Projections of future sea level becoming more dire

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Few of the possible impacts of future climate change have captured more public attention than sea-level rise. Globally, sea-level rise has accelerated since the 19th century, driven primarily by the expansion of warmer oceans and melting glaciers, along with a modest transfer of water into the ocean from the Earth's polar ice sheets. The observed rate of sea-level rise has not been uniform around the globe because of regional factors, but there is no doubt that the average sea-level trend is upwards (1). Implications for the rates and magnitudes of future sea-level rise are less clear, and a new study in this issue of PNAS (2) provides useful insight into how sea level will change through this century and beyond.

There are two main types of sea-level information needed to inform the development of effective climate change policy. First are estimates of the sea-level rise expected in the relative near term, namely by the end of the century. Second are estimates of the sea-level rise that will occur further into the future over many centuries as ice sheets and oceans come into equilibrium with a warmer atmosphere.

The Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC) (1) was unable to provide a strong constraint on estimates of sea-level rise likely to occur by the end of this century. Their projection of 0.26- to 0.59-m sea-level rise by 2100 (under the business as usual A1FI greenhouse gas emissions scenario; ref. 1) represents a lower-bound estimate because it excludes sea-level change caused by rapid dynamical changes in the flow of Greenland and Antarctic ice. The IPCC excluded this information because the quantitative understanding of the dynamics internal to the Earth's great ice sheets was too incomplete. Nonetheless, new research is emphasizing the importance of these poorly understood dynamics when assessing possible rates of future sea-level rise (3–6). Most recently, gravity measurements observed from space have revealed that mass loss from the Greenland and Antarctic ice sheets is accelerating with time and more closely approximates a quadratic trend than a linear one (7).

The observed acceleration in the decline of polar ice sheet mass provides all the more reason to take the new results from Vermeer and Rahmstorf (2) seriously. Their work provides a significant update of previous work (8) and uses the relationship between observed past temperature and global sea level to project a sea-level rise of 0.75–1.90 m for the period 1990–2100. Empirically, this relationship is nonlinear and reflects the evolution of a sea-level rise currently dominated by the warming of the oceans to one dominated by the melting of polar ice sheets. Interestingly, the range of sea-level rise by 2100 projected by Vermeer and Rahmstorf (2) coincides remarkably well with a completely independent assessment of glaciological constraints published last year (0.8–2.0 m; ref. 3).

