World Ocean Heat Content, 1955-2010

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Lamont-Doherty Earth Observatory

Abrupt Climate Change Studies Symposium
"Climate Change: Recent Discoveries and Future Challenges"

NODC Ocean Climate Lab. (OC5) staff

Sydney Levitus- OCL Director

FEDERAL EMPLOYEES:

1)	Tim Boyer	Oceanographer- OCL Team Leader
2)	Daphne Johnson	International Affairs/Physical Scientist
3)	Dr. Igor Smolyar	Oceanographer/International Affairs
4)	Olga Baranova	Physical Scientist/Programmer/Web work
5)	Dr. Ricardo Locarnini	Oceanographer
6)	Melissa Zweng	Oceanographer
7)	Chris Paver	Oceanographer
8)	Carla Forgy	Computer Clerk/Data digitization/QC of data

8 Federal FTEs

CONTRACTORS:

9)	Dr. Alexey Mishonov	Oceanographer
10)	Alexandra Grodsky	Physical science technician, metadata quality control

UCAR VISITING SCIENTIST:

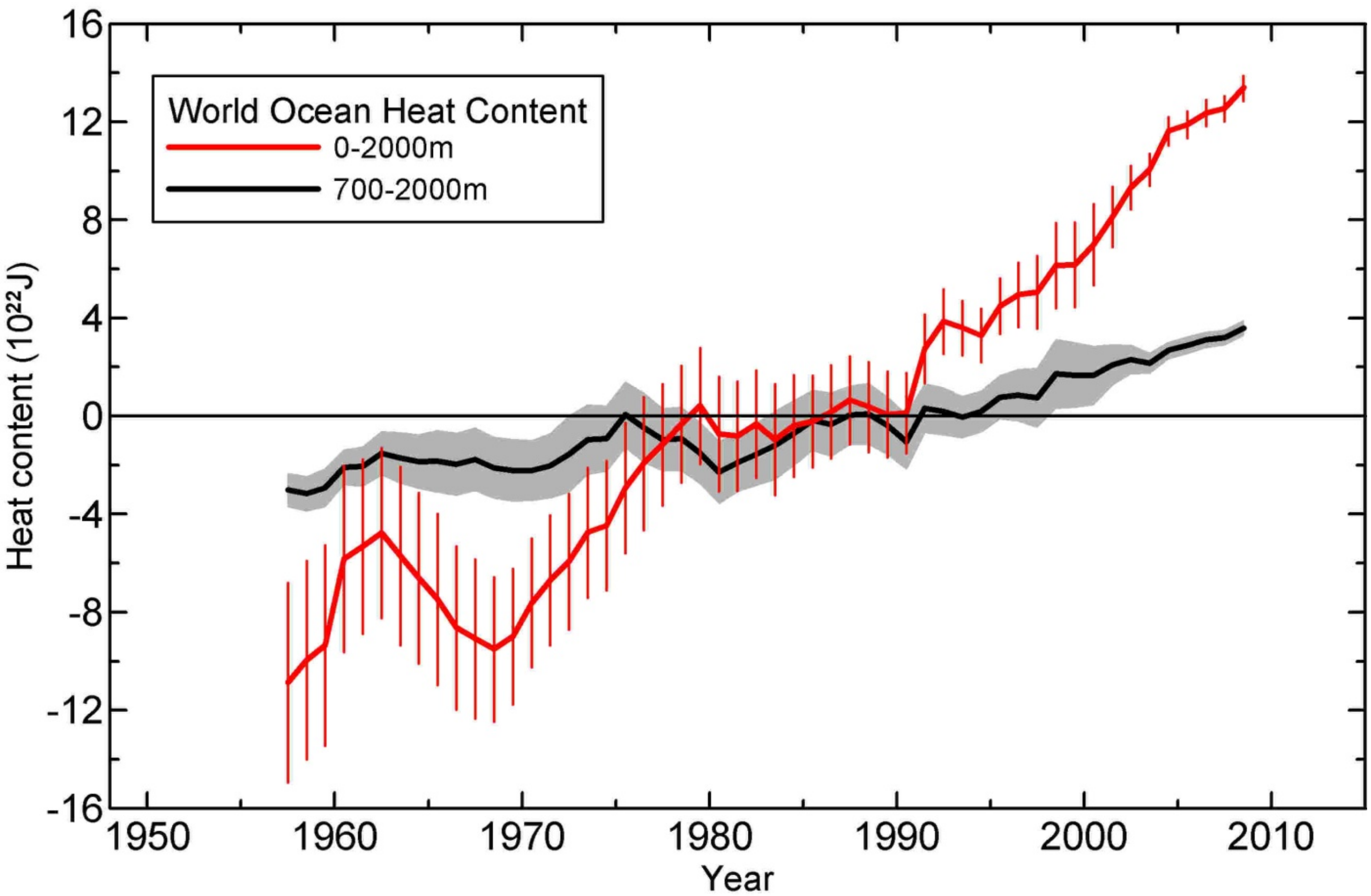
11)	Dr. John Antonov	Oceanographer (UCAR)

CICS scientist:

12)	James Reagan	Faculty Research Assistant (CICS)-Oceanographer

4 non-Federal FTEs

World Ocean Heat Content (0-2000 m), 1955-2010



The 0-2000 m layer of the world ocean has warmed by ~ 0.09°C (~ 0.16°F) [24.0±1.9x10^{22} J] during 1955-2010.

For perspective,

if all the heat stored in the world ocean since 1955 was instantly transferred to the lowest 10 km (5 miles) of the atmosphere, this part of the atmosphere would warm by ~ 65°F.

