2000 Years of Sea Level (+updates)

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- Climate Science
- Oceans
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— stefan @ 20 June 2011 - ()

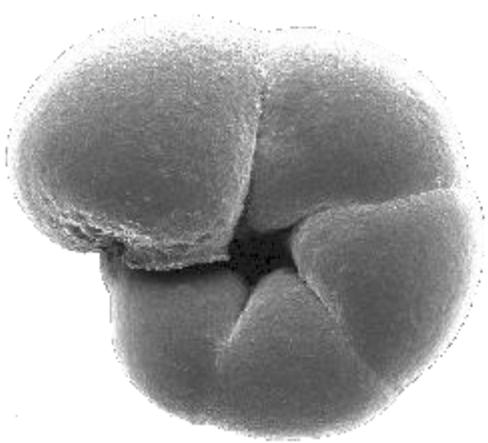
A group of colleagues have succeeded in producing the first continuous proxy record of sea level for the past 2000 years. According to this reconstruction, 20th-Century sea-level rise on the U.S. Atlantic coast is faster than at any time in the past two millennia.

Good data on past sea levels is hard to come by. Reconstructing the huge rise at the end of the last glacial (120 meters) is not too bad, because a few meters uncertainty in sea level or a few centuries in dating don't matter all that much. But to trace the subtle variations of the last millennia requires more precise methods.

Andrew Kemp, Ben Horton and Jeff Donnelly have developed such a method. They use sediments in salt marshes along the coast, which get regularly flooded by tides. When sea level rises the salt marsh grows upwards, because it traps sediments. The sediment layers accumulating in this way can be examined and dated. Their altitude as it depends on age already provides a rough sea level history.

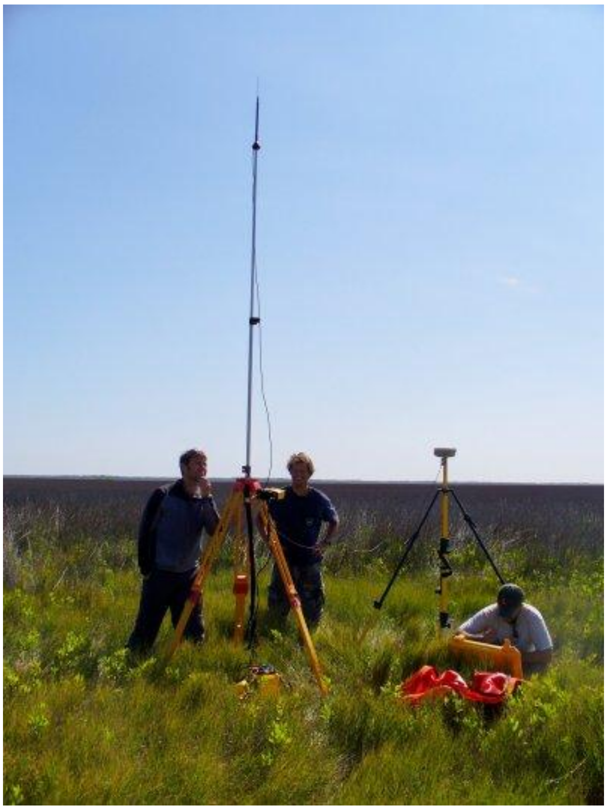
How is sea level reconstructed?

But then comes the laborious detail. Although on average the sediment buildup follows sea level, it sometimes lags behind when sea level rises rapidly, or catches up when sea level rises more slowly. Therefore we want to know how high, relative to mean sea level, the salt marsh was located at any given time. To determine this, we can exploit the fact that each level within the tidal range is characterized by a particular set of organisms that live there. This can be analyzed e.g. from the tiny shells of foraminifera (or forams for short) found in the sediment. For this purpose, the species and numbers of forams need to be determined under the microscope for each centimeter of sediment.



The foram Trochammina inflata under the microscope

To get a continuous record of good resolution, we need a site with a rapid, continuous sea level rise. Kemp and colleagues used salt marshes in North Carolina, where the land has steadily sunk by about two meters in the past two millennia due to glacial isostatic adjustment. Thus a roughly 2.5 meters long sediment core is obtained. The effect of land subsidence later needs to be subtracted out in order to obtain the sea level rise proper.