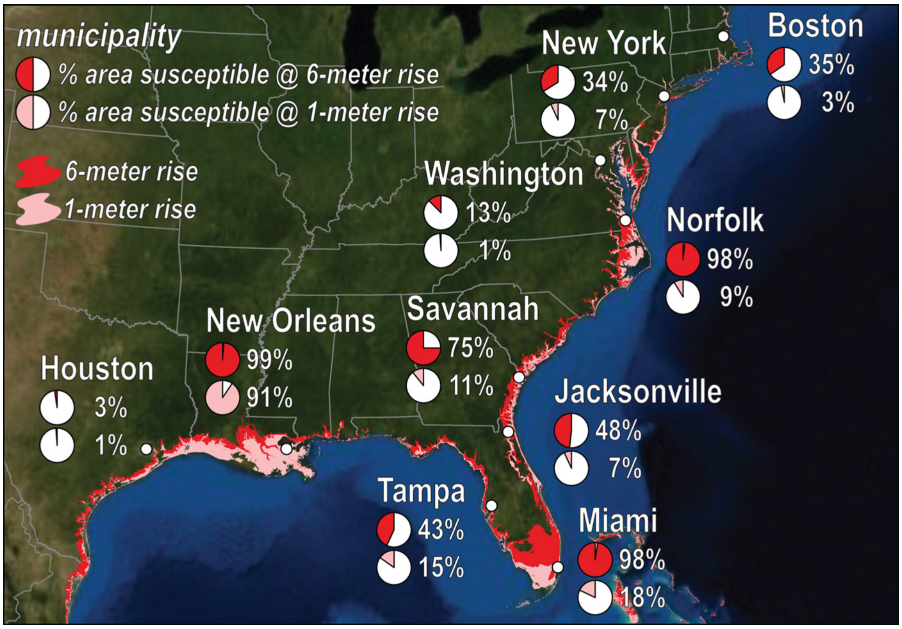

Fig. 1. Spatial extent of 1- and 6-m potential future sea-level rise along the East and Gulf coasts of the United States and for selected major coastal municipalities. Elevation and connectivity to the ocean determine sea-level rise extent. Proportion of land area within municipalities coincident with sea-level rise extent determines percentage of susceptible area. The U.S. Geological Survey and Census Bureau provided elevation and municipality boundary data, respectively.

The take-home point of the new work (2) and independent previous work (3) is that it would be wise to assume that global sea-level rise could significantly exceed 1 m by 2100 unless dramatic efforts are soon made to reduce global greenhouse gas emissions. It is sobering to see Vermeer and Rahmstorf's (2) result that modest reductions of emissions will likely be insufficient to preclude a meter of sea-level rise by 2100 or shortly thereafter and that much deeper cuts than those currently being given serious consideration by the world's political leaders are probably required to avoid the widespread large impacts of a 1-m sea-level rise on the East and Gulf coasts of the United States (Fig. 1) and elsewhere.

As highlighted by Vermeer and Rahmstorf (2), however, caution is warranted in using any relationship based on recent observed temperature and sea-level rise to project the future influence of polar ice sheet decay on sea level. The same holds true for efforts that rely on observed temperature and sea-level change of more distant periods when high-latitude ice sheets were much larger (9). In either case, the past is not necessarily a good analog for the future,

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and projections into a future dominated by the shrinking of interglacial-sized ice sheets are to some extent extrapolations. But again, as highlighted by Vermeer and Rahmstorf (2), glaciologists (3) are also concluding that future sea-level rise caused by this ice sheet behavior could be large.

Then there is the second type of sea-level information needed to inform climate change policy and adaptation. Vermeer and Rahmstorf (2) join an increasing body of work indicating that the relatively slow transfer of Greenland and Antarctic ice sheet mass into the oceans will likely become the primary determinant of sea-level rise later in this century. Just as important, it will take many centuries for these shrinking polar ice sheets and associated sea-level rise to stabilize with a warmer Earth. What policymakers need to know in this case is the amount of eventual sea-level rise to which the Earth will be committed for a given emissions trajectory in this century. In other words, what sea-level conditions will be forced on the future world community by the fossil fuel burners of this century?

A recent article in PNAS (10) shows that global warming will remain largely irreversible for at least 1,000 years after the cessation of greenhouse gas emissions. That article also notes that the persistent warmth could allow substantial ice sheet wastage for centuries to come. The recent IPCC report (1) weighed in on this issue as well, again with sea-level rise implications that may turn out to have been too conservative as new knowledge accumulates. The IPCC focused primarily on the potential demise of the Greenland Ice Sheet and its 7 m of sea-level rise equivalent, given a global warming of between 1.9 °C and 4.6 °C. More recent studies (3, 11), including that by Vermeer and Rahmstorf (2), additionally place emphasis on the Antarctic Ice Sheet as a potential source of eventual future large-scale sea-level rise, a conclusion supported by paleoclimatic and ice-sheet studies (12–15).

Global sea-level rise could significantly exceed 1 m by 2100.

The Antarctic Ice Sheet has many meters of potential sea-level rise to contribute in the future if warming is sufficient. Both the IPCC (1) and Overpeck et al. (13) suggest that warming in this century might be enough to commit future generations to 4–6 m of sea-level rise, or even more, beyond 2100 unless greenhouse gas emissions are reduced dramatically to keep the Earth from warming above ≈2 °C. The new and previously published constraints on rates (2, 3) also suggest that this future sea-level rise commitment could take place at rates approaching or exceeding 1 m per century. The impacts around the globe, including the United States (Fig. 1), would be profound and include the complete elimination of some island nations. This is one of the very real stakes facing those who set policy: should they knowingly allow this to happen?

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