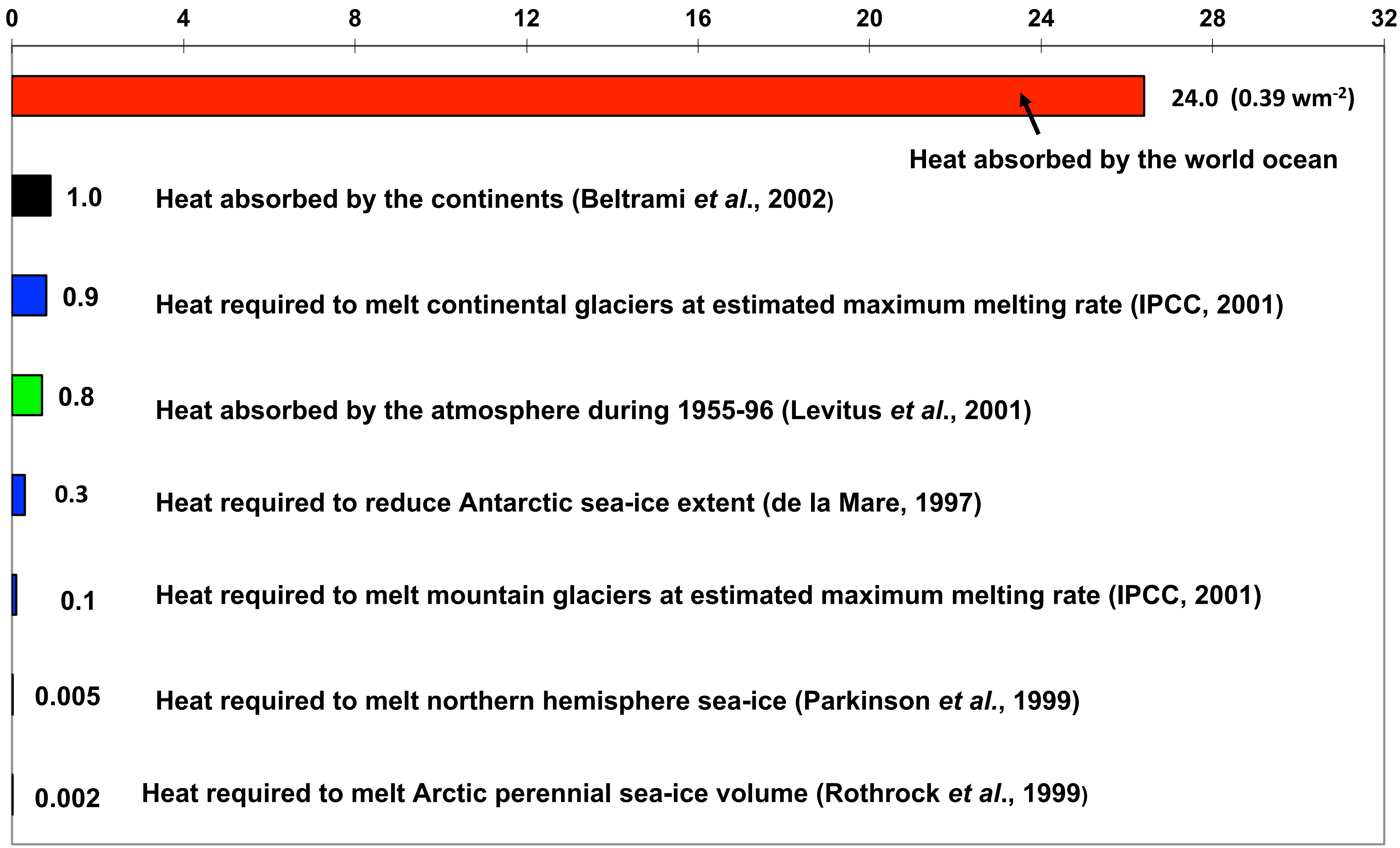
This of course will not happen. It is simply illustrative of the amount of heat stored in the earth system since 1955.

Levitus *et al*. (2012), GRL.

World Ocean heat content (10^{22} J) (1955-2010) for the 0-2000 m (red) and 700-2000 m (black) layers of the world ocean based on running pentadal (five-year) analyses. Reference period is 1955-2006.

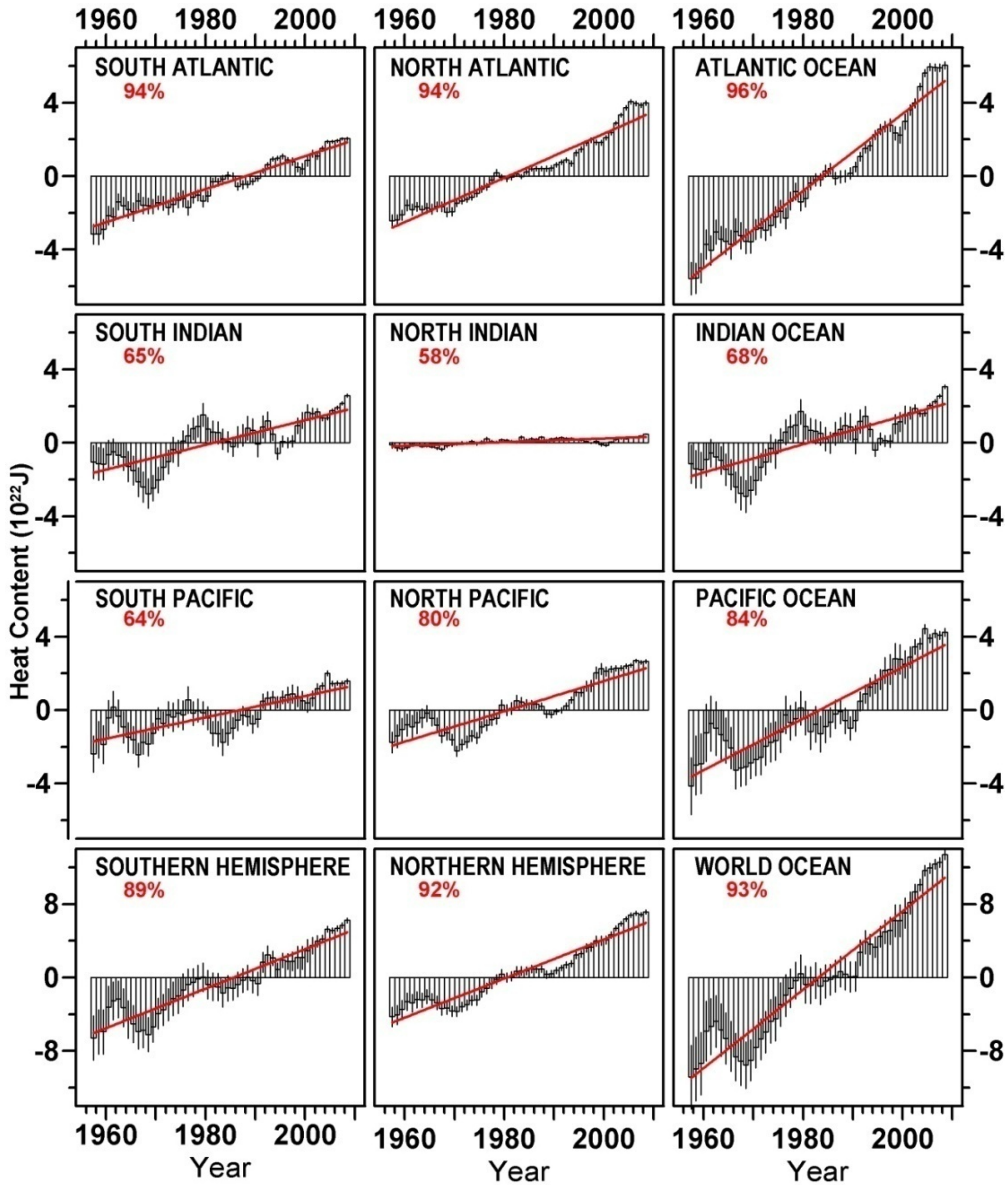
Each pentadal estimate is plotted at the midpoint of the 5-year period. The vertical bars represent +/- 2.*S.E. about the pentadal estimate for the 0-2000 m estimates and the grey-shaded area represent +/- 2.*S.E. about the pentadal estimate for each 0-700 m estimate.

