State of steric sea level rise, 1955-2008

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Definition

The "thermosteric component of sea level change" represents the change of sea level due to warming or cooling of a column of sea water.

Warming of a sea water column results in higher sea level

and

cooling of a sea water column results in lower sea level.

Data and methods

Used all data in the *World Ocean Database* as of January 11, 2009.
All data are available online at: www.nodc.noaa.gov

Data are corrected for all known problems with Argo profiling floats.

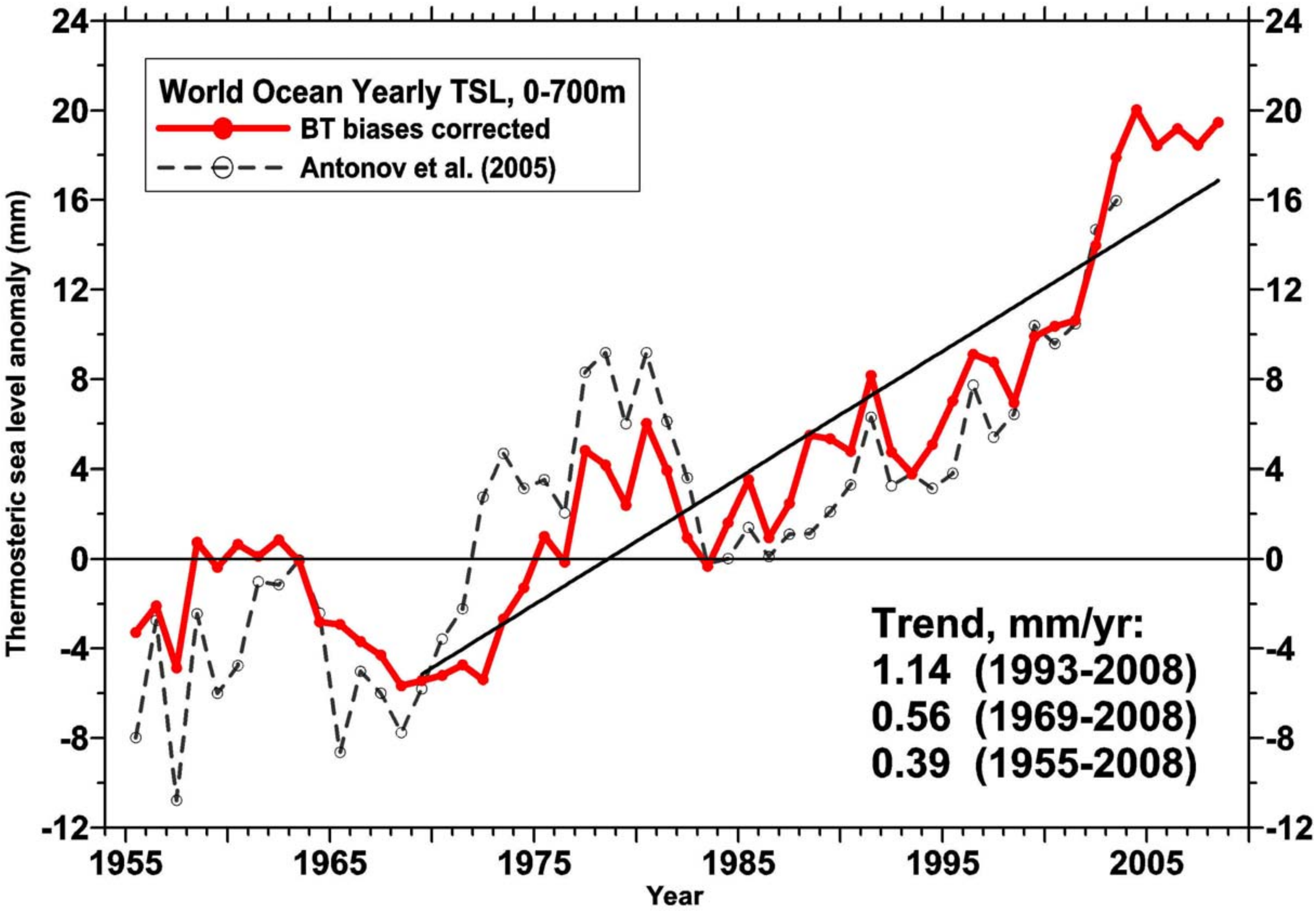
Data are corrected for XBT and MBT biases identified by Gouretski & Koltermann (2007),

but,

XBT bias correction is an ongoing subject of investigation.

Thermosteric component of sea level change (mm), 0-700 m [1955-2008]

The observed rise is consistent with the rise expected due to the observed increase of greenhouse gases (GHGs) in earth's atmosphere and with AOGCMs forced by increasing GHGs.



Results - 1

1) Applying XBT bias corrections substantially reduces the interdecadal variability that existed in our previously published time series of ocean heat content and the thermosteric component of sea level change.

   We agree with Gouretski and Koltermann (2007) and other studies about this.

2) Even so, the trends in ocean heat content and the thermosteric component of sea level change are similar to what we have previously estimated,

   e.g., for the thermosteric component of sea level change:

   trend: ~0.4-0.5 mm/year.

3) The statement by Gouretski and Koltermann (2007) that application of their XBT and MBT bias correction leads to a reduction in ocean heat content (and hence the thermosteric component of sea level change) by a factor of 0.68 for the 0-300 m layer and 0.6 for the 0-3000m layer between the 1957-1966 and 1996 is not supported by this or any other studies.

