Geographical patterns of thermosteric sea level: observations and CMIP3 climate model simulations

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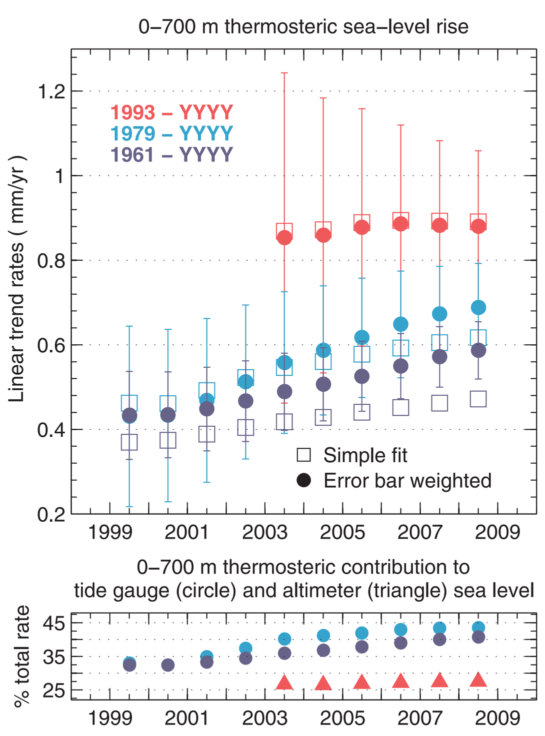
Thermosteric sea level is a major factor contributing to the observed global mean sea-level rise in the latter half of the 20th century[1,2] and is likely to continue to be one of the largest contributing factors in the 21st century[3]. Geographical patterns of sea-level rise are produced in response to dynamical processes[4,5]. Coupled Model Intercomparison Project (CMIP3) model simulations disagree in geographical patterns. Comparisons with observations are required to help understand these differences and to increase confidence in projections of regional sea-level rise[3,6,7]. Here, we describe updated 0-700 m thermosteric sea level estimates[1] for 1961-2008, at global and regional scales, including pressure-corrected Argo data[8].

Objectives

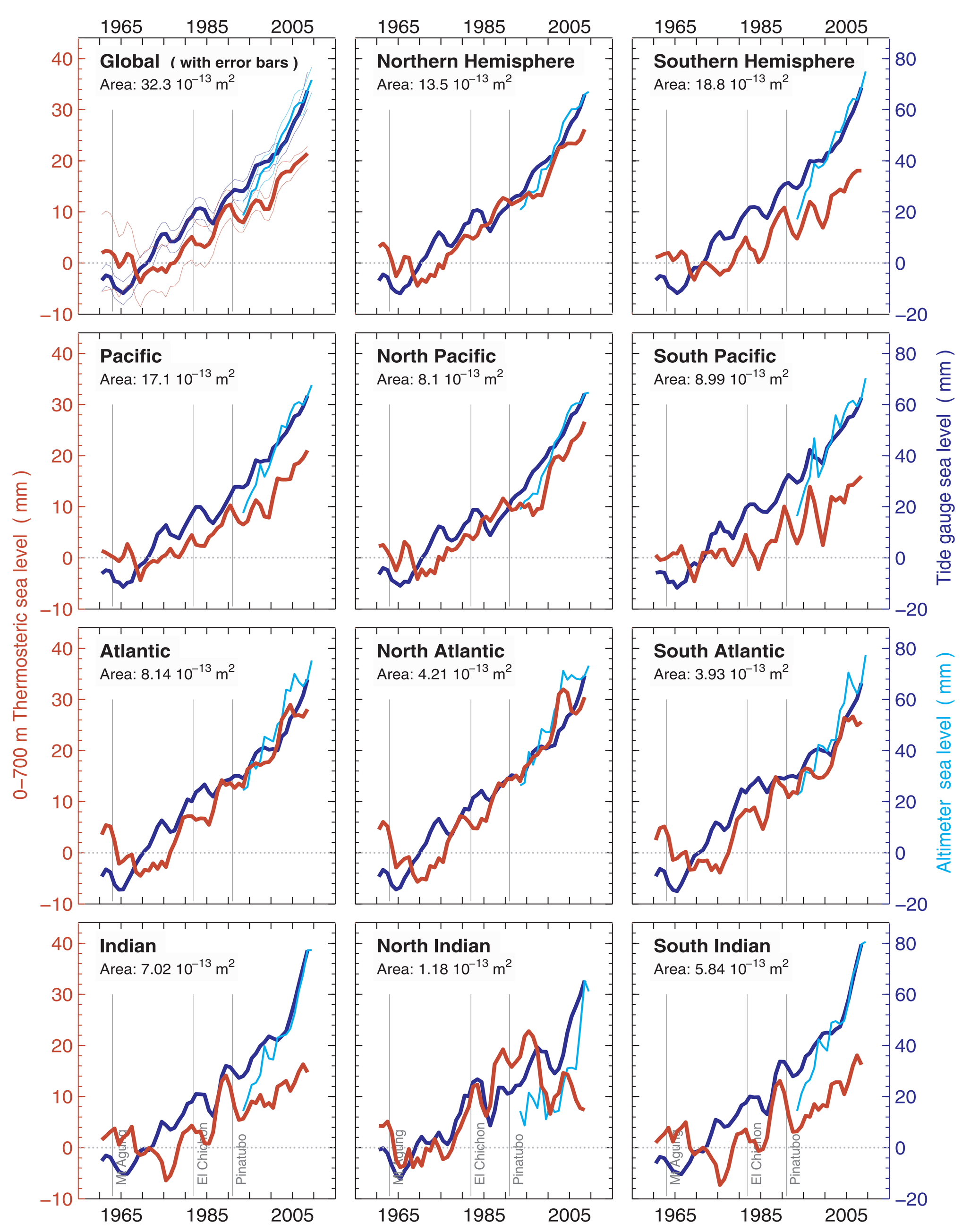
- To describe the regional patterns of upper ocean thermosteric sea-level rise.
- To compare our upper ocean thermosteric sea-level estimates with sea level estimates from tide gauges[2] and altimeter as well as with CMIP3 climate model simulations.



