Grantham Briefing Note 3 – September 2013

Sea level rise

DR FLORA MACTAVISH AND DR SIMON BUCKLE

Overview

- Climate change causes a rise in sea level through thermal expansion of the ocean, melting of glaciers and ice loss from the Greenland and Antarctic Ice Sheets. Between 1901—2010, global mean sea level has increased by around 0.19 [0.17—0.21] metres, based on tide gauge data with satellite data incorporated after 1993.
- The projections for future sea level rise in 2081-2100 compared to 1986-2005 range from 0.26 metres to 0.81 metres. In all scenarios, thermal expansion accounts for the largest individual share, about 30-55 per cent of the total.
- Projections of sea level rise in the 21st Century in the IPCC's Fifth Assessment Report (AR5) are higher than in the Fourth Assessment Report, principally because the contribution of the ice sheets is included. AR5 concluded that there is currently insufficient evidence to evaluate the probability of specific levels of sea level rise above the likely range (Table 1 below).
- Based on current understanding, the only way that sea levels could increase by more than the likely range is if the collapse was initiated of areas of the Antarctic ice sheet resting on the continental shelf but below sea level. There is lack of consensus on the probability of such a collapse and the potential additional contributions to sea level rise cannot be quantified precisely.
- It is virtually certain that global mean sea level rise will continue for many centuries beyond 2100. Sea level rise of between 1-3 metres per degree of warming is expected if the warming is sustained for several millennia.
- The available evidence indicates that global warming above a certain threshold (probably over 2°C but less than 4°C warming since pre-industrial times, and possibly even as low as 1°C) would lead to the near-complete loss of the Greenland Ice-Sheet over a millennium or more, which would cause a global mean sea level rise of approximately 7m.

What determines sea-level rise and why is it important?

Over the long history of the Earth, the continents have changed their positions substantially, but at a very slow rate in terms of human experience, typically a few centimetres per year. For example, the Himalayas were formed when the Indian land-mass collided with the Asian continent, an estimated 40 to 50 million years ago, and the creation, spreading and destruction of the sea bed led to changes to the shape - and depth - of the oceans.

On million year timescales such processes are the main driver of sea level change. On shorter timescales (thousands of years and less), waxing and waning of continental ice becomes a more important factor for the amplitude of sea level change. Ice ages and warmer inter-glacial periods have characterized the last million years as changes in the shape of the Earth's orbit around the Sun altered the amount and distribution of solar energy reaching the Earth and the climate system responded. During the previous interglacial around 120,000 years ago, sea level was several metres higher than today. During warm intervals within the Pliocene epoch (5.33–2.58 million years ago) mean sea level was probably up to 20m higher than today under atmospheric CO_2 concentrations similar to today and global temperatures 2-3.5°C warmer than for pre-industrial climate and comparable to those predicted for the end of this century.

On human timescales, however, these long-term influences are a less important determinant of sea-level change. Far more important are the direct thermal warming of the ocean, the melting of mountain glaciers on land and the loss of ice from the Greenland and Antarctic Ice Sheets, all due to the additional flow of energy into the system caused by human emissions of greenhouse gases. Sea level rise is therefore a direct indicator of the extent of climate change. Nevertheless, it is not straightforward to measure and interpret. Sea level varies across the world and changes in sea level relative to land can differ significantly from the change in global mean sea level due to changing currents and vertical movement of the land and sea floor, which is still responding to the removal of the major ice sheets after the last glacial maximum (around 20,000 years ago). However, in the past 20 years it has been possible to measure sea level directly from satellites with such accuracy that these effects can be disentangled.

The major mountain glaciers (a relatively small contribution) and the huge ice sheets on Greenland and the Antarctic continent would all act to increase sea level by many metres if they disappeared under the impact of sustained warming on centuries and millennia. For example, Levermann et al (2013) estimate that over a 2,000 year period, sea level would rise by 2.3 metres for every one degree Celsius of warming. It is estimated that if Greenland lost its ice sheet, it would raise global sea mean level by about 7 metres; the West Antarctic Ice Sheet could give an increase of about 4 metres, while East Antarctica has enough ice below sea level potentially to cause a sea level rise of around 10 m. The entire East Antarctic ice sheet, including the parts that are grounded above sea level contains ice that would raise sea level by more than 50 metres.