Results - 2

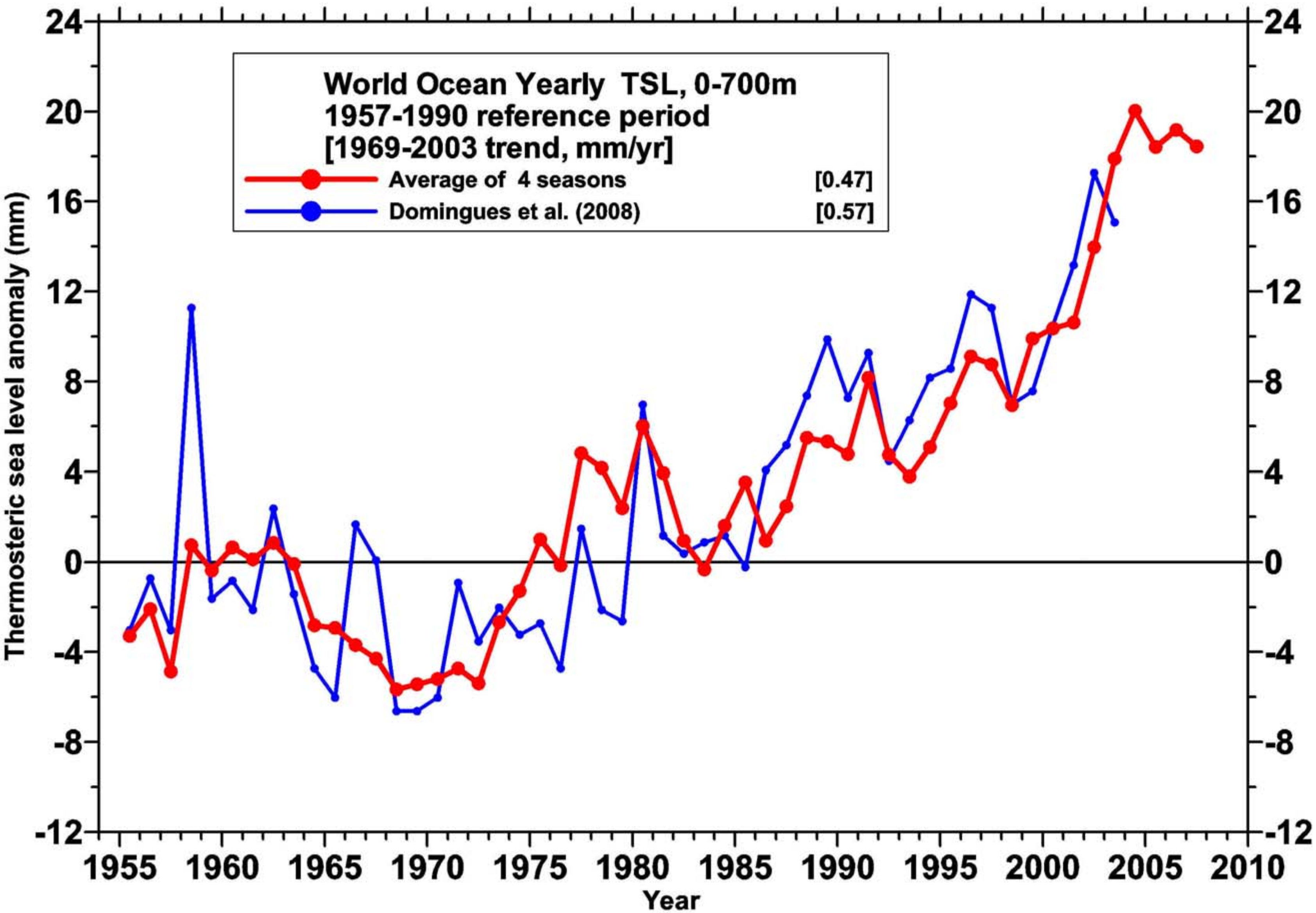
Domingues *et al.* (2008) have obtained similar results using:

a) **the Wijffels *et al*. (2008) XBT bias corrections;**

b) **altimeter data as well as *in situ* temperature profiles;**

c) **the Reduced Space Optimum Interpolation technique of Alexey Kaplan.**

Comparison between present work and the estimate by Domingues *et al*. (2008) [Thermosteric component of sea level change , 0-700 m]



Results - 3

However,

when we apply the Wijffels *et al.* (2008) corrections to our temperature profile database we obtain somewhat different results for the post-1992 period as compared to Domingues *et al*. (2008) and our present work.