Global mean trends

Upper ocean global mean thermosteric sea level estimates indicate a multidecadal trend rise of 0.59 ± 0.07 mm yr^{-1} for 1961-2008; 0.62 ± 0.07 mm yr^{-1} for 1979-2008; and 0.88 ± 0.18 mm yr^{-1} for 1993-2008. Historical trends are likely underestimated if not weighted by their time-dependent errors.

Upper ocean thermosteric sea level contributes about 35 to 45% of the global mean observed sea-level rise from 1961/1979 to 2003/2008 (filled circles). From 1993 to 2003/2008, the contribution is smaller, about 25 to 30% (red triangles).



Global and basin time series

Updated sea level[2] (blue curves, tide gauge and altimeter) and thermosteric sea level[1] (red curves) estimates indicate multidecadal rise at global and basin scales. The Atlantic Ocean has the fastest warming rates, followed by the Pacific and Indian Oceans. Faster rise is observed in the northern hemisphere, particularly in the Atlantic and Pacific. Interannual to interdecadal variability seems larger in the southern hemisphere oceans, where there are fewer in situ observations. Variability in sea level is not necessarily mirrored in upper ocean thermosteric sea level. The impact of major volcanic eruptions (vertical lines) is evident in the global mean and in most of the ocean basin time series.

