A new view on sea level rise

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Has the IPCC underestimated the risk of sea level rise?

In its 2007 report[1], the Intergovernmental Panel on Climate Change (IPCC) projected a global sea level rise of 18 to 59 centimetres from 1990 to the 2090s, plus an unspecified amount that could come from changes in the large ice sheets covering Greenland and Antarctica.

But the physical climate models used by the IPCC have some limitations, prompting the search for alternative approaches to estimating sea level rise. New semi-empirical approaches are based on the idea that the rate of sea level rise is proportional to the amount of global warming — the warmer it gets, the faster ice melts — and they use past sea level and temperature data to quantify this effect.

Over the course of the twentieth century, the rate of sea level rise has roughly tripled in response to 0.8 °C global warming[2]. Since the beginning of satellite measurements, sea level has risen about 80 per cent faster, at 3.4 millimetres per year[3], than the average IPCC model projection of 1.9 millimetres per year. The difference between the semi-empirical estimates and the model-based estimates of the IPCC can be attributed largely to the response of continental ice to greenhouse warming. The IPCC range assumes a near-zero net contribution of the Greenland and Antarctic ice sheets to future sea level rise, on the basis that Antarctica is expected to gain mass from an increase in snowfall. Observations show, however, that both ice sheets have been losing mass at an accelerating rate over the past two decades[4].

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Recent studies predict that sea level could rise by more than one metre this century if greenhouse gas emissions continue to escalate.

A number of recent studies taking the semi-empirical approach have predicted much higher sea level rise for the twenty-first century than the IPCC, exceeding one metre if greenhouse gas emissions continue to escalate (Fig. 1). These new results have found wide recognition in the scientific community, as recent broad-based assessments show[5–7]. The question is: how plausible are the new estimates?

Although the popular media tend to focus on the upper limits of these projections, reaching the upper limits is, by definition, extremely unlikely. And at the high temperatures that produce extreme rises in sea level, predicting the response of the climate system is difficult. Upper limits also depend on how uncertainties are treated. Comparing the central estimates of sea level rise projections is therefore more informative. For a moderately pessimistic emissions scenario, named A1B, which results in about 3 °C global warming above the 1990 level by the 2090s, the IPCC projects 35 centimetres of sea level rise. This, rather implausibly, assumes no acceleration beyond the rate of sea level rise observed during the past 15 years, despite temperatures increasing by four times as much as in the twentieth century. A recent study by Martin Vermeer and me[8], in contrast, yields a central estimate of 124 centimetres by 2100 and 114 centimetres by 2095.

ALL THE ICE

Semi-empirical models have the merit that they reproduce past sea level rise very well, unlike the physical models used thus far. But they too have a serious limitation: there is no way to ensure that the historic relationship between sea level rise and temperature will continue to hold in future.

So how can we critically assess the robustness of the empirical relationship? Global warming raises sea level through two processes: thermal expansion of the ocean, and the addition of water to the ocean from melting land ice. For thermal expansion, researchers have tested the semi-empirical methods against complex ocean–atmosphere models and found that the sea level response of these vastly more complex physical models is reproduced well[8]. If