This suggests that the use of altimeter data

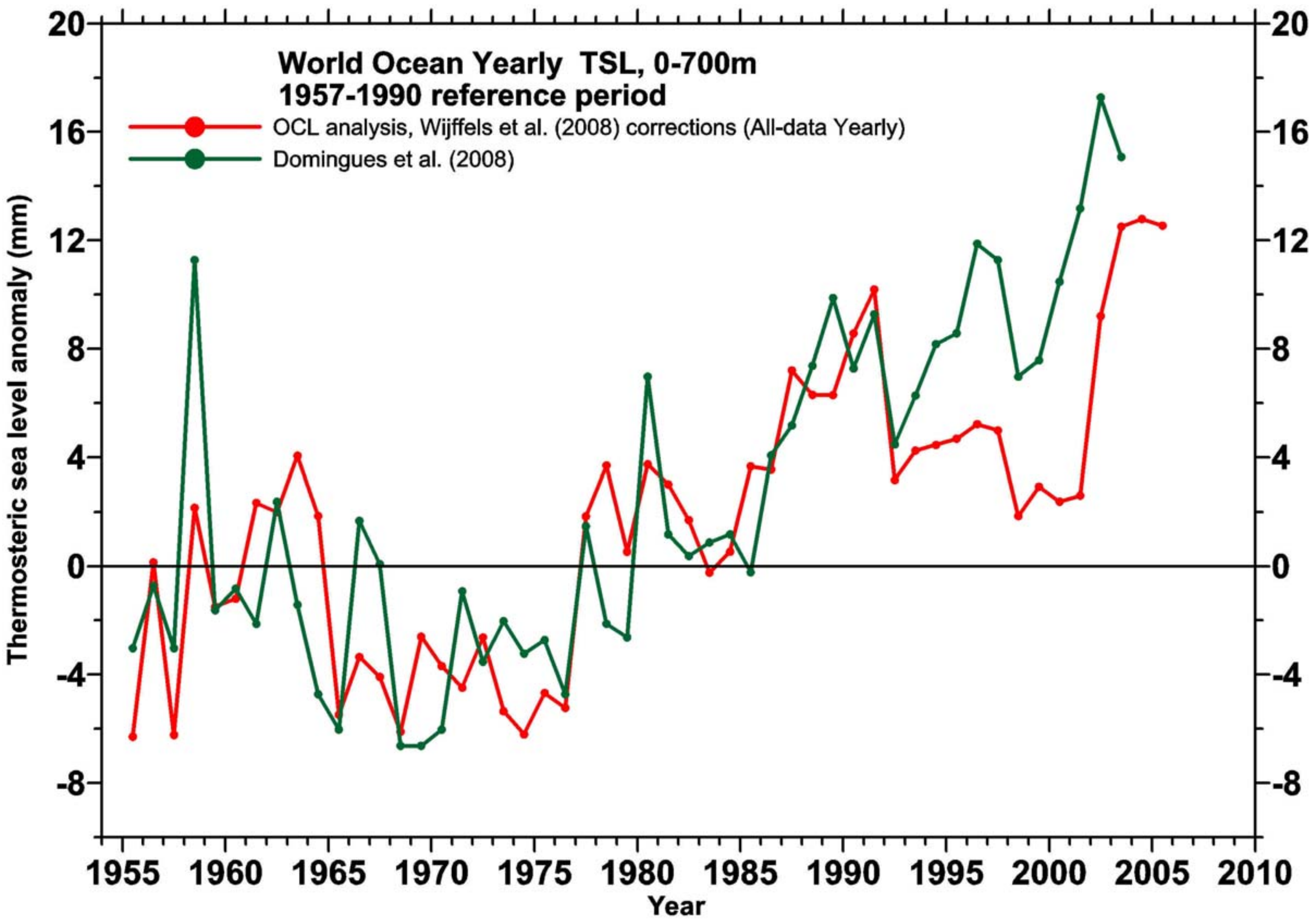
and the

Reduced Space Optimum Interpolation (RSOI) technique used by Domingues *et al.*

to estimate the thermosteric component of sea level change has a substantial effect on the estimation of this quantity for the post-1992 period which is the period for which we have altimeter data.

The Domingues *et al.* estimate is similar to our direct data-based estimate prior to 1993 except that is has high frequency variability that is larger in amplitude than our own estimates. Which analysis is "more" correct?

Comparison between present work and estimate made by applying the Wijffels *et al.* (2008) XBT corrections to WOD data. [Thermosteric component of sea level change , 0-700 m]



Results - 4

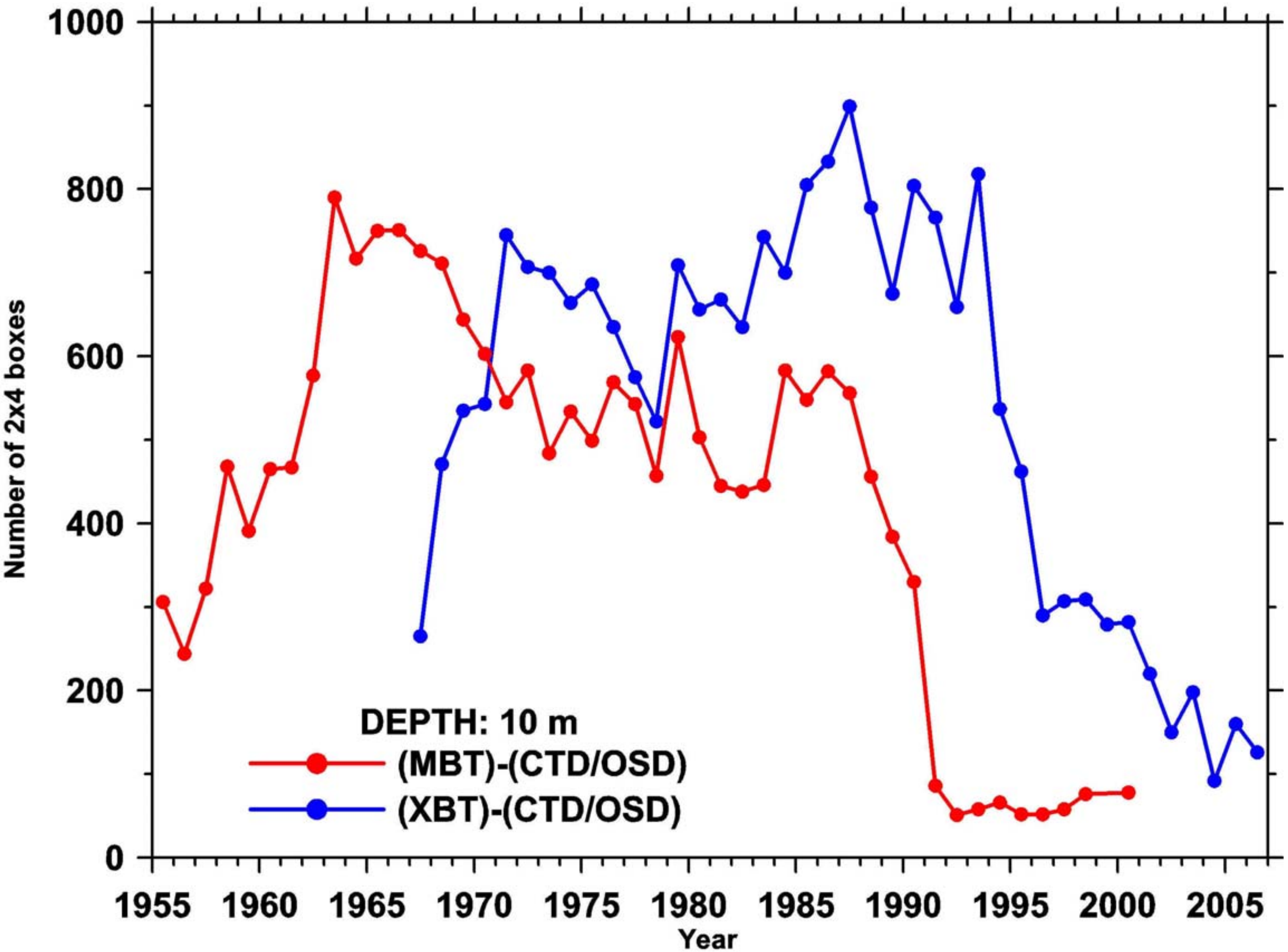
Similar to the work we have done with the *Wijffels et al.* (2008) XBT bias corrections,

we have applied the XBT bias corrections of Ishii and Kimoto (2009) to our database.

