A QUESTION OF DEVELOPMENT
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Sea level rise: observations, projections and uncertainty

A MAJOR RISK FOR COASTAL AREAS

Sea level rise due to climate change is an important risk factor for growing populations living in coastal areas. This issue reports on the observations, projections for the 21st century and major uncertainty surrounding the behaviour of ice sheets with their increasing melt rates whose future contribution to sea level rise could be underestimated.

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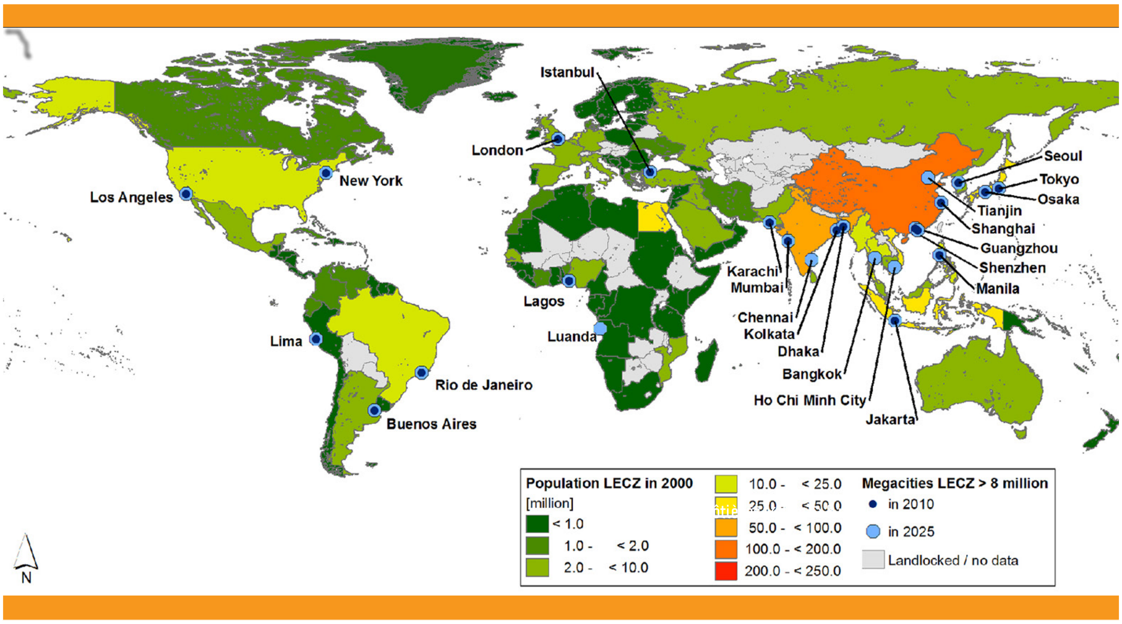
Rising sea levels are threatening coastal populations

In 2000, some 625 million people (10% of the world population) were living in low-lying coastal areas (<10 m), particularly in Asia with its many densely populated deltas (see Map 1). This number had risen to 700 million people by 2010 and will continue to grow in coming decades due to the combined effect of demographic growth and accelerating coastal urbanisation. At the same time, global warming will continue to drive up sea levels, representing a threat to these populations and raising many questions as to the adaptation strategies required to manage the associated risks (submersion, frequent flooding and saltwater infiltration of groundwater resources).

Measurements taken by tide gauges and satellites show that the average sea level has already increased approximately by +20 cm since 1900. This rise has accelerated in recent decades from an average +1.4 mm/year over the 1930-1992 period to +3.3 mm/year from 1993 to 2009. Globally, the two main factors behind this phenomenon are: (i) melting land ice (glaciers and ice sheets), responsible for around two thirds of the rise in the sea level from 1993 to 2009; and (ii) thermal expansion of the oceans due to the rise in water temperatures, responsible for the other third. Land ice melt, especially melting polar ice sheets, is an increasingly important factor. From 1993 to 2003, Greenland and Antarctic ice sheet mass loss accounted for less than 15% of the rise in the global sea level. From 2012 to 2016, it accounted for around 35%.

Behind the global average sea level rise figures lie substantial regional and local disparities due to such factors as the spatial heterogeneity of warming and changes in ocean dynamics. Over the 1993-2015 period, for example, the sea level in the West Pacific rose three times more than the global average. ...