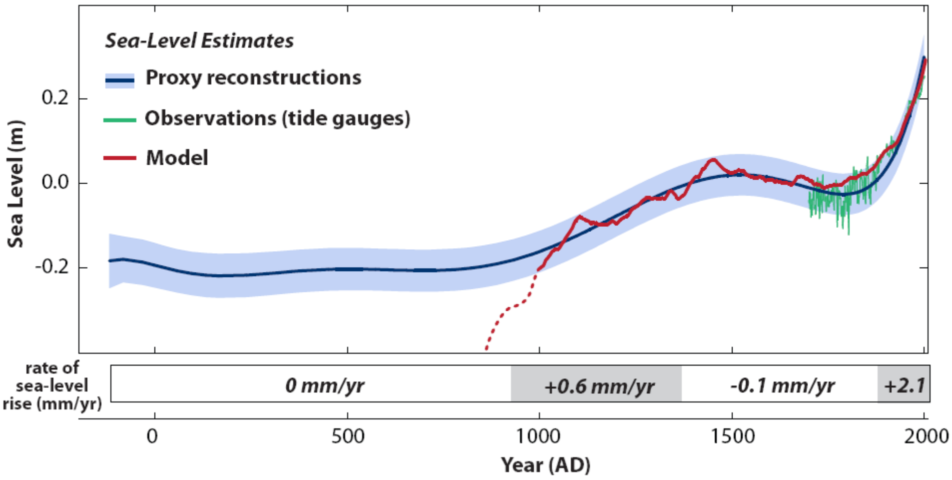


Ben Horton and Reide CorbettPostdocs Andy Kemp and Simon Engelhart in the field at Tump Sand Point, one of the study sites [Sorry for photo mix-up]

How did sea level evolve?

The graph shows how sea level changed over the past 2000 years. There are four phases:

- Stable sea level from 200 BC until 1000 AD
- A 400-year rise by about 6 cm per century up to 1400 AD
- Another stable period from 1400 AD up to the late 19th C
- A rapid rise by about 20 cm since.



Sea level evolution in North Carolina from proxy data (blue curve with uncertainty range). Local land subsidence is already removed. The green curve shows ~~measurements from a nearby tide gauge~~ a reconstruction based on tide gauges from around the world (Jevrejeva et al. 2006, 2008). The red curve shows results from a simple model connecting global temperature with sea level. For the last millennium the sea level curve follows what can be expected from temperature – the two independent reconstructions thus mutually reinforce each other by their consistency. Before 1000 AD there is a discrepancy: warm temperatures in the reconstruction used would lead to rising sea level, but the sea level reconstruction is flat. However, temperature data from before 1000 AD are sparse and less reliable, and lowering temperatures in this period by only 0.2ºC removes the discrepancy. Thus, a possible explanation for the discrepancy is that the temperature reconstruction is a little too warm before 1000 AD.

These data are valid for North Carolina, where they are also in agreement with a local tide gauge ~~(green)~~(Fig. 2 in the paper). But they also agree with another proxy data set from Massachusetts. Sea level changes along the US Atlantic coast do not need to fully coincide with global mean sea level, however. Even though the level rises uniformly if I fill water into my bath tub, the ocean has a number of mechanisms by which local sea level can deviate from global sea level. One of these mechanisms can also occur in the tub: the water can "slosh around", in the oceans on multidecadal time scales. And there are some other factors as well, like changing ocean currents or changes in the gravitational field (due to melting continental ice). In the paper these factors are estimated and it is concluded that the North Carolina curve should be within about 10 cm of global mean sea level.

Connection to climate

I was involved in this study, together with Martin Vermeer and Mike Mann, to analyse the connection of the sea level data with climate evolution. We used a simple semi-empirical model, which basically assumes that the rate of sea level rise is proportional to temperature. In other words: the warmer it gets, the faster the sea level rises. This connection has already been established for the past 130 years, but it also works well for the past millennium (red curve). There is a discrepancy before 1000 AD (see figure caption).

According to this model, the rise after about 1000 AD is due to the warm medieval temperatures and the stable sea level after 1400 AD is a consequence of the cooler "Little Ice Age" period. Then follows a steep rise associated with modern global warming. Modern tide gauge and satellite measurements indicate that sea level rise has accelerated further within the 20th Century.

Reference: Kemp et al., Climate related sea-level variations over the past two millennia, PNAS 2011.

Further info on sea level: see the PIK sea level pages.

Update 21. June. I'd like to clarify two issues that have come up in discussion of our paper.