Acknowledgments

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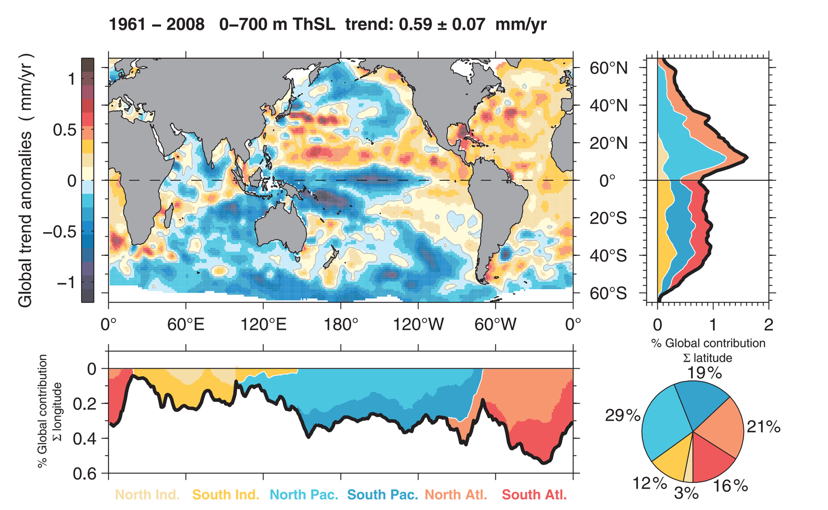
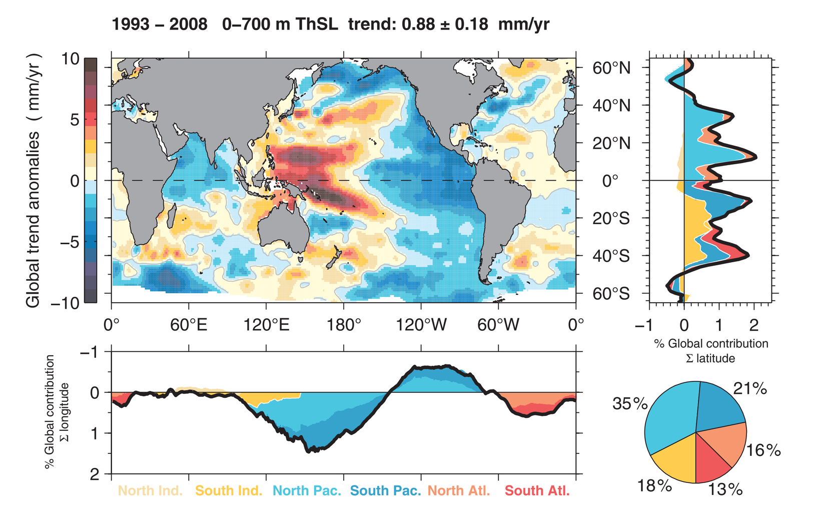
Basin contribution and regional trend patterns

For 1961 to 2008, regional thermosteric trends are greater than the global mean value in the Atlantic Ocean, along 20°N in the Pacific Ocean as well as near its eastern side. Geographical patterns for 1979-2008 and 1993-2008 correlate well with each other but differ from the 1961-2008 pattern. In the 1979/1993-2008 periods, the largest trends are centred around the Australia-Asia-Pacific region while the lowest trends are in the eastern Pacific (e.g. ENSO/PDO-like structure). Despite regional pattern sensitivity to trend periods, basin contributions to the global mean trend are relatively steady: about 15% for the Indian Ocean, 35% for the Atlantic Ocean and 50% for the Pacific Ocean. Thermosteric and altimeter/tide gauge sea level trends for 1993-2008 are highly correlated (not shown), however, this correlation is smaller for historical periods. The residuals between these fields for different trend periods (not shown) tend to be larger in the southern hemisphere, where there are fewer tide gauges and ocean temperature observations.