Changes in Earth's Heat Balance Components (10^{22} J) during 1955-2012 (0-2000 m)



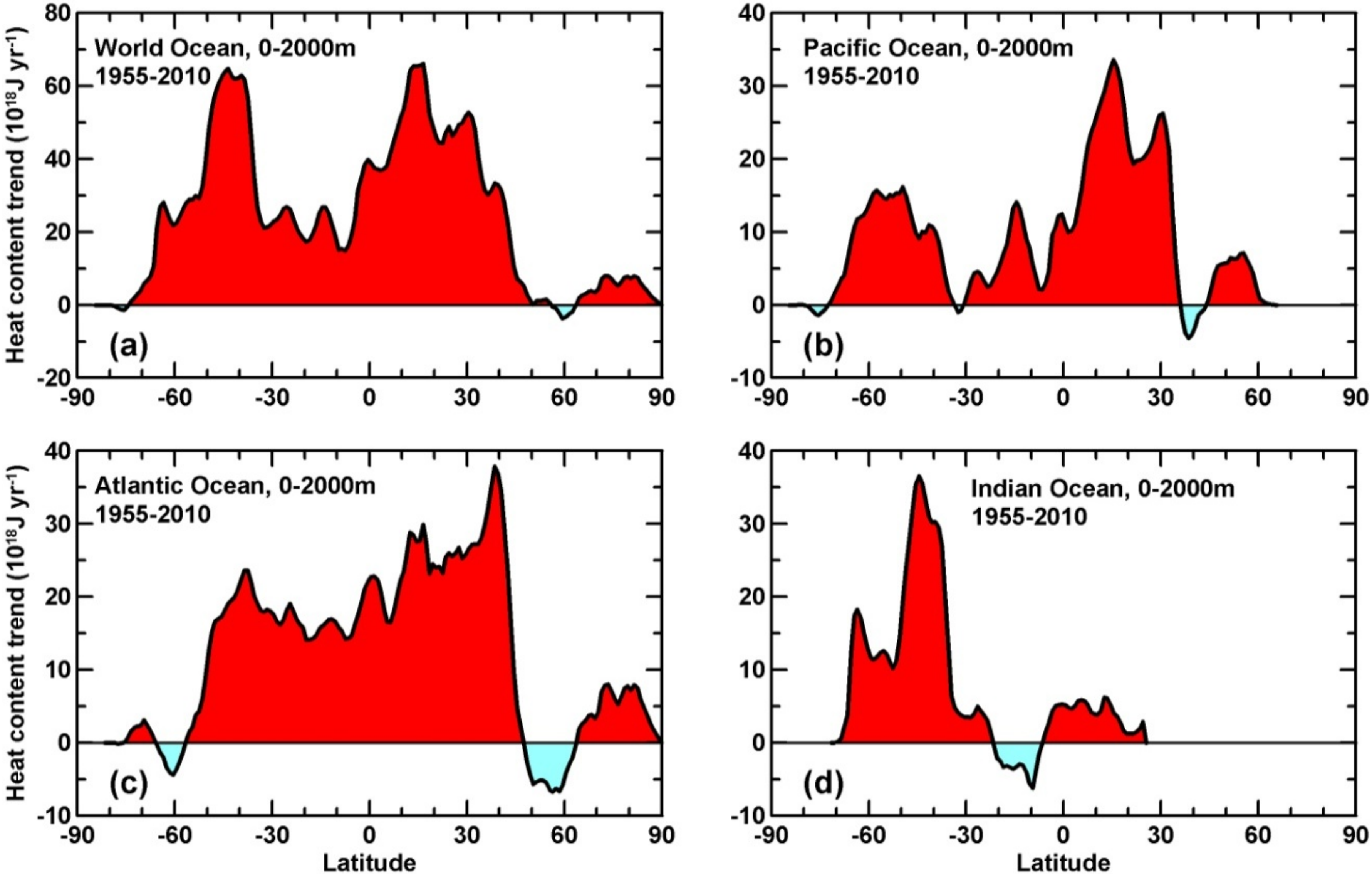
The world ocean accounts for ~90% of the heat absorbed by the earth system during 1955-2012.

Time series (1955-2010) of ocean heat content (10^{22}J) for the 0-2000 m layer



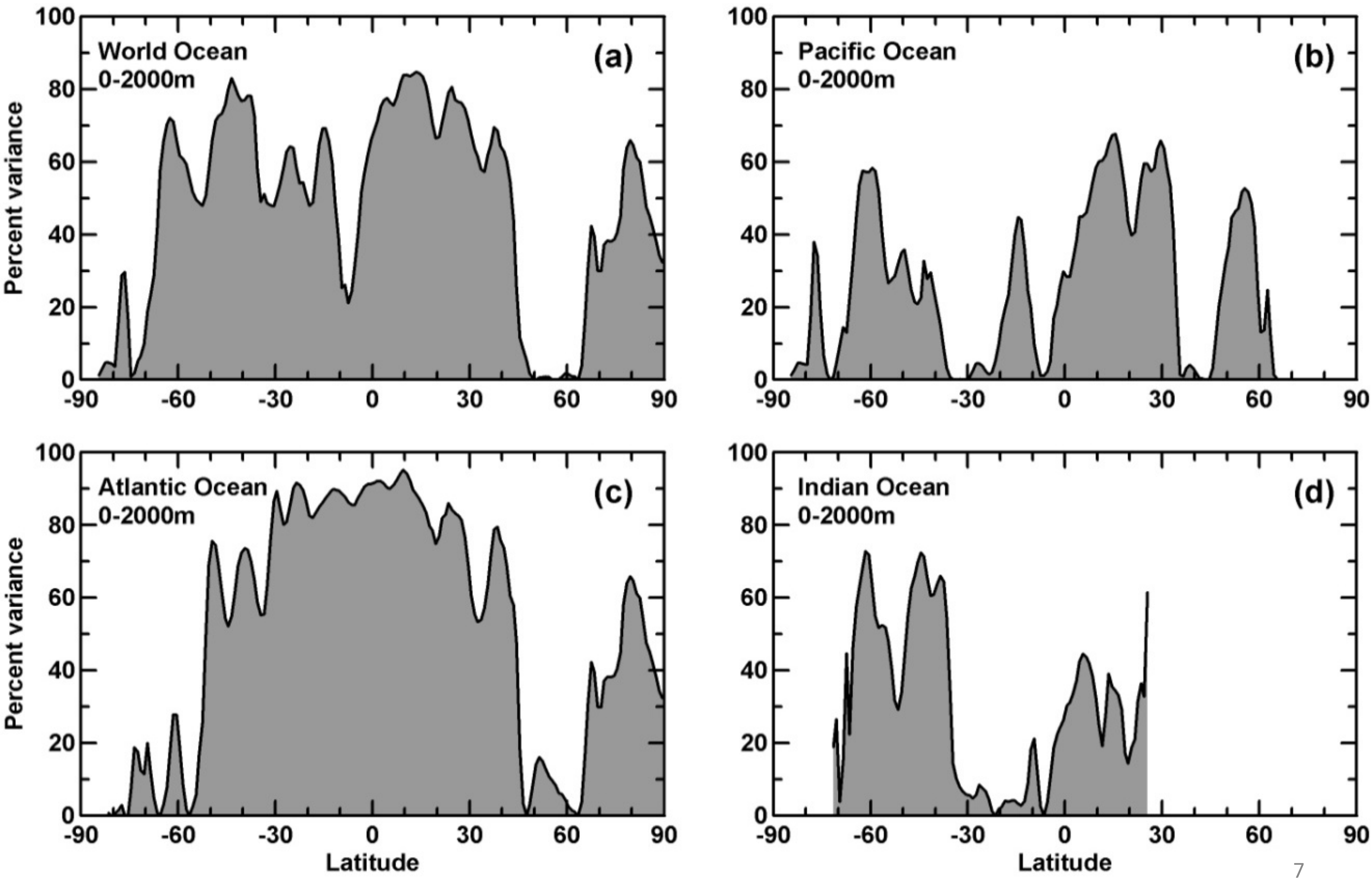
Time series of ocean heat content (10^{22}J) for the 0-2000 m layer for the major ocean basins based on running pentadal analyses.
Each pentadal estimate is plotted at the midpoint of the 5-year period. The vertical bars represent +/- 2.*S.E. about the pentadal estimate.
The linear trend line and the percent variance accounted for by the linear trend are shown in red on each panel. **Reference period is 1955-2006.**