We obtain very good correspondence (not shown) between our ocean heat content estimates and hence our estimates of the thermosteric component of sea level change.

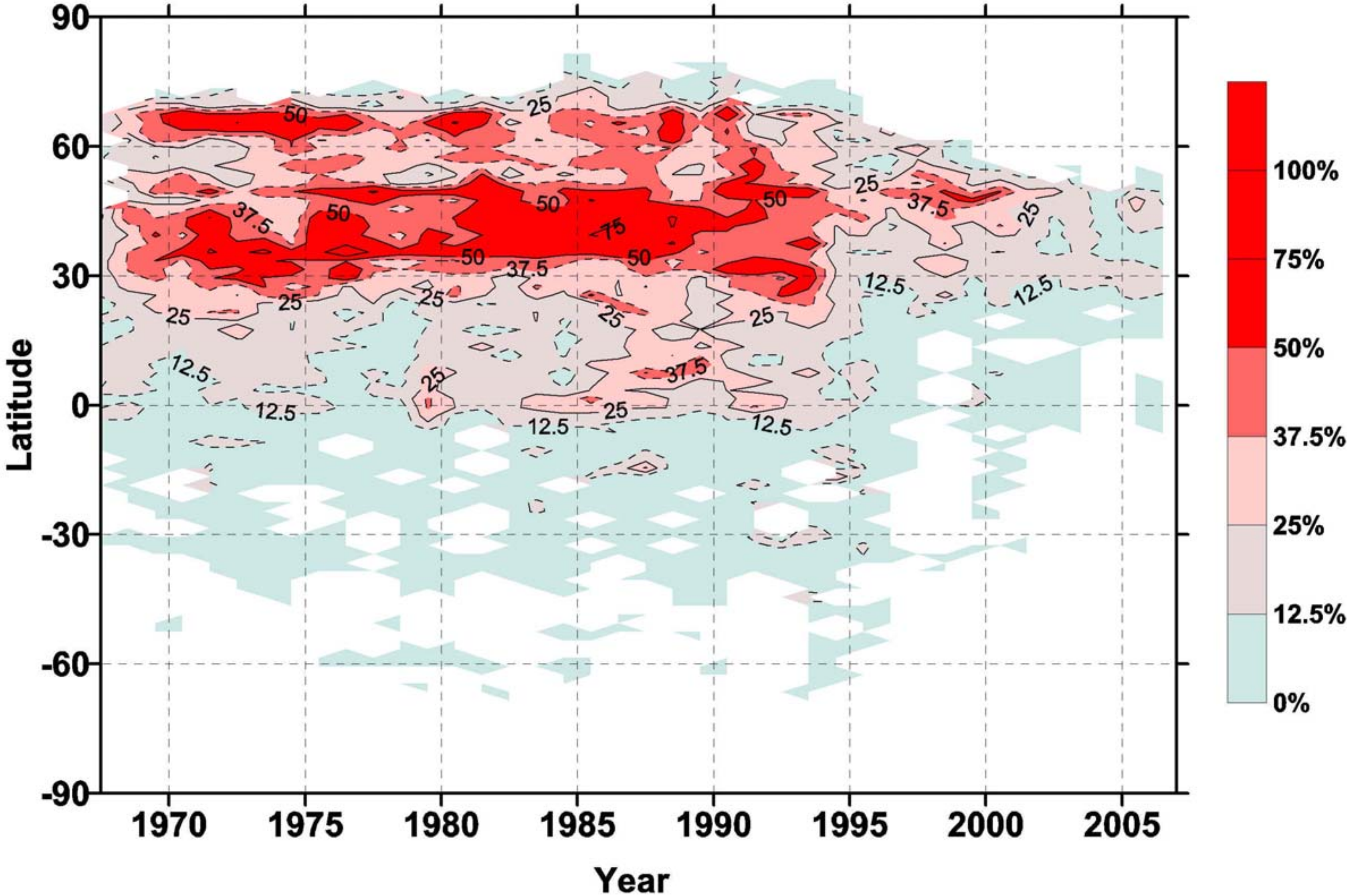
However, no technique developed to eliminate XBT biases does so completely and more work remains to improve the corrections of these biases.

Time series of the number of 2° x 4° boxes per year of the MBT minus OSD/CTD difference pairs and a similar series for XBT minus OSD/CTD difference pairs. These difference pairs are used to generate our T corrections. Need more difference pairs for this technique to work better.



