

Improved estimates of upper-ocean warming: implications for climate models and sea-level rise

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Puzzles about ocean warming and sea-level rise

Two key uncertainties in the 2007 Intergovernmental Panel on Climate Change Report^{1,2} (IPCC AR4) are:

- (1) Global mean sea-level rise from 1961 to 2003 is larger than the sum of all known contributions.
- (2) The large decadal variability in global mean ocean heat content (thermometric sea level) observed during the 1970-1980s is not reproduced by climate models.

What are the difficulties?

Incomplete global coverage could result in inaccurate (possibly biased) estimates of global ocean heat content.

Systematic biases have been discovered³ in temperature data from expendable Bathy-Thermographs (XBTs), associated with errors in the estimated depth. XBT data comprise more than 50% of the ocean observing system.

Objective

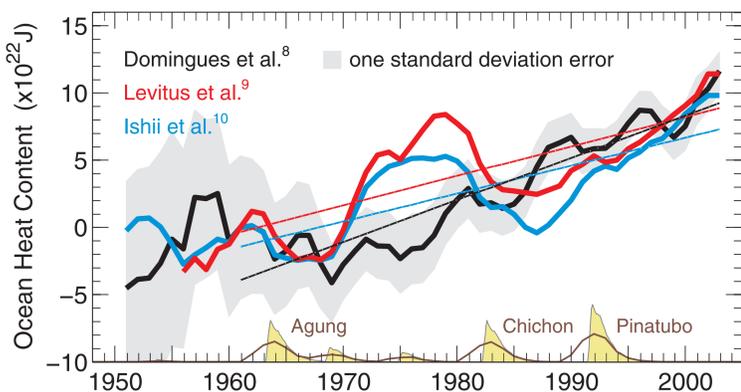
To estimate quasi-global (65°S to 65°N) ocean heat content and thermometric sea level for the upper 700 m of the oceans, from 1950 to 2003.

Method

We use a reduced-space optimal interpolation technique^{4,5,6} to recover the large-scale robust climate signals that can be derived from sparse ocean data. To minimise the XBT biases, we apply a recent time-variable fall-rate correction⁷.

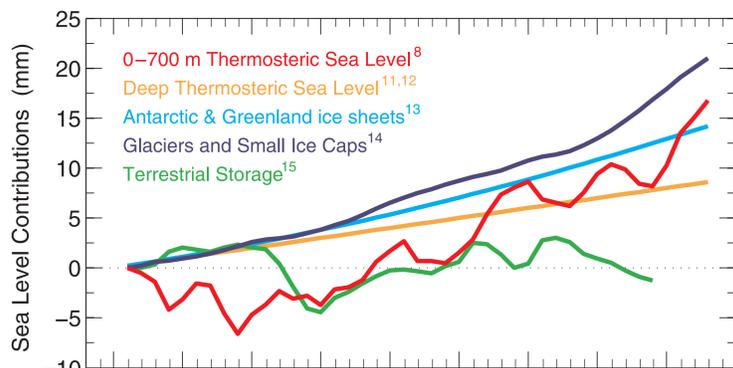


Comparison with previous upper-ocean (0–700 m) estimates



Our ocean warming (black) trends for 1961–2003 are about 50% larger than earlier estimates but about 40% smaller for 1993–2003. The large rise in the early 1970s and the subsequent fall, which dominate previous estimates, are mainly the result of instrumental biases⁷.