In this century, the ice sheets are affected by a number of different processes, including thinning – and in some cases break up - of the marine-based ice-shelves by the ocean and consequent acceleration of the flow of the land-based glaciers into the ocean. The omission of this process from the estimates of sea level rise in the last assessment report, AR4, due to a lack of confidence in projections available at that time, was controversial.

Sea level changes even on a smaller scale over the next century are, however, of potentially serious concern. A large proportion of the human population lives on or close to low-lying coastal regions, often in major cities of which there are an expanding number as both global population and urbanisation increase. This increases our exposure to current risks of flooding and storm surges. A "very severe tropical cyclone" over southern Myanmar in 2008 created a devastating storm surge that resulted in more than 100,000 deaths. More recently, in October 2012 Hurricane Sandy and the associated storm surge caused damage of some US$65 billion in the United States.

Added to this greater exposure, climate change will increase the risks of such catastrophic events in future. Without enhanced protection, rising mean sea level will increase the severity and probability of damaging storm surges and flooding hitting major population centres, even if there is no change in the frequency and intensity of hurricanes, cyclones and other major storms. For example, Hallegatte et al (2013) estimate annual losses due to floods affecting the world's 136 largest coastal cities at US$6 billion per year in 2005. These are projected to increase to US$52 billion with socioeconomic change alone by 2050. With climate change and subsidence, the authors suggest that protection would have to be upgraded in order to avoid losses of US$1 trillion per year. This equates to roughly 1.5% of current global GDP.

What does the IPCC Fifth Assessment Report (AR5) say about observed sea level rise?

AR5 reports that:

- Between 1900 and 2010, global mean sea level has increased by around 0.19 [0.17—0.21][1] metres, based on tide gauge data and satellite data after 1993.
- The mean rate of sea level rise was very likely 1.7 [1.5—1.9] mm per year in the period 1900—2010 and was very likely 3.2 [2.8—3.6] mm per year in the latter part of this period, between 1993 and 2010. Similarly high rates likely occurred between 1930 and 1950.
- It is likely that the magnitude of extreme sea level events has increased since 1970.

Since AR4, it has been possible to obtain better observational estimates for the individual contributions to global mean sea level rise. The AR5 report assesses that the evidence now available gives a clearer account than in previous IPCC assessments of 20th Century sea level change. In particular:

- Ocean thermal expansion has very likely contributed 0.8 [0.5 to 1.1] mm per year of sea level change during 1971-2010, with the majority of the contribution coming from the upper 700 metres of ocean.
- The global glacier contribution (excluding those on the margins of the Greenland and Antarctic Ice Sheets) to sea level rise was 0.25 to 1.00mm per year during 1971-2010.
- There is very high confidence that the Greenland ice sheet has lost mass over the past two decades and high confidence that the Antarctic Ice Sheet has lost mass over the same period. The rate of loss has accelerated by a factor of about six for Greenland and almost five for Antarctica between the periods 1992-2001 and 2002-2011. For Greenland, there has been a pronounced regional warming, which may be due to a combination of regional variability and a global warming trend.

[1] The range in square brackets is the 90% uncertainty interval. This is expected to have a 90% likelihood of covering the value being estimated. There is an estimated 5% likelihood that the value could be above the range given and 5% likelihood that the value could be below that range. A best estimate of the value is given where available. Uncertainty intervals are not necessarily symmetric about the corresponding best estimate.

- The Greenland Ice Sheet contributed 0.59 [0.43 to 0.76] mm per year to sea level rise over the period 2002-2011, and Antarctica contributed 0.40 [0.20 to 0.61] mm per year over the same period.
- According to models, climate-related changes to water storage on land (i.e. changes in snow cover, surface water, soil moisture and ground water) have not made long-term contributions to sea level change for recent decades. Human induced changes (reservoir impoundment and groundwater depletion) have contributed at least several tenths of a millimetre per year to sea level change.

What does AR5 say about projected sea level rise?

AR5 future projections of sea level rise for the 21st Century are shown in Table 1 (below). The projections are higher than those in AR4, principally because the contribution from melting ice sheets is now included. There are likely to be significant regional differences in the rate and level of sea level change.