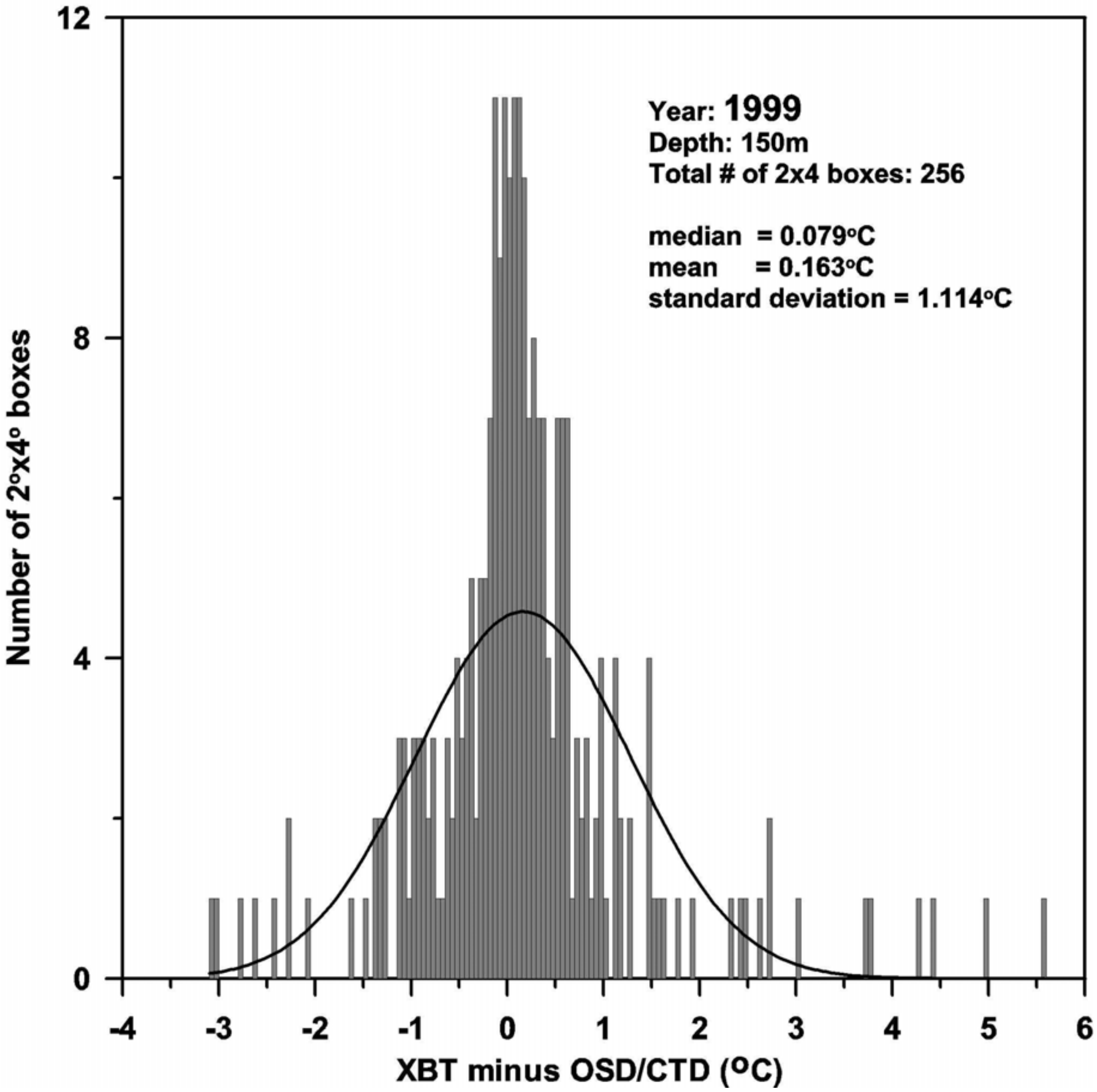
Location of XBT/(OSD/CTD) station pairs used to compute the XBT bias.
(% area having difference pairs in each 1° latitude belt.

Strong northern hemisphere difference pair bias as there is with the actual data.