Linear trend (10^{18} J yr^{-1}) (1955-1959) to (2006-2010) of zonally integrated ocean heat content as function of latitude for the 0-2000 m layer.

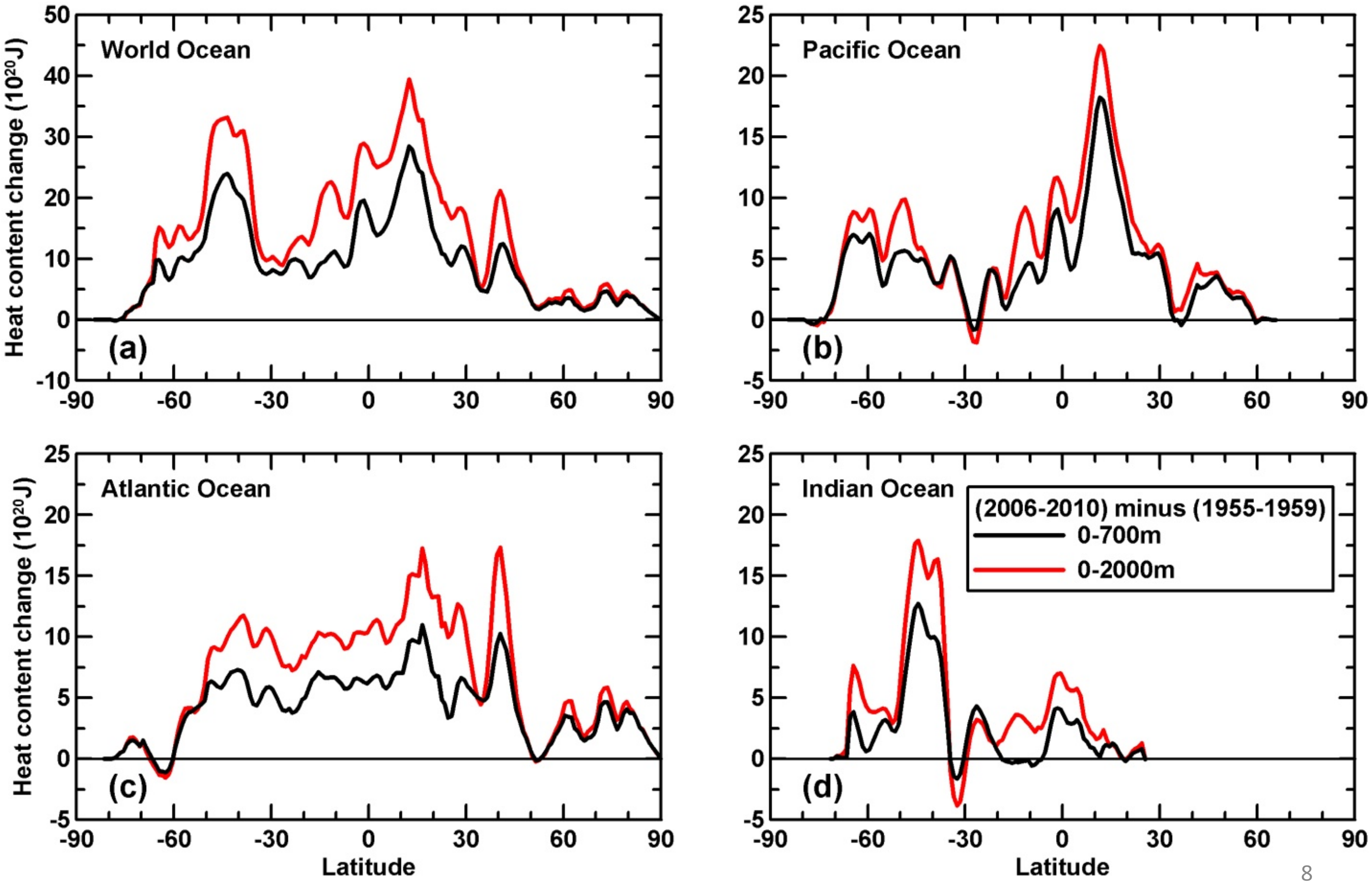


Red indicates a positive trend and blue a negative trend.