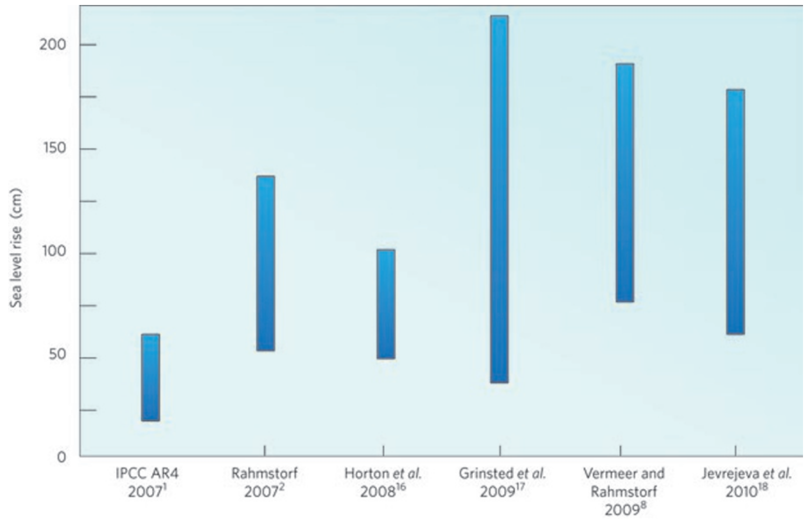

Figure 1 Range of rises. Estimates for twenty-first century sea level rise from semi-empirical models[2,8,16–18] as compared to the IPCC Fourth Assessment Report (AR4)[1]. For exact definitions of the time periods and emissions scenarios considered, see the original references.

the physical models do a good job on thermal expansion, then so will suitable semi-empirical models.

Whether the response of continental ice to warming is well represented by empirical models is harder to judge, though the linear dependence on temperature is similar to that also used in glacier modelling studies and by the IPCC. The semi-empirical approach, however, was recently criticized in the popular media[9] on the grounds that it is, to a large extent, calibrated to the past glacier contribution, and that glaciers would be "largely gone by 2050". Apart from this being just not so, the melting of all glaciers would add 60 centimetres to global sea level[10], a lot more than in the worst-case scenario projected by semi-empirical models for 2050. And that contribution would be in addition to seawater expansion and melting of continental ice sheets.

Perhaps a more important argument is that the semi-empirical method does not treat mountain glaciers separately from ice sheets, but considers all ice as a continuum. The melting rate of an ice surface depends on the local climate, not on whether this ice surface is part of a small mountain glacier or a big ice sheet. The climatic conditions under which glaciers and ice sheets exist overlap. So, for example, the total ice surface found currently in regions with an annual mean air temperature of −12 °C consists of almost equal shares of ice from glaciers and ice sheets. In warmer regions the share from glaciers is larger, and in colder regions the share from ice sheets is larger. At −12 °C annual mean temperature, the ice is already affected by melting during some days of the year. As the global climate warms, some of the glacier ice will vanish, but this will be compensated for as ice at colder temperatures — including that from ice sheets — becomes subject to melting. The linear relationship in the semi-empirical formulae therefore holds because we are not going to run out of ice to melt any time soon.

But this view considers only surface mass balance, without taking account of the kind of rapid, nonlinear ice-flow changes that some glaciologists expect for the future. The semi-empirical approach has been criticized for not accounting for such changes; if they indeed lie in wait, this approach will, if anything, underestimate future sea level rise.

MELT MATH

Of the IPCC's central estimate, for the A1B scenario, of 35 centimetres of sea level rise by the 2090s, most — some 23 centimetres — is expected to result from thermal expansion of the ocean. If this is correct, we can subtract those 23 centimetres from our sea level rise estimate of 114 centimetres to give 91 centimetres, or 80 per cent of the total rise, that would need to come from land ice melting. Such a scenario is hardly inconceivable, given that land ice has, in fact, contributed 80 per cent of the observed sea level rise over the past five years[11].

If two-thirds of glacier ice were lost, this would add 40 centimetres to the global sea level, which is close to the lower bound of 37 centimetres recently estimated by glacier experts[12]. In that case, the percentage contribution of glacier melting to sea level rise would remain the same as in past decades[13]. The big ice sheets would then need to contribute only about 50 centimetres — corresponding to less than one per cent of their mass — to bring sea level rise up to 114 centimetres. None of this appears any less plausible than the IPCC's assumptions.

At the end of the last ice age, the Earth slowly warmed by 4–7 °C globally[14] and lost almost two-thirds of its land ice in the process. That raised sea level by 120 metres, at rates often exceeding a metre per century[1]. It seems that nothing in the present ice-sheet configuration would rule out similar rates in future[15]. How much of the remaining 65 metres' worth of land ice will humans melt if we warm the planet by a further several degrees?

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