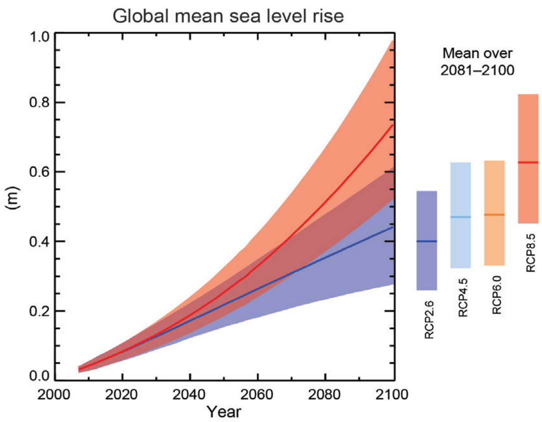
MAP 1. POPULATIONS IN LOW-LYING COASTAL AREAS (< 10 M) IN 2000



Source : Neumann *et al.* (2015)

Projections for the 21st century

FIGURE 1: PROJECTIONS OF THE GLOBAL MEAN SEA LEVEL RISE (IN M) COMPARED WITH THE MEAN LEVEL MEASURED OVER THE 1986-2005 PERIOD FOR DIFFERENT GREENHOUSE GAS (GHG) EMISSIONS SCENARIOS



Source: Intergovernmental Panel on Climate Change (IPCC), Summary for Policymakers, 2013

Key: RCP = Representative Concentration Pathway. RCP2.6: scenario of a decrease in GHG emissions; RCP8.5: scenario of high GHG emissions; RCP4.5 and RCP6.0: scenarios of intermediate GHG emissions.

The global sea level projections presented in the 2013 IPCC report range from tens of extra centimetres in 2100 for a scenario of a sharp reduction in greenhouse gas emissions (RCP2.6) to an increase of nearly one metre over the current level in the event of continued high GHG emissions (RCP8.5) (see Figure 1). These projections, based on the digital simulation of physical processes, take account of ocean warming and changes in glaciers and ice sheet surface mass balance. They do not, however, factor in possible major changes in ice sheet dynamics.

Uncertainty over ice sheet developments

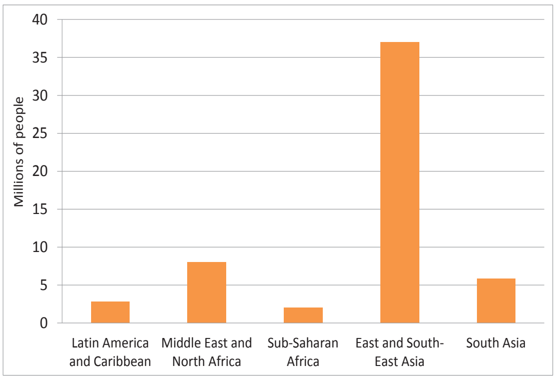
Ice loss from the Greenland and Antarctic ice sheets has risen sharply in recent decades. The Greenland ice sheet's contribution to sea level rise grew from an average 0.09 mm/year in 1992-2001 to 0.59 mm/year in 2002-2011. The Antarctic ice sheet's contribution rose from an average 0.08 mm/year in 1992-2001 to 0.40 mm/year in 2002-2011. The acceleration in ice loss has been particularly sharp since the mid-2000s.

This trend is faster than expected. Since the 2013 IPCC report, a number of studies have pointed up that the future contribution of the ice sheets to the rise in sea levels may well have been greatly underestimated. Factoring new physical processes into the digital ice sheet models would therefore probably drastically change how the models respond to warming.

There is particular concern about the future behaviour of the West Antarctic Ice Sheet. This portion of the ice sheet is grounded below sea level, making it particularly sensitive to ocean warming. Recent observations have reported a large underwater melt, a receding grounding line and thinning of the floating ice shelves that extend away from several major glaciers. This is weakening the buttress effect of these ice shelves and accelerating glacier flow toward the sea, raising fears of possible destabilisation. The melting of all the ice in this region would raise the sea level by some 4 metres, but the speed at which destabilisation might take place is uncertain.

The study of past climates can, to a certain extent, provide additional clues. In the last interglacial period 120,000 years ago, the global mean temperature was just 1 °C to 2 °C higher than in the pre-industrial period, but the sea level was an estimated 6 to 9 metres above the current level. A very sharp rise from 2 to 3 metres is thought to have occurred at the end of this interglacial period, possibly within a few decades, suggesting that the Greenland or Antarctic ice sheet could have rapidly destabilised at the time and that this could therefore happen in the future, even though little is known at this stage about the physical processes that might cause such a phenomenon.