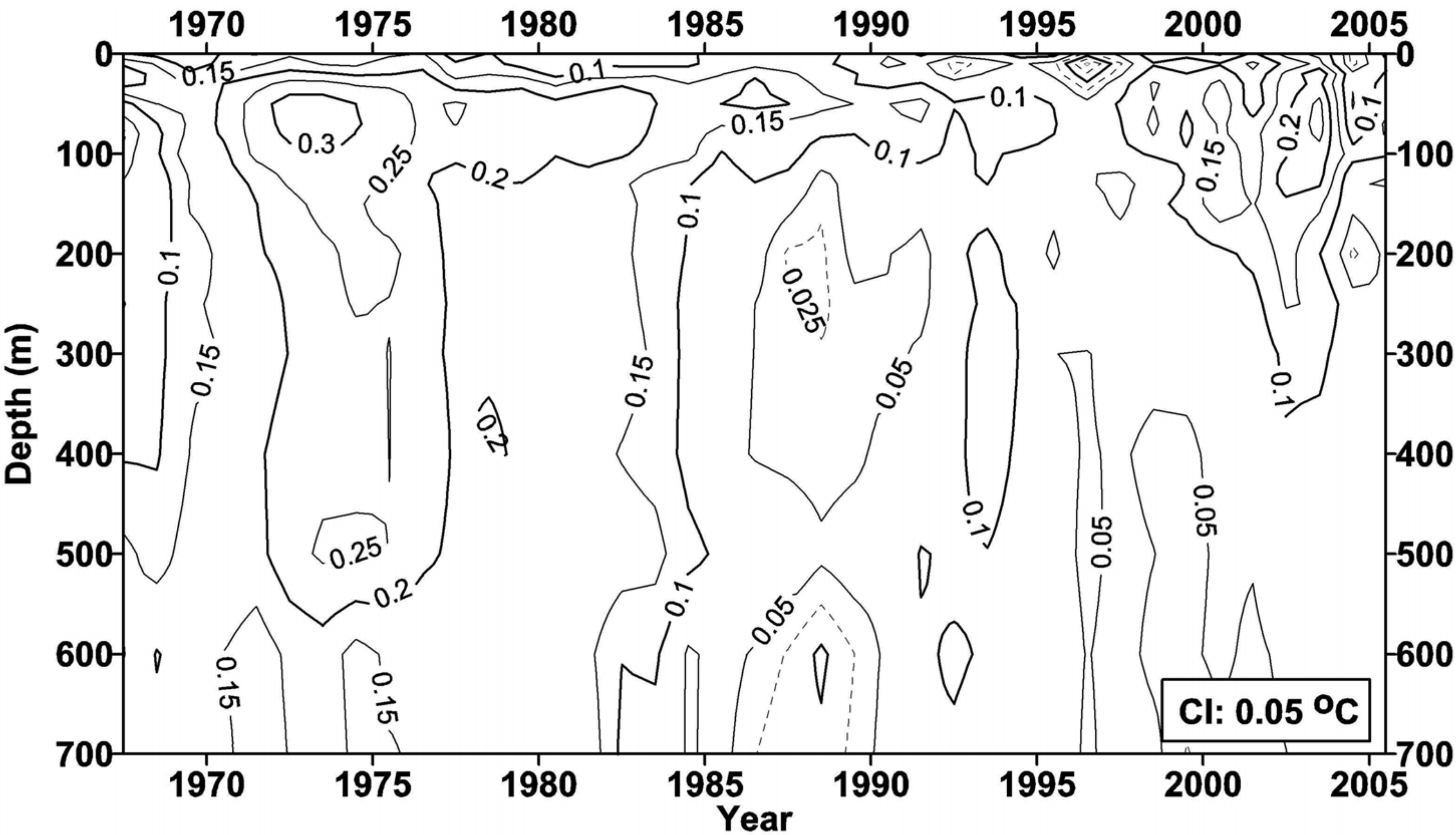


Frequency distribution of 2 x 4 XBT minus OSD/CTD temperature differences (°C) for 1999 at 150 m depth. Median need to be used.

°C



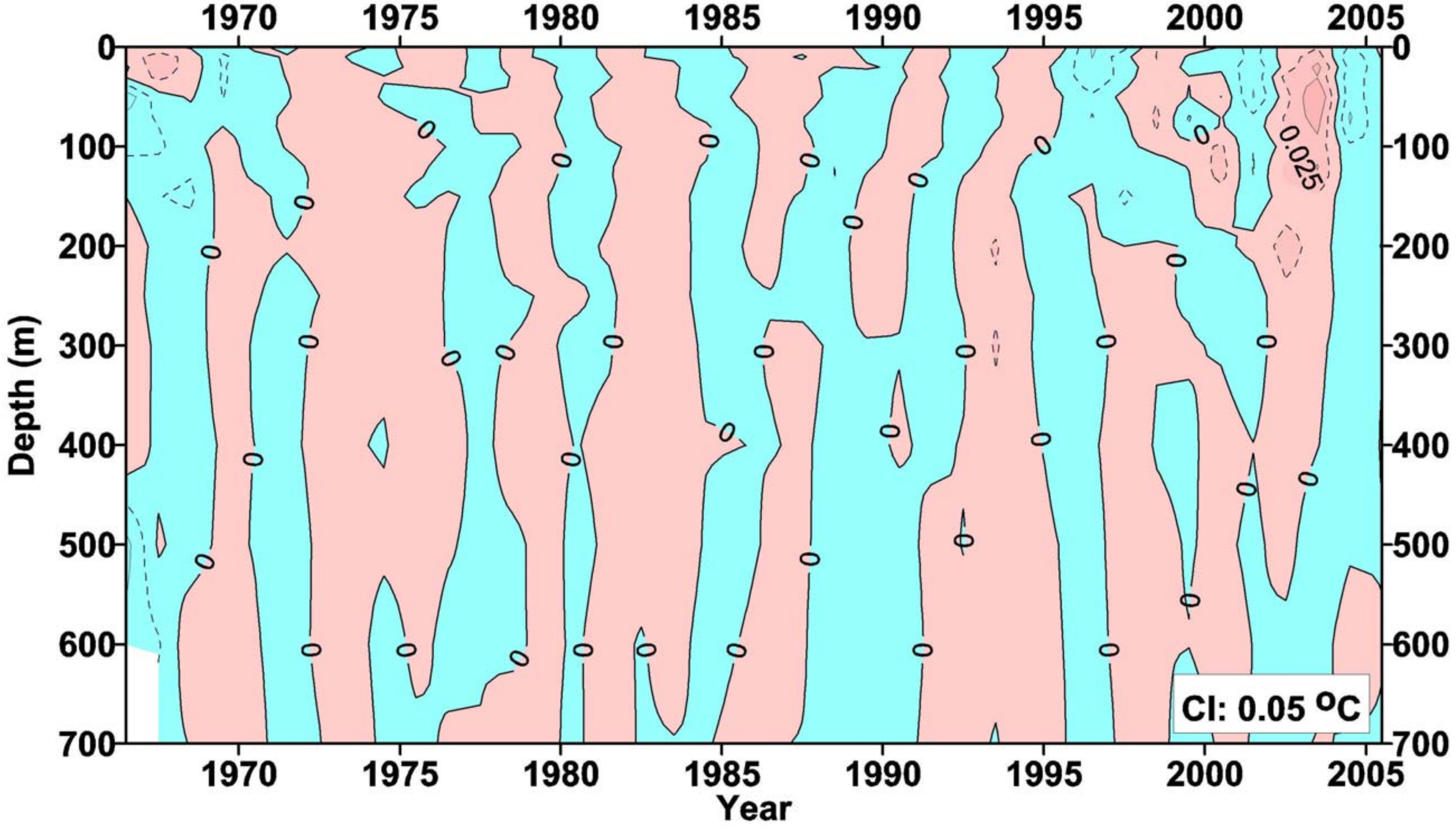
Temperature values we used to correct XBT bias



Time series of the offsets (°C) between XBT and OSD/CTD based on the median of the offsets after bias corrections have been applied twice.

After the first application new T profiles computed to reduce the bias in our monthly T climatologies that we use to remove the effect of the annual cycle from each standard depth temperature observation.

Calculations are based on at least 30 2°x 4° boxes per year and level. Red indicates positive value, blue indicates negative values.