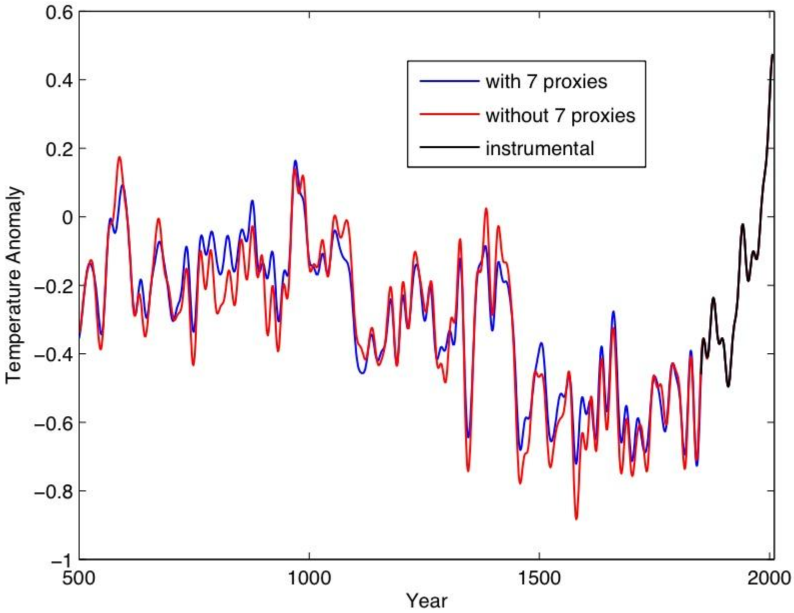
The first is: what can we learn from this for future sea level? A proper answer has to be given in another paper, but we can note now that the model fit to the new proxy data is highly consistent with the fit we obtained in 2009 to the tide gauge data. Hence it implies almost the same future projections as in our 2009 paper (75-190 cm by 2100).

The second issue is a misunderstanding of our Fig. 4D. The blue and green curves shown there, labelled Rahmstorf (2007) and Vermeer & Rahmstorf (2009), do *not* show sea level predictions we made in those earlier papers. They show new predictions (or rather hindcasts) *with the model equations* used in those two papers, for comparison with the more sophisticated equation used in the present paper. As we write in the paper: "These two models were designed to describe only the short-term response, but are in good agreement with reconstructed sea level for the past 700 y." The former means we never used them to compute long-range hindcasts – they are merely shown here for comparison purposes, so that readers can see what difference the additional term in Eq. 2 actually makes. And the good agreement for the past 700 years was quite a surprise to me – I did not expect these simple models to hold up for such a long time scale.

Update 2 (June 23)

People have asked whether the use of the Tiljander proxies in the Mann et al (2008) EIV surface temperature reconstructions matters for the conclusions of this or any related studies. The answer, as provided previously in the literature (see this reply to a comment in PNAS) is no.

The impact of whether or not these proxies are used was demonstrated to be minimal for the Northern Hemisphere land+ocean EIV reconstruction featured in Mann et al (2008) [see Figure S7b of the Supplementary Information of that article, which compares the reconstruction both with and without 7 potential 'problem proxies', that include the Tiljander proxies; a similar comparison was also made in Figure S8 of the Supplementary Information for the followup article by Mann et al (2009)] . The same holds for the specific global mean EIV temperature reconstruction used in the present study as shown in the graph below (interestingly, eliminating the proxies in question actually makes the reconstruction overall slightly *cooler* prior to AD 1000, which–as noted in the article–would actually bring the semi-empirical sea level estimate into *closer* agreement with the sea level reconstruction prior to AD 1000).



Comparison of Mann et al (2008) global mean (land+ocean) temperature reconstruction with and without the 7 proxy records discussed in the text [shown in both cases is the low-frequency (>20 year timescale) component of the reconstruction]. Reconstruction is based on calibration against the HadCRUT3 series using the global proxy network

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References:

Mann, M.E., Zhang, Z., Hughes, M.K., Bradley, R.S., Miller, S.K., Rutherford, S., Proxy-Based Reconstructions of Hemispheric and Global Surface Temperature Variations over the Past Two Millennia, *Proc. Natl. Acad. Sci.*, 105, 13252-13257, 2008

Mann, M.E., Zhang, Z., Rutherford, S., Bradley, R.S., Hughes, M.K., Shindell, D., Ammann, C., Faluvegi, G., Ni, F., Global Signatures and Dynamical Origins of the Little Ice Age and Medieval Climate Anomaly, *Science*, 326, 1256-1260, 2009