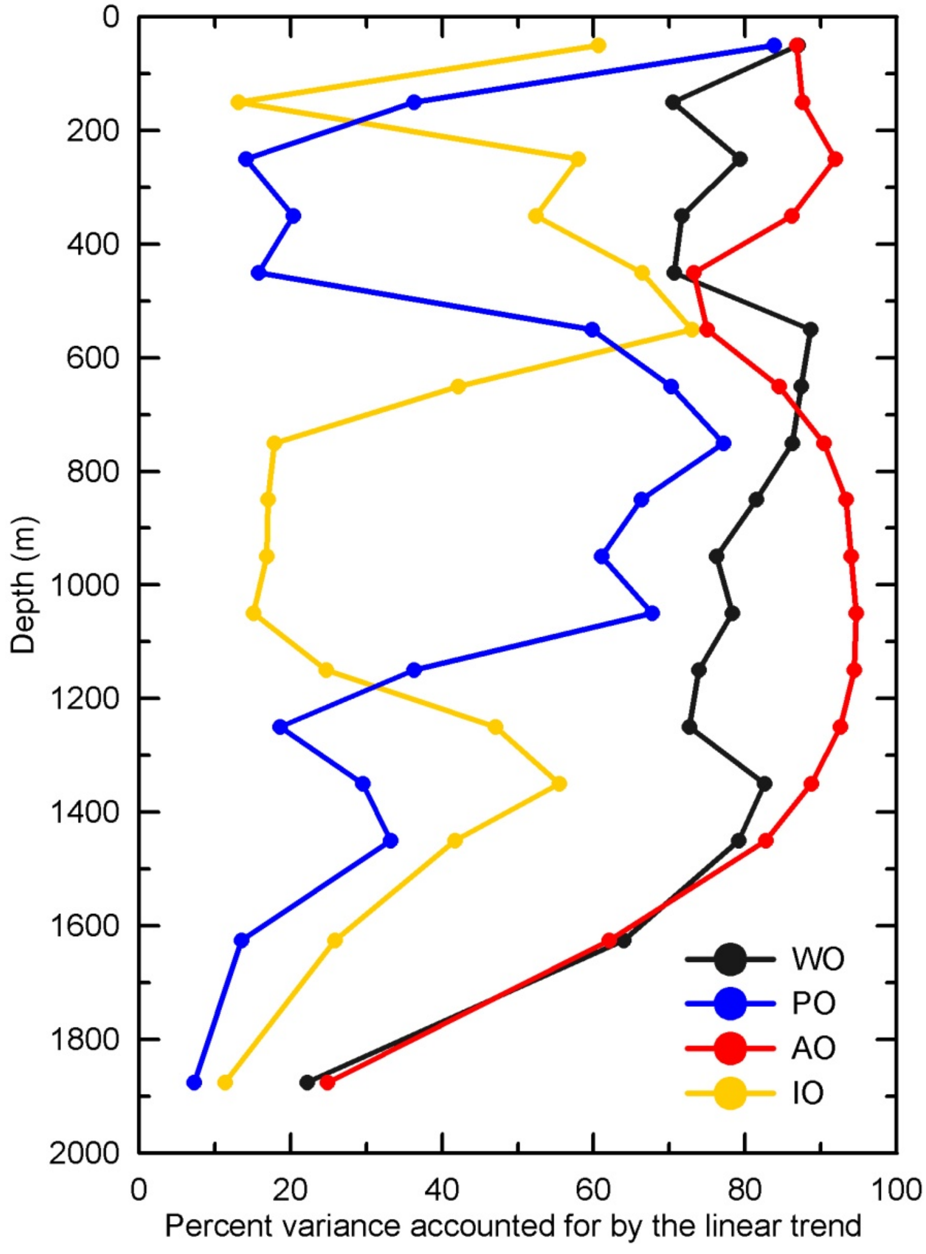
Percent variance accounted for by the linear trend of zonally integrated ocean heat content (0-2000 m) as a function of latitude for individual ocean basins



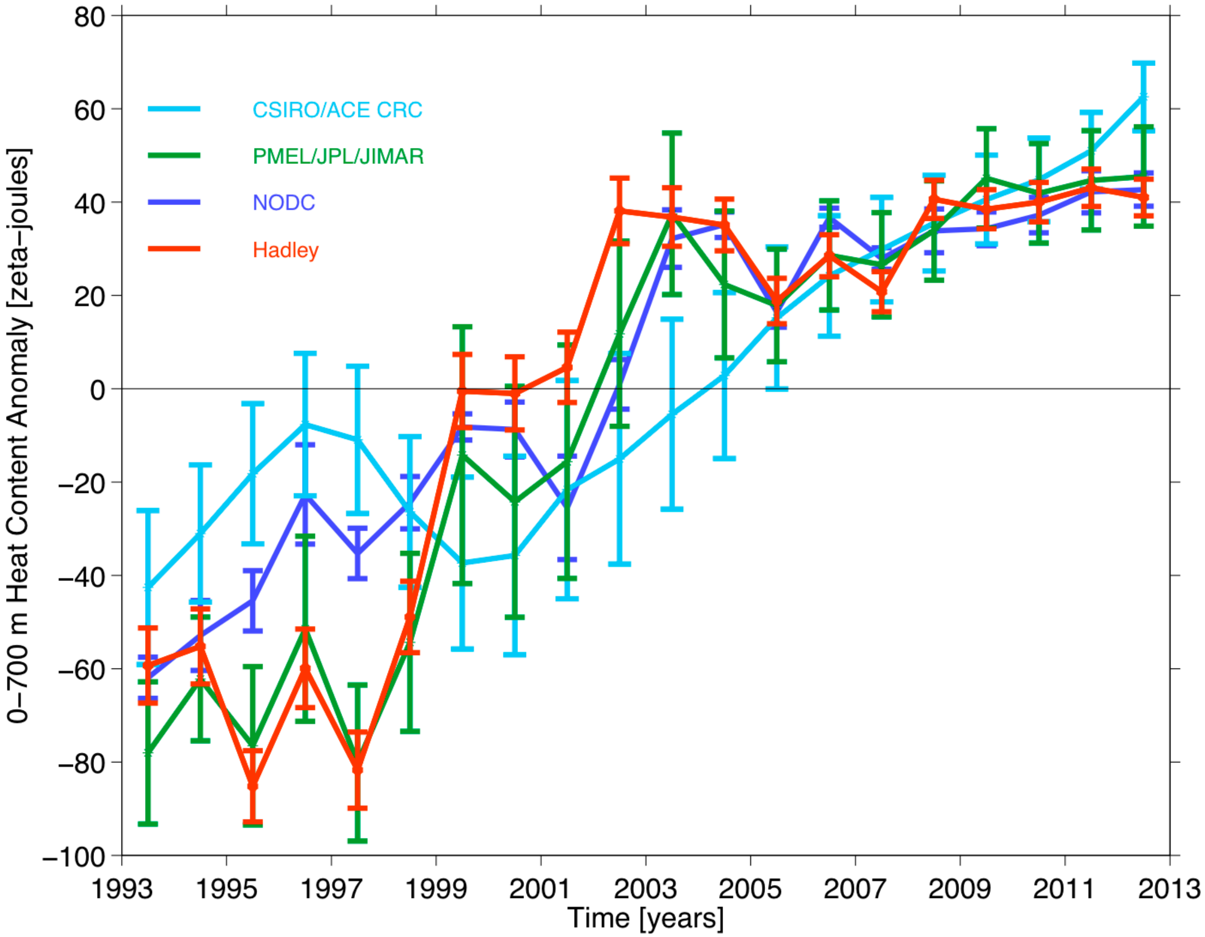
Zonal integral of the difference (2006-2010) minus (1955-1959) in OHC700 and OHC2000 for the World, Pacific, Atlantic, and Indian oceans as function of latitude. Units of all curves are 10^{20} J.



Percent variance accounted for by the linear trend of ocean heat content by 100 m-layers for 1955-2010 for individual ocean basins



World Ocean Heat Content (0-700 m), 1955-2012



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Johnson, G. C., J. M. Lyman, J. K. Willis, S. Levitus, T. Boyer, J. Antonov, S. A. Good, C. M. Domingues, S. Wijffels, and N. Bindoff, 2013.
Global Oceans: Ocean Heat Content.
In State of the Climate in 2012, Blunden, J., and D. S. Arndt, Eds., Bulletin of the American Meteorological Society, 94, submitted.

Time series of annual average global integrals of in situ estimates of upper (0–700 m) OHCA (1021 J, or ZJ) for 1993–2012 with standard errors of the mean
.
The CSIRO/ACE CRC estimate (smoothed by a 3-year running mean) and its uncertainties are updated following Domingues *et al.* (2008).