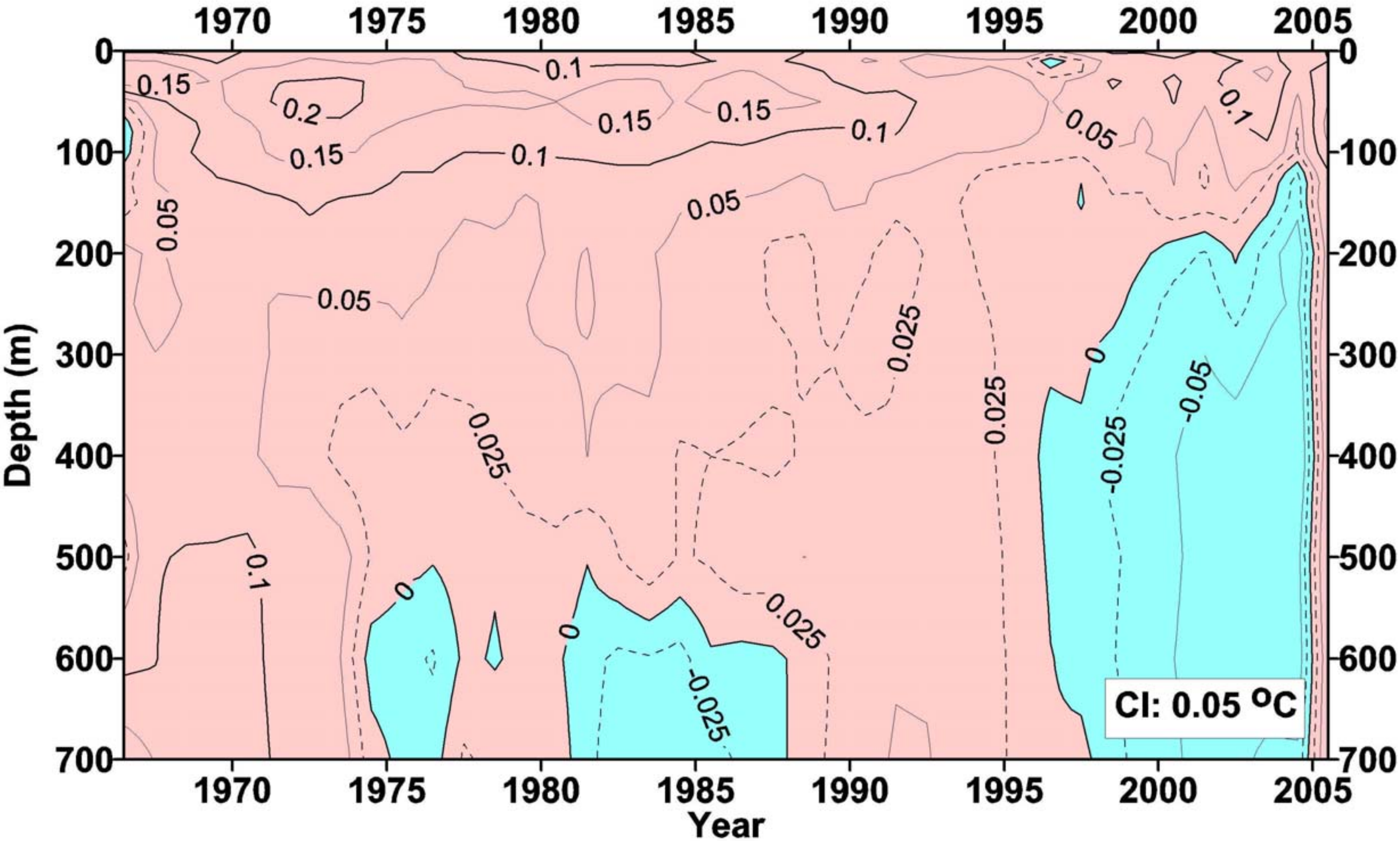


However there are still "local" differences between XBT and OSD/CTD data pairs.

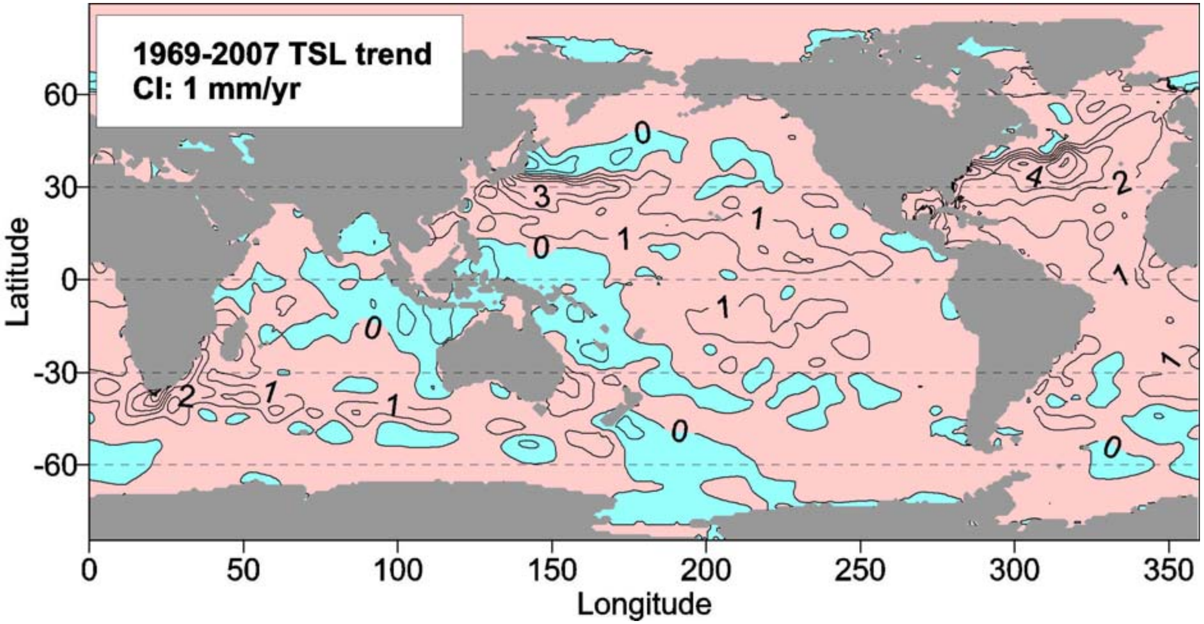
Time series of the offsets (°C) between XBT and OSD/CTD data after the *Wijffels et al.* (2008) bias corrections have been applied based on the median of the offsets. Note that modeling XBT bias simply as a drop-rate correction does not eliminate the systematic bias in the upper 100 m of the water column. This is not a surprise and could be surmised from Fig. 9 of Wijffels *et al.* (2008). The same result is found with Ishii's drop-rate corrected XBT data.