FIGURE 2. NUMBER OF PEOPLE LIVING IN AREAS IN 2000 THAT WOULD BE SUBMERGED BY A SEA LEVEL RISE OF +1 M



Data source: Dasgupta et al. (2009)

Such major uncertainty surrounding the physical mechanisms that will determine the future of the Greenland and Antarctic ice sheets means that there is no consensus as to their future impact on the global sea level rise. This impact could be much greater than the estimates used for the Figure 1 projections. For example, the extreme scenario considered by the US National Oceanic and Atmospheric Administration in a report published in 2017 is based on the hypothesis of a mean rise of +40 cm as of 2040 and +60 cm in 2050, rising to +2.5 m in 2100. Such a scenario would have major repercussions for the coastal regions of many AFD intervention areas, especially in Asia and Africa.

Exposed populations and additional risk factors

The sea level rise will not be uniform across all oceans. Deviations from the global mean can hit levels of +30% and -50% in certain regions. This variability therefore needs to be taken into account in any estimation of local and regional impacts. Nevertheless, rough estimates can be obtained based on a uniform rise. In the developing countries, for example, a one-metre rise would submerge the land inhabited by 56 million people in 2000. This figure increases to 90 million people for a two-metre rise. Exposed populations are found mainly in Asia, in particular in East and South-East Asia (see Figure 2), including over 20 million people in China. The two countries most at risk in terms of population percentage are Vietnam and Egypt, with 10% of their population in 2000 living in areas that would be submerged in a one-metre scenario.

Note that these rough estimates also omit future demographic changes and non-climate phenomena, which could play a key role at local level.

• **Demographics and urbanisation:** There has been a particularly sharp rise in population and urbanisation in developing country coastal areas in recent decades, driven by demographic growth and migratory movements. This trend looks set to continue, if not accelerate, automatically driving up the number of people exposed to rising waters. Socioeconomic and demographic scenarios for the 21st century predict that the number of people living in low-lying coastal areas (<10 m) could grow by 58% to 71% to reach over one billion in 2050, with most of this growth in Asia and Africa.

• **Non-climate factors:** Impact studies need to consider not only the climate-related global sea-level rise and regional variations, but also non-climate factors that play a role in the relative sea level. Local sea level variations can be in excess of 10 cm/year, which is much higher than the average rise of 3.2 mm/year currently observed globally. These can be due, in particular, to natural or anthropogenic subsidence[1] phenomena. In the 20th century, East Tokyo sank 4.4 m, Shanghai 2.6 m and Bangkok 1.6 m. Among the anthropogenic factors responsible for this are the weight of buildings and pumping of groundwater, which can cause major sediment compaction. The construction of dams and irrigation systems can also have significant repercussions by reducing the flow of sediment at river mouths. Sediment loads can then become insufficient to offset subsidence or erosion. Marine sand mining is also responsible for accelerated coastal erosion and beach loss in many parts of the world. And then there are the natural coastal dynamics wrought by the currents and waves. So there is a lot more to how the coastline evolves with the rising sea level than just the submersion of areas currently located below the projected level.

A rise in the average sea level also implies expanding flood-risk areas, especially when storms hit when they can temporarily expand up to several metres beyond

[1] Subsidence is the gradual sinking of the Earth's surface..

their normal area. Estimation of the impacts of sea level rise therefore needs to take into account both the areas that would be permanently submerged by the sea and the areas at greater risk of flooding.

Conclusion

This brief overview of current knowledge on sea level rise illustrates the huge uncertainties surrounding the projections at both global and regional levels. The main question at global level concerns the behaviour of the polar ice sheets. The 2013 IPCC report was highly circumspect on the question, but more recent publications suggest that their future contribution to sea level rise may have been substantially underestimated. If the worst-case scenarios currently envisaged were to come about, we could see the average sea level rising dozens of centimetres by the middle of the century with significant impacts on AFD intervention countries at risk (see Map 1). Locally, it is also important to take into account non-climate phenomena that have an effect on the relative sea level as well as the risks of the expansion of flood-risk areas. Drawing up local and regional scenarios for the entire planet is therefore a particularly complicated task.

The maximum value of sea level rise to be considered for local level impact studies can therefore only be chosen on a case-by-case basis based on the extent of risk deemed acceptable for a given region. However, putting to one side the uncertainty over how the climate system will respond to greenhouse gas emissions, some regions appear more vulnerable than others, due mainly to population and urbanisation dynamics. In addition to the small island states, many countries in Asia with their densely populated deltas (Bangladesh and Vietnam in particular) and in Africa combine a low level of development with high coastal population growth.

These observations raise questions as to the sustainability of economic and urban development in coastal areas and highlight the need to: (i) conduct local risk studies to design protective and adaptive measures, and (ii) factor in the non-climate phenomena of subsidence and changes to sedimentary dynamics.

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