

Sea level rise as a defining feature of dangerous interference with the climate system

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1. A significant instance of dangerous interference

In the UNFCCC, most nations of the world have agreed to stabilise greenhouse gas concentrations in the atmosphere at a level that will prevent “dangerous interference with the climate system” (Article 2). A key question for policy thus is: what level can this be? We here propose a criterion involving long-term sea level rise.

We argue that a significant likelihood of causing a global sea level rise in the range of 3-5 m over the next few centuries (say, by the year 2300) would constitute a “dangerous interference”, since such a sea level rise would destroy much of the current world coastlines, including small island states, many large cities, most beaches and many coastal ecosystems.

We further argue that a global-mean warming of 3°C, if sustained for around three centuries, is likely to cause such a sea level rise. Hence, a long-term stabilisation target of greenhouse gases at a level equivalent to CO₂-doubling (over the pre-industrial value of 280 ppm, i.e., a CO₂-equivalent of 560 ppm) would not be sufficient to prevent a “dangerous interference” and would not meet the letter and spirit of the UNFCCC.

2. Estimating sea level rise for stabilized greenhouse gas concentrations

To analyse this problem, we need to consider the following causes of sea level rise: thermal expansion of sea water, as well as the addition of melt-water from Greenland, Antarctica and small glaciers and ice caps.

For *thermal expansion*, the IPCC TAR (Fig. 11.15a) shows a number of model simulations which give contributions in the range of **0.4-0.9 m** in 300 years for an idealised CO₂-doubling scenario. There is some risk that the number could be substantially higher if there was a strong weakening of the thermohaline ocean circulation, a risk which is not fully taken into account in these models as they do not include melt-water runoff from the Greenland ice sheet, which would increase the probability for such a weakening.

For *mountain glaciers*, about 0.5 m sea level equivalent is held in ice (IPCC TAR, p. 677). A sustained global warming of 3°C would imply larger warming over continental and high-latitude regions, and would over three centuries eliminate most of these glaciers. Assuming 80% loss, we expect a contribution of **0.4 m** sea level rise from this source.

For *Greenland*, the ice sheet model result presented in the IPCC TAR (Fig. 11.16) indicates a melt-water contribution of 0.9 m by 2300 for a local warming of 5.5 °C (this warming is a reasonable estimate for a global-mean warming of 3 °C, given the

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polar and continental amplification found in all climate models). However, this model does not include mechanisms of rapid melting due to formation of melt-water ponds on the ice sheet surface and the seepage of melt-water through cracks to the ice-sheet base. Current observations show this mechanism and a dynamical response of the ice in operation (e.g., speed-up of the Jakobshavn glacier flow). Hence, the above estimate is likely to be a lower limit, and a range of sea level rise from Greenland of **0.9-1.8 m** is a reasonable expectation.

For *Antarctica*, much depends on the response of the West Antarctic Ice Sheet (WAIS) to global warming (the much larger East Antarctic Ice Sheet is considered to be stable). Until and including the TAR, a rapid disintegration of the WAIS was considered very unlikely, since ice sheet models did not show a large sensitivity of the ice sheet to a melting of the ice shelves (ice floating on the ocean in front of the ice sheets) on century timescales. In the meantime, however, the Larsen B ice shelf has spectacularly disintegrated in 2002, and measurements have shown a strong speed-up of the ice streams behind this ice shelf. Hence, the stable ice sheet models have been proven inadequate, and an accelerated flow of ice into the ocean must be expected if further (and larger) ice shelves disintegrate. With a sustained global warming of 3°C and associated warming of Southern Ocean waters, this is considered likely by glaciologists. As witnessed with the Larsen A and B shelves, ice shelves appear to have a critical temperature threshold at which they rapidly disintegrate. It is difficult to estimate the rate of the resulting ice outflow, given that current ice sheet models do not reflect the relevant mechanism. However, a rough estimate if ice shelf collapse were to trigger ice sheet disintegration would give **1-2 m** sea level rise from this source by 2300 (at a constant rate this would correspond to a decay of the WAIS over a time span of 900-1800 years, a conservative estimate, as some believe disintegration could occur in 300-400 years).

Adding the ranges for all these sources together, we obtain a range of sea level rise by 2300 of **2.7-5.1 m**. Given the assumptions made above, in some cases somewhat more pessimistic than those of the TAR, we do not want to rule out a significant chance that sea level rise could turn out to be lower. However, we believe that our assumptions are by no means extreme or represent an unlikely worst case scenario; there is also a significant chance that sea level rise could turn out to be substantially higher. In other words, a sea level rise in the range of 3-5 m, which we considered to be an instance of “dangerous interference with the climate system” above, is quite likely even for a scenario of equivalent-CO₂ doubling. To avoid it, a long-term climate stabilisation target well below 3°C must be chosen. Even a stabilisation target of 2°C cannot necessarily be considered “safe” in terms of the sea level rise caused, although in this case there is not only a proportionally smaller sea level rise but also a lower, but still significant, risk of triggering ice shelf disintegration in Antarctica.

A “back-of-envelope” calculation may add perspective: current global sea level rise measured from satellite altimeter observation is around 2.8 cm/decade. If this is the result of the 0.6°C warming over the past century, and if the response were linear, then a 3°C warming might roughly cause five times the current rate of sea level rise, i.e., 1.4 m per century. In this admittedly simplistic linear sense, current observed sea level rise is at least not inconsistent with a 3-5 m rise by 2300. Note that the non-linearity in the system (large time delay in sea level response, thresholds of ice sheets) tends to favour a smaller initial response and a disproportionate sea level rise later in time and for larger warming.

It should further be noted that this sea level rise will still be in full swing in the year 2300 even if CO₂ concentration has been stable since before the year 2100, as both thermal expansion and ice sheet melting are slow processes which come to completion only on a time scale of 1-2 millennia. Hence, citizens in the year 2300

would not only have to cope with sea levels several meters higher than at present, but they would also need to cope with ongoing further rise.

3. Conclusion

The slow response of sea level is the reason why we need to consider the multi-century time scale; present policy decisions will affect sea level for centuries to come. Consider how 18th Century statesmen would be regarded today, had they knowingly decided to accept flooding of cities like Amsterdam, Hamburg, London, Manila, New York, Shanghai and Venice without making every effort to prevent it.

Our understanding of the dynamics of sea level rise will improve in the course of time and this may lead to important modifications of the present argument. But unless new knowledge shows that the risks are much smaller than we must currently assume, it would be irresponsible to forego the option to stabilize greenhouse gas concentrations at a level significantly below twice the pre-industrial level. Stabilization goals then have to be set accordingly.

As with any danger, risking a sea level of 3-5m should be considered dangerous although it is not certain to occur: it would be dangerous even if it were just not very unlikely (say, had more than a 10% chance of occurring). As a matter of fact, at the present state of knowledge, it is likely to happen if equivalent CO₂ will be stabilized at twice the pre-industrial level. We propose that preventing the risk of drowning major cities of the world is required by Art. 2 of the UNFCCC.