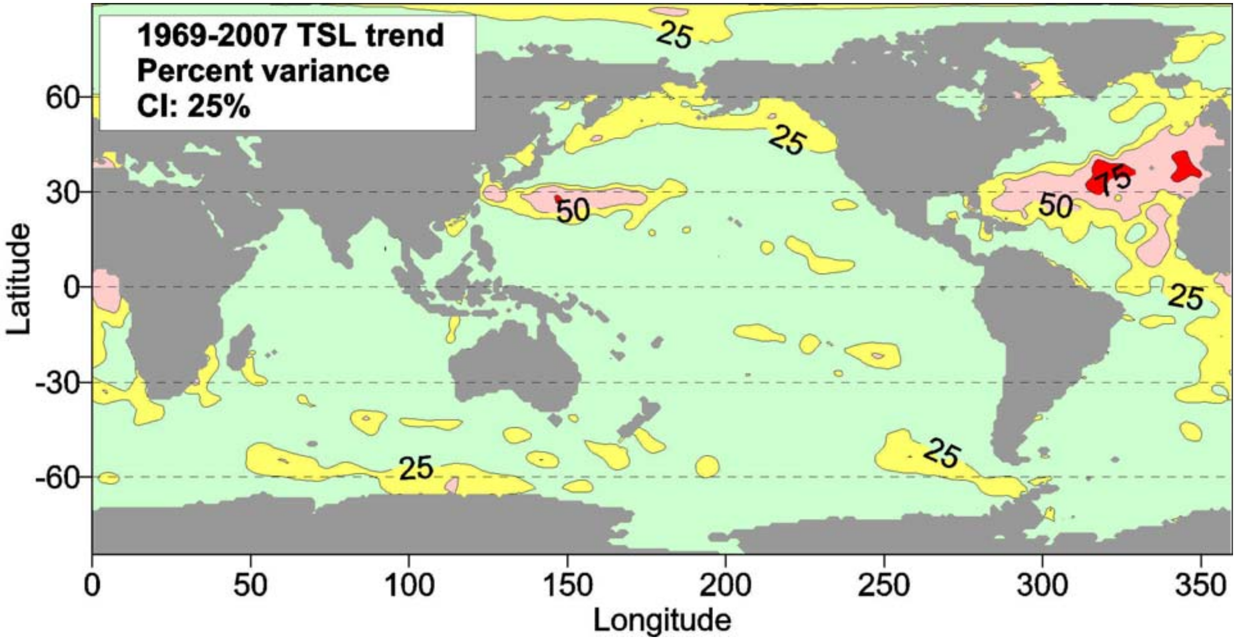
The 0-100 m layer does not contribute that much to the 0-700 m global heat content integral so finding high correlation between altimetric sea level changes and those from bias-corrected XBT data is not surprising. One has to be very careful about claiming that the XBT bias problem is simply due to drop-rate errrors. It is not.

Calculations are based on at least 30 2°x4° boxes per year and level. Red indicates positive value, blue indicates negative values.



Linear trend of the thermosteric component of sea level change, 1969-2007





Definition

The "eustatic component of sea level change" represents a change in sea level due to the actual amount of fresh water added or removed from a water column.

The "halosteric component of sea level change" represents the change of sea level due to freshening or salinification of a column of sea water.

Freshening of a sea water column results in higher sea level

and

salinification of a sea water results in lower sea level.

Results

Not as much salinity data as there are temperature data for the world ocean.

Antonov et al. (2002) estimate:

0.50 mm/yr thermal expansion for 0-3000m for 1957-1994
0.05 mm/yr haline contraction for 0-3000m for 1957-1994

The haline contraction estimate implies an increase of freshwater of 470 km^3 /year if the ocean freshening did not include any component due to melting sea ice.

This is equivalent to an eustatic sea level increase of 1.3 mm/yr.

Munk (2003) estimates an eustatic sea level increase of 1.8 mm/year.
Wadhams and Munk (2004) estimate an eustatic sea level increase 0.6 mm/year.

Discussion

Even after correcting for XBT and MBT biases, the long-term trend in the thermosteric component of sea level change is of the order 0.4-0.6 mm/year, similar to what we previously published.

More work is required on XBT bias corrections to improve estimates of the thermosteric component of sea level change.

The Argo profiling float program will provide much needed data to estimate the thermosteric component of sea level change and thus perhaps help "close" the sea level budget. Note that Argo measurements only measure to ~2000m at best.

The IOC *Global Oceanographic Data Archaeology and Rescue Project* is still providing valuable historical temperature and salinity data for estimation of the steric component of sea level change.

The observed rise is consistent with the rise expected due to the observed increase of greenhouse gases in earth's atmosphere and with AOGCMs forced by increasing GHGs.

Near global (66°S-66°N) sea level from altimetry

Note the ~ 11 mm increase in 1997 and subsequent decrease. The global sea level mean can change substantially on a scale of several months during an El Nino event. What are the physics responsible for this? Thermosteric versus halosteric versus freshwater transfer between continents and ocean (ocean eustatic change)?

detrended