

Sea Level Rise and its Implications¹

The changing level of the sea is undisputed. Sea level variations have occurred throughout history and will continue to occur into the future. Over the past several million years, global sea level has risen and fallen approximately 120m. However, according to the IPCC's Fourth Assessment Report, there is "strong evidence that global sea level gradually rose in the 20th century and is currently rising at an increased rate" [IPCC, 2007a Ch.5: 409], and it appears that the changes occurring in ocean systems today are broadly consistent with the effects of warming due to anthropogenic climate change. The increase in greenhouse gas concentrations in the Earth's atmosphere as a result of human activities has led to warming, which causes the sea average sea level to rise through thermal expansion, melting of glaciers and ice sheets, and changes in land-stored water. Given that sea level is rising with "proportionately much greater increases compared to temperature," even if greenhouse gas emissions were stabilised at current levels today – which would lead global temperature increases to level off and stabilise in about 100 years – global sea levels may continue to rise even further into the future [Meehl et al., 2005].

The consequences of rising sea levels will obviously depend on the magnitude of the rise, but are likely to be significant both in terms of the consequences for human coastal settlements and general living standards (economic and societal impacts), and in terms of environmental costs (physical impacts on natural systems).

Economic and societal impacts are already evident in some regions. The coastal populations most at risk are those occupying small islands or low lying land (see Figure 1). Populations in these areas will have no choice but to migrate further inland, as is already occurring in some parts of the world, such as the Pacific Island nation of Kiribati (2 uninhabited islands disappeared underwater in 1999, with populated islands increasingly at risk of submersion or forced abandonment due to salination of the soil) and remote villages in Alaska (Kivalina). One reason for forced migration is that rising sea levels will result in the loss of agricultural lands due to permanent submersion, or to frequent flooding causing salinity of the water table and making the soil unproductive. Such effects are likely to be particularly bad in developing countries in South and South East Asia [Javellana, 2007]. Looking at a subset of 84 developing countries, a recent World Bank Study has quantified the number of people at risk according to the magnitude of sea level rise as being 56 million for a 1m rise; 89 million for a 2m rise; and 245 million for a 5m rise [Dasgupta et al., 2007]. It is feared that rising sea levels could create large numbers of "environmental refugees", which could lead to significant domestic and/or international tensions.

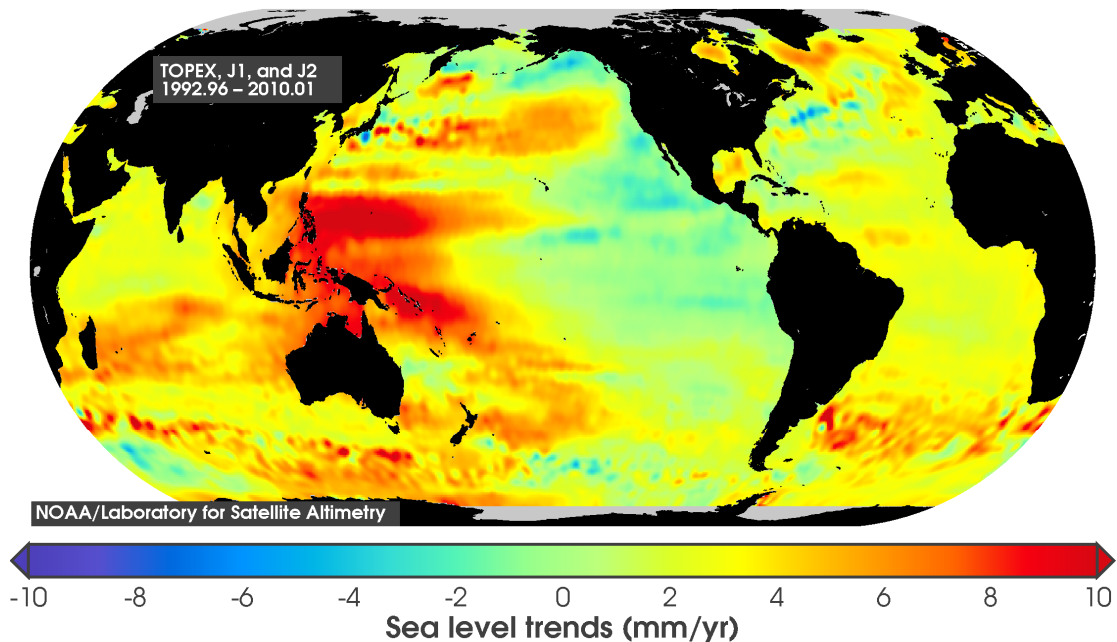
Economically, given that GDP per capita is generally above average for coastal populations and cities [Dasgupta et al., 2007] and that coastal areas are critical to international trade and commerce in today's globalised economy, large disruptions to important port cities would have widespread ramifications. Alongside port infrastructure, inland infrastructures such as roads, railways and airports in low-lying regions are vulnerable to loss or damage [US EPA, 2009]. Other industries important to GDP, in particular travel and tourism, would also be severely affected.