The multi-decadal sea level budget



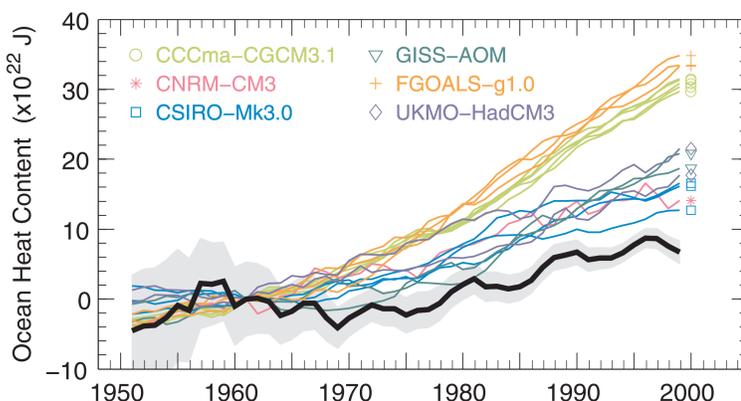
The sum of all contributions is consistent with the observed sea-level rise from 1961 to 2003.

The different decadal variability is probably an indication of the uncertainty in the estimates and the (unknown) variability in the cryospheric and deep-ocean contributions.

Satellite altimeter sea level diverges after 1999, implying a higher rate of rise. It is unclear why the *in situ* and satellite estimates diverge, and careful comparison is urgently needed.

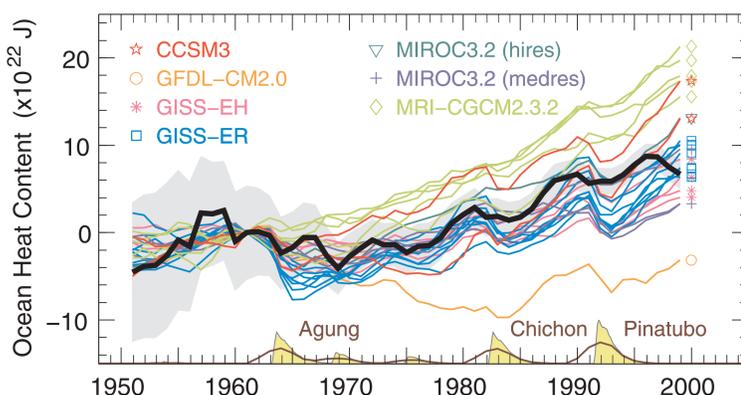
Comparison with climate model simulations including anthropogenic and other forcings

Models without volcanic forcing

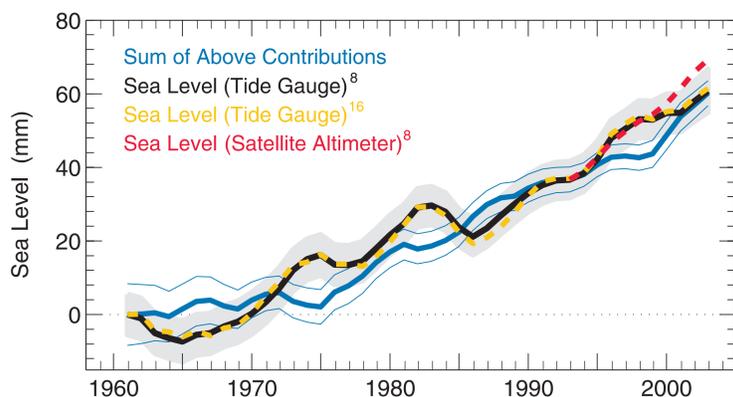


The decadal variability in models without volcanic forcing is not in good agreement with the observations. The simulated multi-decadal trends overestimate the observed ocean warming.

Models with volcanic forcing



The decadal variability in models that include volcanic forcing is in good agreement with the observations. The simulated multi-decadal trends tend to underestimate the observed ocean warming (30% smaller in the upper 300 m and 10% smaller in the upper 700 m).



Conclusions

Our estimates show that the rate of ocean warming and thermometric rise from 1961 to 2003 is about 50% larger than previously reported.

The closure of the sea level budget over multi-decadal periods, and the agreement of the observed and simulated ocean heat content decadal variability, increase confidence in the present results and represent progress since the last two IPCC reports^{1,17}.

There is an ongoing need for careful quality control of ocean data and continuous monitoring of the oceans using diverse observations that can be checked against each other.

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Acknowledgements

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