 % ;
- Sea level rise will not be uniform. About 70% of the coastlines worldwide are projected to experience sea level change within 20 % of the GMSL change.



Source: AR5, IPCC 2013.

Role of ice sheets

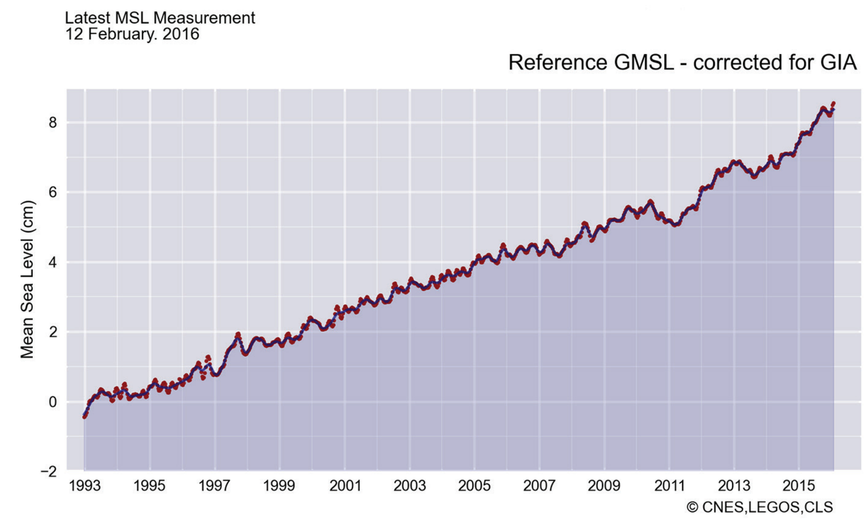

Source: AR5, IPCC 2013.

- Multiple interactions between ice sheets, solid earth and the climate system ;
- Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, is initiated, could cause GMSL to rise substantially above the likely range during the 21st century ;
- Changes in surface mass balance of the Greenland ice sheet will lead to a positive contribution *(high confidence)*. Increase in snowfall on the Antarctic ice sheet is expected *(medium confidence)*, resulting in a negative contribution. Changes in outflow from both ice sheets will likely make a contribution in the range of 0.03-0.20 m by 2080-2100 *(medium confidence) ;*
- *High confidence* that sustained warming greater than some threshold greater than about 1°C *(medium confidence)* but less than about 4°C *(medium confidence)* would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a GMSL rise of up to 7 m.

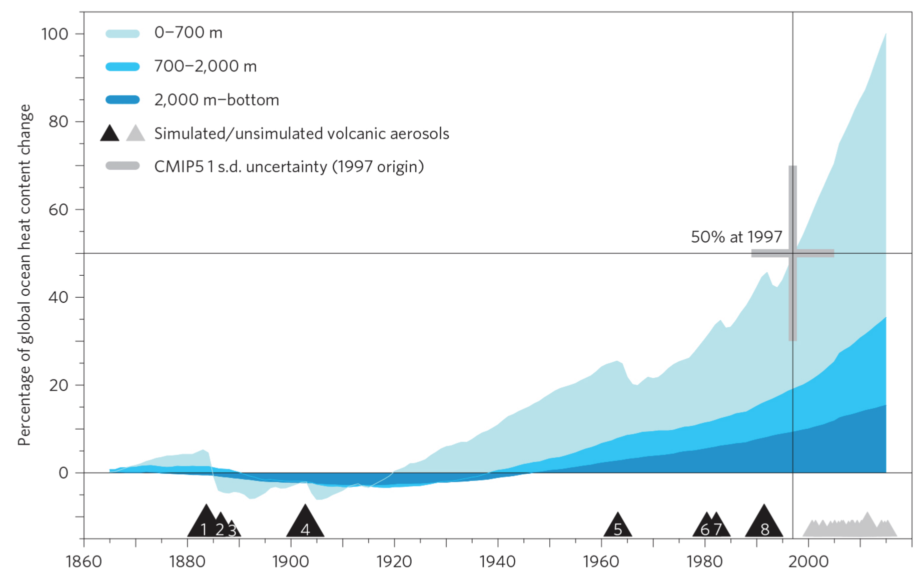
Emerging findings

Sea level rise

- Unabated global mean sea-level rise over the satellite altimeter era: improved bias drift estimates *(Watson et al, Nature Climate Change, 2015)* ;
- 20th century GMSL rise extremely likely faster than during any of the previous twenty-seven centuries *(Kopp et al, PNAS, 2016)* ;
- Since 1970, anthropogenic forcing is the dominant contribution (70 %) to GMSL rise (Dangendorf, Nat. Comm., 2015 ; Slagen et al., Nat. Clim. Change, 2016).