As far as physical impacts are concerned, unless shore protection measures are taken, it is virtually certain that sea level rise, even at the lowest magnitude predicted, will cause some currently dry land to become (tidally or frequently) inundated or even permanently submerged. The lowest lying coastal lands are obviously the most at risk, with those in developing countries arguably at greater risk due to a lack of resources to put in place and maintain flood control mechanisms (as exist in the Netherlands, for example). Rising sea levels will also likely result in an increased rate of erosion of coastal land – affecting coastal

¹ This paper aims to illustrate some of the contributing factors to the emergence of risks described in the IRGC report "The Emergence of Risks: Contributing Factors". This report is part of phase 1 of IRGC's project on Emerging Risks. More information can be found online at <http://irgc.org/Project-Overview,219.html>

headlands, spits and barrier islands – especially those with sandy shores. Loss of wetland areas through submersion is another strong possibility.

Figure 1: The trend towards rising sea levels



Source: NOAA / NESDIS Center for Satellite Applications and Research,
http://ibis.grdl.noaa.gov/SAT/SeaLevelRise/LSA_SLR_maps.php

These physical changes will necessarily have an impact on biodiversity, potentially leading to loss. Many species are specifically adapted for a particular type of coastal habitat and may be threatened if this habitat is affected by erosion, increased salinity, loss of wetlands, mangroves and tidal marshes, more frequent flooding, etc. Further changes in coastal climate will result if ocean circulation becomes affected by rising sea levels – as more fresh water is added to the oceans via the melting of land ice or more run-off from rivers, sea waters not only rise, but become less salty, which makes them less dense and could affect the meridional overturning circulation (MOC, which includes the Gulf Stream). Because the MOC delivers heat to the northern seas and nearby land areas, changed circulation could thus affect climates in parts of the northern hemisphere.²

The consequences of this emerging risk are therefore on a very large, if not global, scale. However, there are several factors that influence the development of this risk and can either amplify or attenuate negative outcomes. Of these factors, **varying susceptibilities**, we have already seen – it is clear that low-lying areas and small islands are most at risk from a sea level rise of any magnitude. Geography is, in this case, a key amplifier of risk. As a subset of these vulnerable regions, less developed populations have greater susceptibility due to the fact that they have fewer resources to prepare for or mitigate any negative impacts caused by rising waters.

The next, and certainly the most important, factor is **scientific unknowns** – because the number of key scientific unknowns related to the phenomenon of sea level rise make it extremely difficult to make accurate predictions about where, when and by how much the sea level will rise.

² Climate models used by the IPCC show a large spread in predictions for reductions in the MOC, from no response, to a 50% reduction by 2100 [IPCC, 2007b]

The IPCC has made a number of projections for sea level rise (which include associated levels of uncertainty) under each of its emissions scenarios (SRES) [IPCC, 2007c]. These projections range from a sea level rise of 38cm under the most optimistic emissions scenario (B1) to a rise of 59cm under the most pessimistic emissions scenario (A1F1), all by 2099 [IPCC, 2007a, Ch10:820]. Other studies on the impact of sea level rise have chosen to take a more pessimistic view of projected GHG emissions growth and give greater weight to the probability of ice sheet break-up, concluding that a sea level rise of between 1-3m (or even

5m if ice sheets melt rapidly) is possible by 2100. Such studies take a more precautionary approach and leave a larger margin of safety when assessing which areas of the globe might be at risk [Dasgupta et al., 2007].