The PMEL/JPL/JIMAR estimate is a weighted integral (Lyman and Johnson 2008) using data and instrument bias corrections described in the text with uncertainty estimate methodology following Lyman *et al.* (2010).

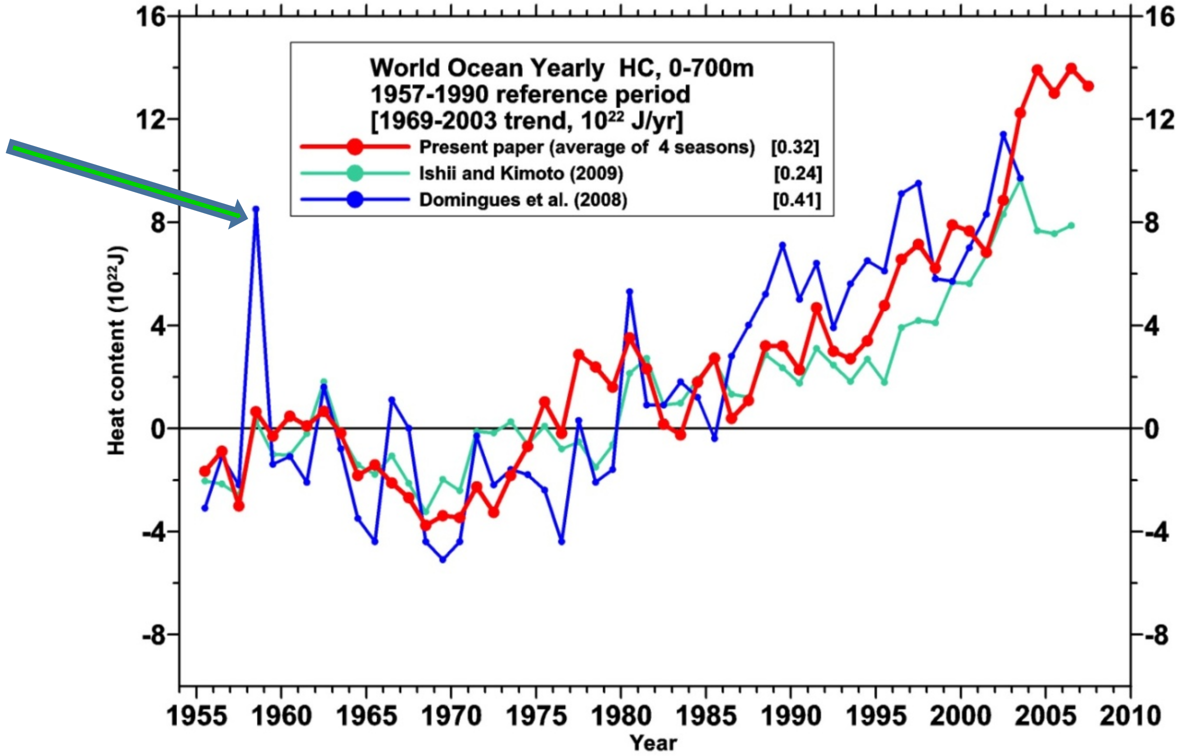
The NODC estimate (http://www.nodc.noaa.gov/OC5/indprod.html) follows Levitus et al. (2012). Uncertainties are estimated solely from the variance of quarterly estimates of OHCA.

The Hadley estimate is computed from gridded monthly temperature anomalies (relative to 1950–2012) calculated from EN3 v2a data following Palmer et al. (2007). An updated version of the instrument bias corrections of Gouretski and Reseghetti (2010) (V. Gouretski, personal communication) was applied. Uncertainty estimates follow Palmer and Brohan (2011).

For comparison, all estimates have been individually offset (vertically on the plot), first to their individual 2004–2012 means (the best sampled time period), and then to their collective 1993–2012 mean (the record length).

Assumption and techniques to compute OHC (0-700 m) differ between various studies

In the Domingues *et al.* (2008) paper they applied a 3-year running mean so this spike does not appear in their paper.



Domingues *et al*. (2008) compute OHC "indirectly".

1) Compute monthly thermosteric components of sea level change from temperature profiles.
2) Compute 30 leading EOFs to "model variability of the time-varying sea level", using spatial patterns of sea level from 14 years of altimetric data.
4) Add an additional constant (a spatially uniform field) to represent changes in the global mean.
5) Construct OHC by using regression coefficients between OHC & thermosteric sea level, computed on a 10° grid.

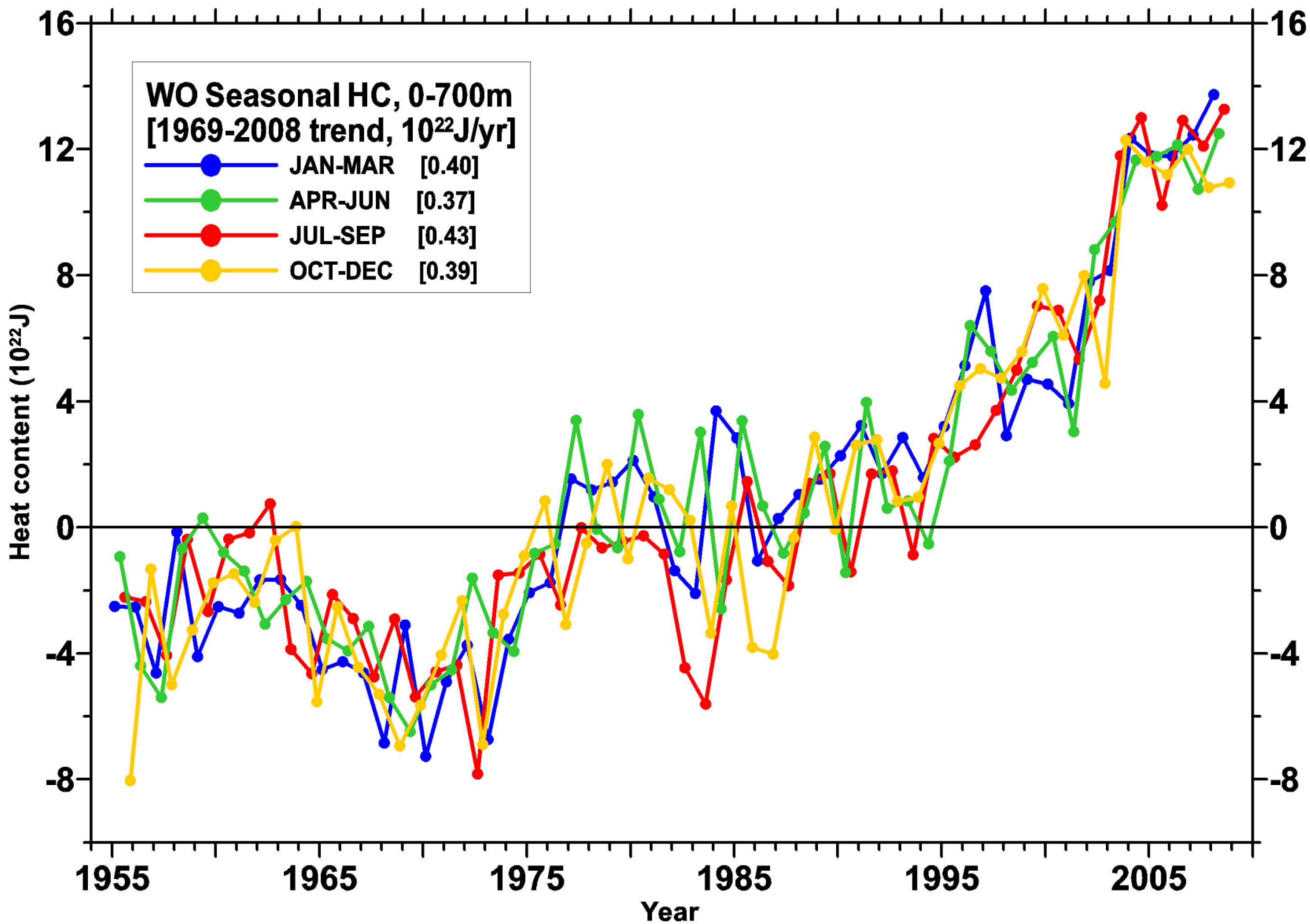
Ishii & Kimoto (2009)