The rate of sea level rise in the 21st century is very likely to exceed the rate observed in the period 1971—2010. The rate is projected to stabilise at about 4.5mm per year by the middle of the 21st century in RCP2.6. In RCP8.5 the rate continues to accelerate, reaching 11 [7—15] mm per year during 2081-2100 and by 2100, the range of global mean sea level rise is 0.53-0.97m. In all scenarios, thermal expansion is responsible for the largest individual contribution to mean sea level rise, accounting for about 30-55 per cent of the total.

Table 1: Projected long-term changes in global mean sea level rise for 2081-2100 by scenario.

Scenario[2]	**Change relative to 1986-2005 (metres)**	
	Mean	*Likely range* (5-95% of model ranges)
RCP2.6	0.40	0.26 to 0.55
RCP4.5	0.47	0.32 to 0.63
RCP6.0	0.48	0.33 to 0.63
RCP8.5	0.63	0.45 to 0.82

By 2100 (medium confidence), between 15-55 per cent of present glacier volume is projected to be eliminated under RCP2.6 and 35-85 per cent under RCP8.5. There is high confidence that the Greenland Ice Sheet will make a positive contribution to sea level rise over the 21st Century. Surface melting on the Antarctic Ice Sheet is projected to remain small, while there is medium

[2] The Fifth Assessment Report uses new greenhouse gas emissions scenarios known as representative concentrations pathways (RCPs). They are each named after the amount of radiative forcing in W per square metre in 2100. They include some element of mitigation. They are (low to high forcing, where high radiative forcing means high greenhouse gas concentrations): RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

confidence that snowfall there will increase. The likely end of the century range from rapid changes in ice outflow from the Greenland and Antarctic Ice Sheets combined is 0.03 to 0.20 metres in RCP8.5 and 0.03-0.19 metres in the other RCPs. This is the main reason why the projections are greater than those given in AR4. The AR4 5-95 per cent range for global mean sea level rise across scenarios for the period 2090—2099 relative to 1980—1989 was 0.18 to 0.59 metres.

AR5 concluded that there is currently insufficient evidence to evaluate the probability of specific levels of sea level rise above the likely range in Table 1 above. Based on current understanding, the only way that sea levels could increase by more than the likely range is if the collapse of the marine-based sectors of the Antarctic Ice Sheet was initiated. These sectors comprise the areas of the ice sheet resting on the continental shelf but below sea level and include most of the West Antarctic Ice Sheet. There is lack of consensus on the probability of such a collapse and the potential additional contributions to sea level rise cannot be quantified precisely. But AR5 expresses medium confidence that it would not exceed several tenths of a metre during the 21st Century.

It is virtually certain that global mean sea level rise will continue for many centuries beyond 2100. Sea level rise of between 1-3 metres per degree of warming is expected if the warming is sustained for several millennia (low confidence). Ocean thermal expansion increases with warming, while the glacier contribution decreases over time due to their limited volume. In Antarctica, the increase in surface melting could exceed accumulation beyond 2100.

The available evidence indicates that global warming above a certain threshold (probably over 2°C but less than 4°C warming since pre-industrial times, and possibly even as low as 1°C) would lead to the near-complete loss of the Greenland Ice-Sheet over a millennium or more, which would cause a global mean sea level rise of approximately 7m.

References

Cook, C. P., van de Flierdt, T., Williams, T., Hemming, S. R., Iwai, M., Kobayashi, M., ... & Yamane, M. (2013) Dynamic behaviour of the East Antarctic ice sheet during Pliocene warmth, Nature Geoscience 6, 765–769 doi:10.1038/ngeo1889

Hallegatte, Stephane et al, (2013) *Future flood losses in major coastal cities*, Nature Climate Change 3, 802–806 doi:10.1038/nclimate1979

Intergovernmental Panel on Climate Change, Assessment Report 5, Technical Summary (2013)

Levermann, Anders, et al. *The multimillennial sea-level commitment of global warming*, Proceedings of the National Academy of Sciences 110.34 (2013): 13745-13750

Webster, P., *Myanmar's deadly daffodil*, Nature Geoscience 1, 488 - 490 (2008), doi:10.1038/ngeo257

Najman, Y. (2006)*The detrital record of orogenesis: A review of approaches and techniques used in the Himalayan sedimentary basins* Earth-Science Reviews, Volume 74, Issues 1–2, pages 1–72