These projections are highly uncertain because of the following unknowns:

Firstly, the trajectory of global greenhouse gas emissions and associated rates of warming are uncertain and depend on what kind of mitigation action is taken; secondly, many ocean observations are poorly sampled in space and time with satellite observations only having been available since the early 1990s, thus making long-term trends hard to identify with certainty; thirdly, there are gaps in the scientific knowledge regarding present day glacier volume and the processes involved with the discharge of ice from ice sheets; and finally, there is a great deal of regional heterogeneity with sea level rising at up to several times the global mean in some areas, while falling in others. It is also possible – although the IPCC does not deem it likely to occur in the 21st century – that abrupt changes in the climate could cause large scale changes in ocean circulatory systems or the rapid loss or collapse of the Greenland or West Antarctic Ice Sheets. If such an event occurs, sea level will rise much more than forecast under the most extreme IPCC scenarios. For example, if the Greenland ice sheet alone were to pass the tipping point where it would be committed to disappearing completely (models suggest there is a critical temperature threshold for this), global sea level would rise by about seven metres, though this process is slow and would occur over hundreds of years.

The role of **positive feedbacks** in the climate system contributes to the above uncertainties. There are numerous positive feedbacks operating simultaneously that have the effect of amplifying the warming of the atmosphere (which, in turn, contributes to causing sea level rise). For example, as temperatures warm, permafrost melts, which releases the powerful greenhouse gas methane, and this contributes to further atmospheric warming. Rising temperatures also melt snow and sea-ice, which reduces the reflectance of the earth's surface (since ice and snow are white, they reflect sunlight and reduce the amount of solar radiation absorbed), again contributing to atmospheric warming [Frame and Allen, 2008]. To further complicate matters, there are also negative feedbacks operating (e.g., radiation feedback, where warmer temperatures increase evaporation, which increases cloud cover, which has the effect of reducing the amount of solar radiation absorbed). The cumulative effect of all the positive and negative feedbacks occurring must be considered when making projections about future rates of warming, which is a difficult task given that many of these feedbacks are not well understood.

In the face of such difficulties accurately predicting how temperatures will rise and how this will affect sea levels, globally, regionally or locally, what can be done to minimise the risks? There is an enormous amount of scientific effort being devoted to reducing the relevant scientific unknowns, better understanding feedback mechanisms etc., but even while uncertainties remain, there are governance options that should be considered and that have the potential to attenuate the negative impacts that sea level rise may bring:

- Adaptation (including regulation)

Adaptive measures may include building physical defences against rising sea waters, such as has been done in the Netherlands (the system of dams, dykes and dunes maintained to prevent flooding). This may be combined with efforts to modify existing coastal settlements deemed to be at risk, including coastal infrastructures – although this would be extremely expensive, slow, and depending on the level of risk, may not be worth the time and expense.

A more attractive adaptation strategy in many places may be to implement regulations regarding new settlements and infrastructure built near the coast; to not allow construction in particularly risky zones and make sure that special precautions are taken for any settlement deemed necessary. The amount of political will, financial and human capital required for all of these measures will be great, and it is likely that many developing countries at risk will not possess the required resources. Alternatively, or additionally, policies could be put in place to encourage migration away from the coast and to promote new settlements inland.

- Mitigation

International efforts to mitigate global climate change have thus far had mixed results – despite the general acceptance of the problem and of the IPCC’s warnings, the agreements reached and the level of emissions reductions achieved so far are inadequate to solve the problem of rising sea levels. Whatever temperature increase is observed over the course of the 21st century, it is likely that sea level will rise by more than a factor of 3 (percentage-wise) compared to the temperature change. While it is too late to rely on mitigation alone as a way to prevent dangerous rises in sea level, given that, as stated above, “sea level rise commitment is considerably more than temperature change commitment” [Meehl et al., 2005], it will be important to continue to strengthen global climate change mitigation efforts in order to keep sea level rise to a minimum.

- Migration

Migration away from the lowest elevation coastal zones, although expensive and socially and economically disruptive, may be necessary in some high risk areas. Because current population movements are toward, rather than away from, coastal areas, encouraging migration inland is not likely to be simple. More research needs to be done into the factors driving coastward population movements so that the most effective regulatory or adaptive measures can be implemented as part of a risk management strategy. For all coastal states, it would also be useful to analyse urbanisation with a spatially explicit framework and do a systematic global assessment of urban areas within a narrow coastal band. Such studies will help to determine with more certainty what the risks are, how many will be affected, and if migration is an appropriate response.

References

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