1)supplemented T profile data with (synoptic SST obs.) * (climatological MLD).

All OHC studies must make instrumental bias corrections if they use bathythermograph data.
The corrections are made differently.

Overall the results of these different studies are similar for the long-term trend but differ on annual time scales.

Seasonal OHC time series- Levitus *et al*. (2009)



Seasonal time series of yearly ocean heat content (10E+22 J) for the 0-700 m from this study and their trends for 1955-2008.
Linear trends for each season for 1969-2008.
Reference period is 1955-2006.
These seasonal estimates are independent of each other.

The future of estimates of OHC and earth’s heat balance.

Such estimates are of critical scientific and societal importance

The future of OHC estimates and determination of earth’s heat balance depends on
the success of the Argo project.

Overall this international project has been a great success.

However, problems with the existing Argo profiling float project have occurred.

WHOI effort is not satisfactory.

120 WHOI-deployed floats have been “greylisted” due to a software problem.

Not only has the community lost any data that was, or could have been, collected from these floats

but this error

represents a loss of ~ $1.2-1.6 million for the ocean & climate communities.

New ocean monitoring technologies

1) **Profiling floats that extend to depths as deep as 6 km and measure T & S.**

U.S.A. (6 km) , Japan (4 km), France (3.5 km) in development.

Also, SBE is developing improved sensors (this is my understanding).

2) **Gliders that extend to depths as deep as 6 km.**

Already demonstrated by Prof. Charlie Eriksen & colleagues at U. Wash.

Further development is ongoing.

These instruments will greatly improve monitoring of the world ocean for weather forecasting, climate assessments, fisheries research,….

"Extended Vertical Resolution" – WOD13 & WOA13 & regional climatologies

High-vertical-resolution data are being submitted in ever increasing amounts Including:

profiling floats,

gliders,

Relatively new instruments

XBTs,

XCTDs

CTDs.

This will allow the scientific community to better understand the physics of the Ocean, improve model initial and boundary conditions, and improve OHC estimates.

Will better resolve smaller scales associated with sill depths, channels, etc.

Newly developed NODC objective analysis products

Extended-vertical-resolution (EVR) is being introduced for WOD & WOA & other products such as regional climatologies. In preparation by Tim Boyer and colleagues at NODC.

WOD profiles will be available at 102 standard depth level between the surface and 5500 m depth as compared to 33 levels in previous works and WOA analyses will be performed at these same 102 levels (Boyer *et al.* (2013)).

1) **Every 5 m for 0-100 m layer**

2) **Every 25 m for 100-500 m layer**

3) **Every 50 m for 500-2000 m layer**

4) **Every 100 m for 2000-5500 m layer**

5) **Actually can be extended down to 9,000 m depth.**

Why the change to EVR?

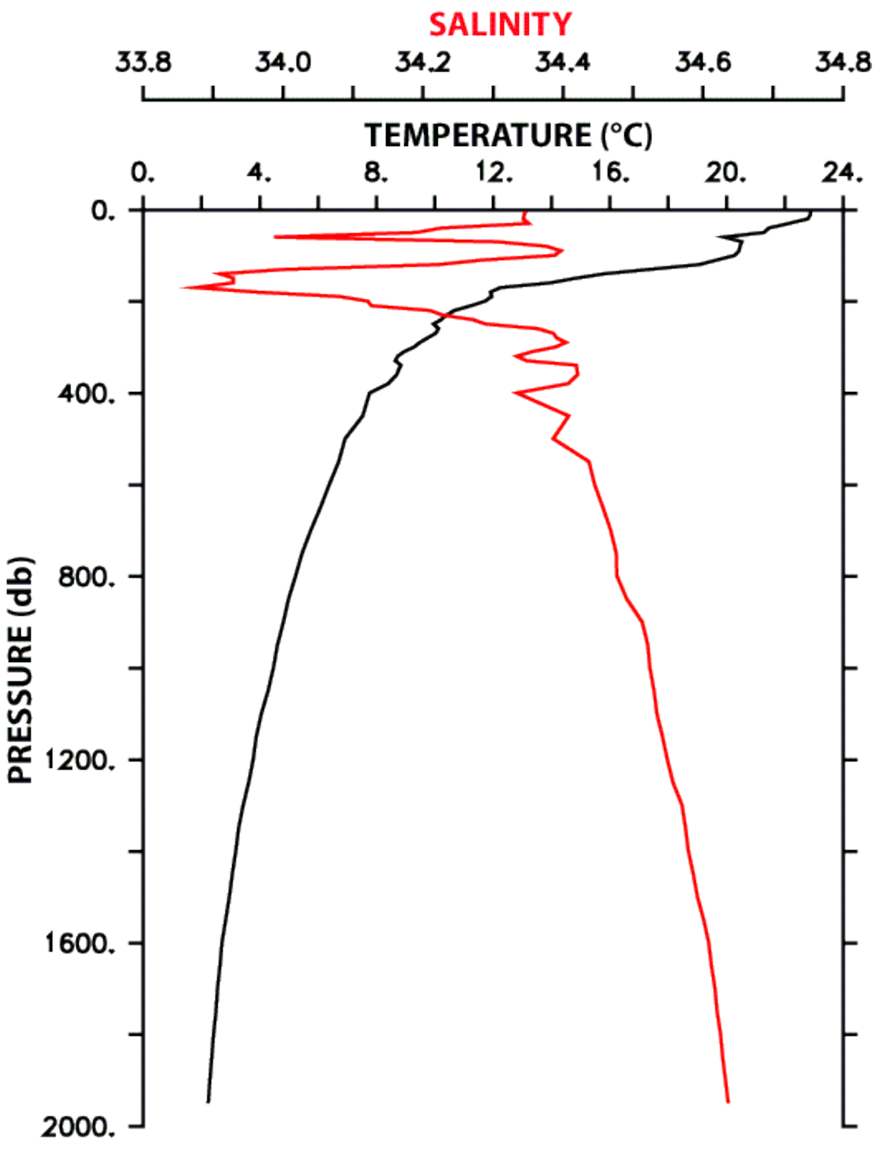
1) **Data such as high-resolution CTD, profiling floats, XBTs permit this.**

2) **Models now have much greater vertical resolution.**

3) **Requests from users.**

Argo profile from the subtropical N. Atlantic

courtesy of Steve Riser, U.W.