Ocean heat content



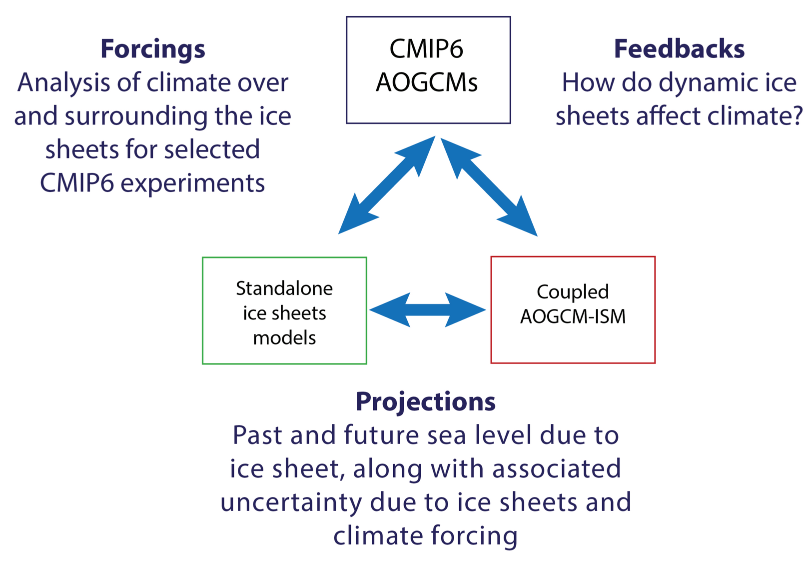
Source: Gleckler et al, Nature Clim. Change, 2016.

- Unabated planetary warming since 2006 at rate of 0.4-0.6 W/m² with most of the heat gain in the Southern hemisphere extratropical ocean *(Roemmich et al, Nature Climate Change, 2015, von Schuckmann et al, Nature Climate Change, 2016)*
- Half of total increase during the industrial era has occurred in recent decades, multi-model mean from historical simulation consistent with data *(Gleckler et al, Nature Clim. Change, 2016)*.

Future regional changes

- Time of emergence, when signal due to human influence emerges from natural variability, substantially earlier for regional sea level (2020 for 50 %of oceans) than for surface air temperature *(Lyu et al, Nature Climate Change, 2014)* ;
- Methodological developments to quantify observed and projected regional departure of regional sea level rise to GMSL *(e.g. Carson et al, Clim. Change, 2016, Adhikari et al, GMD, 2016)* ;
- New assessments of the role of salinity change in different ocean basins *(Durack et al, ERL, 2014)*.

Methodological developments



- Over Antarctic, better understanding of discrepancies between semi-empirical models and process-based projections until 2100 *(Mengel et al, PNAS, 2016)* ;
- New Greenland bed topography *(Morlighen et al., Nat. Geosc., 2014)* and new understanding of Greenland ice sheet hydrology *(Foster et al., Nat. Geosc., 2014 ; Lindback et al., GRL, 2015)* ;
- New understanding of dynamical thinning of NE Greenland *(DeConto and Pollard, Nature, 2016)* and Antarctic glaciers: role of southern ocean warming and ice shelves *(Wouters et al., Science, 2015 ; Paulo et al., Science, 2015 ; Scmidtko et al., Science, 2014 ; Alley et al., Nat. Geosc., 2014 ; Trusel et al, Nat. Geosc., 2015 ; Alley et al., Ann. Rev. Earth Plan. Sci., 2015 ; Mengel et al., Nat. Clim. Change, 2016)* ;
- Improving projections of ice sheet contributions to sea-level is a key focus of the Ice Sheet Model Intercomparison Project (http://www.climate-cryosphere.org/activities/targeted/ismip6) (Figure).

Recent scientific advances since the AR5: Antarctic ice sheet

- Potential sea-level rise from Antarctic ice sheet instability constrained by present day observations *(Ritz et al, Nature, 2015)* ;
- Using paleoclimate data to assess the response to the Antarctic ice sheet to ocean warming and/or atmospheric CO_2 concentration *(Dutton et al., Science, 2015)* ;
- Assessing the multi-millennial commitment of the Antarctic ice sheet to future sea-level rise: substantial ice loss prevented only in RCP2.6 ; higher emissions lead to 0.6-3 m contribution to sea level rise by 2300 *(Golledge et al, Science, 2015)* ;
- Calibration of processes against paleoclimate sea level estimates: hydrofracturing of buttressed ice shelves and structural collapse of marine-terminated ice cliffs give Antarctica the potential to contribute more than **one meter** GMSL rise by 2100 and **more than 15 m** by 2500 if GHG emissions continue unabated *(DeConto and Pollard, Nature, 2016)*.

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