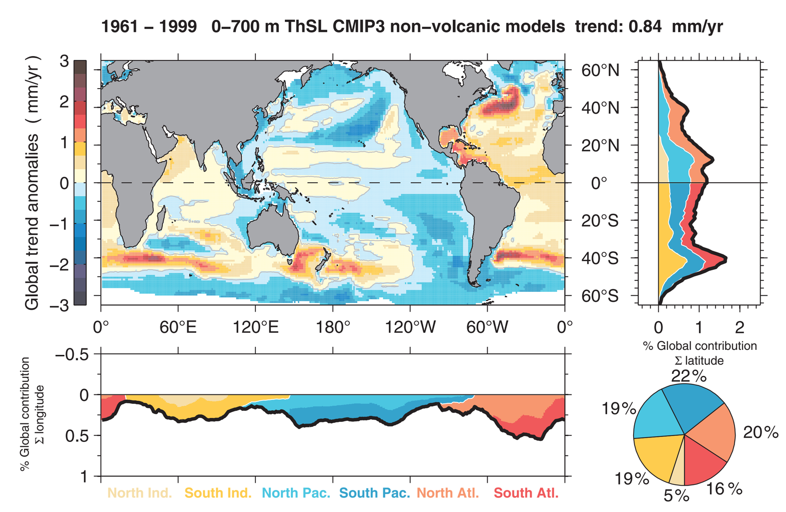


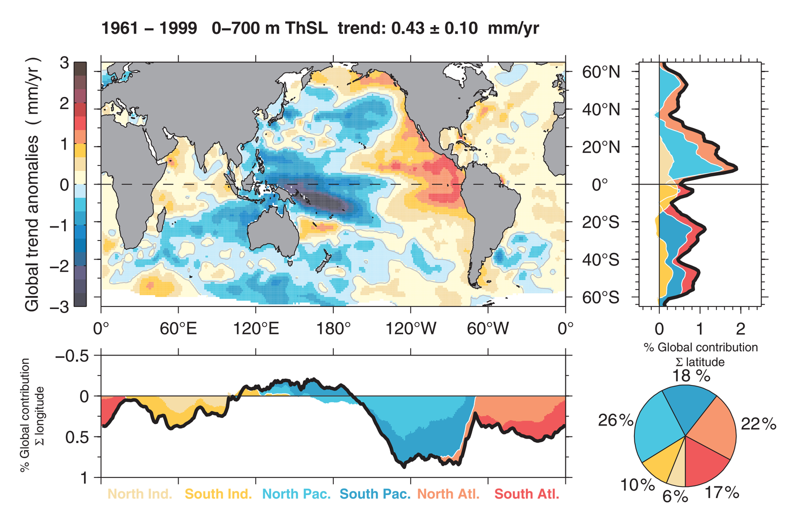


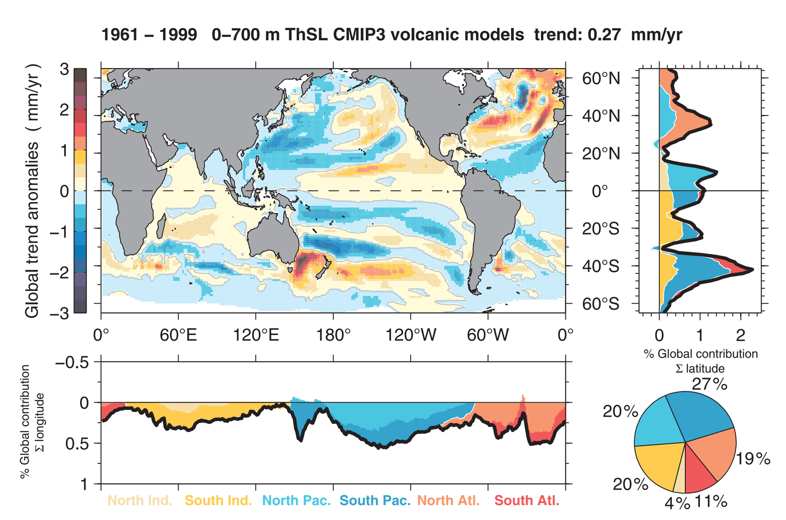
Comparison with CMIP3 models (1961–1999)

The ensemble average of models without volcanic forcing (no-V, top) has twice the observed global mean thermosteric sea level trend, show an obvious warming along 40°S not seen in the observations, and lack the geographical patterns observed (middle) in the Pacific Ocean. The regional patterns in the Pacific Ocean from the ensemble average of models with volcanic forcing (V, bottom) are closer to the observations but agree less in the South Atlantic and South Indian. The V-models underestimate the observed global mean trend and show an obvious warming along 40°S in the South Pacific, not clear in the observations.

The basin contributions to the simulated global mean trend in no-V and V models are similar: about 25% for the Indian Ocean, 30-35% for the Atlantic Ocean and 40-45% for the Pacific Ocean.







Conclusions

Updated thermosteric sea level estimates indicate a global rise of about 0.59 ± 0.07 mm yr^{-1} for 1961-2008 in the upper 700 m of the oceans, with 15% from the Indian Ocean, 35% from the Atlantic Ocean and 50% from the Pacific Ocean. The thermosteric contribution is about 35 to 45% of the global mean observed sea-level rise.

Geographical patterns of observed thermosteric sea level change are complex and sensitive to the periods over which trends are calculated. Comparison with CMIP3 simulations (1961-1999) shows that no-V models lack the observed Pacific Ocean trend patterns and overestimate the observed global mean trend. V-models compare better with observed Pacific patterns but agree less in the South Atlantic/Indian oceans. They also underestimate the observed global mean trend. Thermosteric sea-level rise along 40°S is strikingly stronger in no-V than in V-models but intriguingly missing in our observed patterns.

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