Need to resolve and understand the physics of smaller-scale phenomena than we have in the past.

NODC High-Resolution Ocean Regional Climatologies

http://www.nodc.noaa.gov/OC5/regional_climate/

New ***NODC Ocean Regional Climatologies Project*** aims at creating high-resolution regional climatologies in the key areas where data allow sub-one-degree resolution on 102 standard depth levels.

High-resolution regional climatologies can provide the oceanographic basis for climate and marine ecosystem studies at ***NOAA and elsewhere*** in key regions, where more oceanographic detail is needed for analysis, forecasting, climate and ocean modeling, environmental assessments and other applications.

To date, three regional climatologies have been completed and published at the NODC web site.

These climatologies are the:

1) Gulf of Mexico Regional Climatology,

2) ***Oceanographic Atlas of the East Asian Seas,***

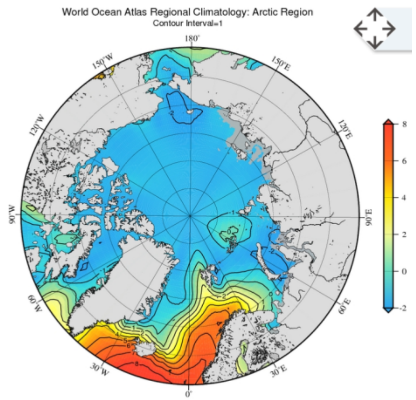
3) Arctic Regional Climatology.

Two new regional climatologies are being currently created :

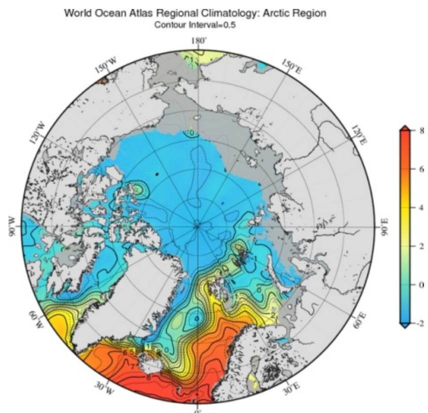
1) Barents Sea Regional Climatology,

2) Greenland-Iceland-Norwegian Seas Regional Climatology.

High-Resolution Arctic Regional Climatology



Winter T(°C) at 30 m; 1-degree resolution



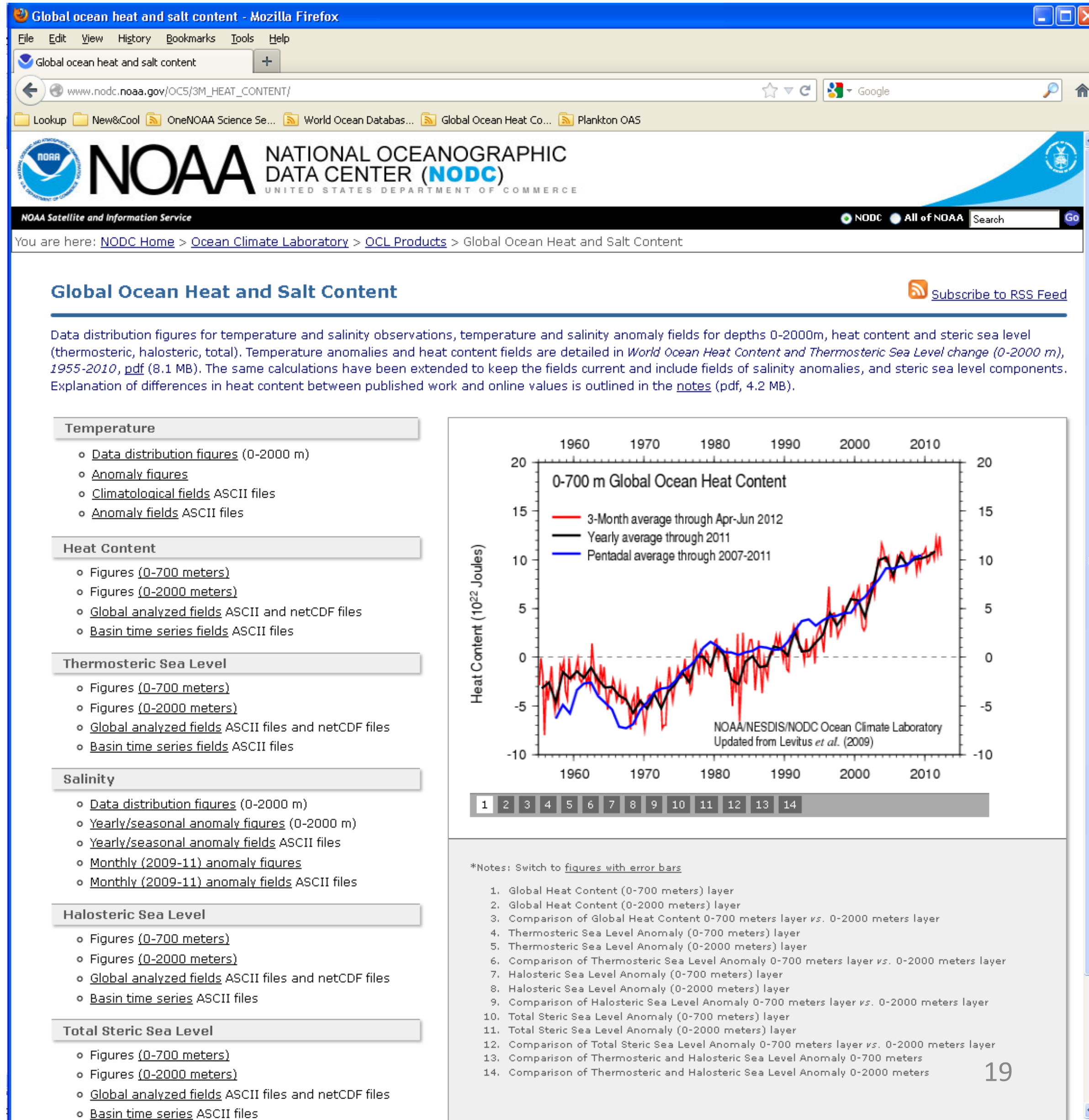
Winter T(°C) at 30 m; 1/4-degree resolution

What are some of our products that are available online?

World Ocean T anomalies, S anomalies, Heat Content, and Steric Components of sea level change, (0-700 m, 0-2000 m) updated every 3 months.

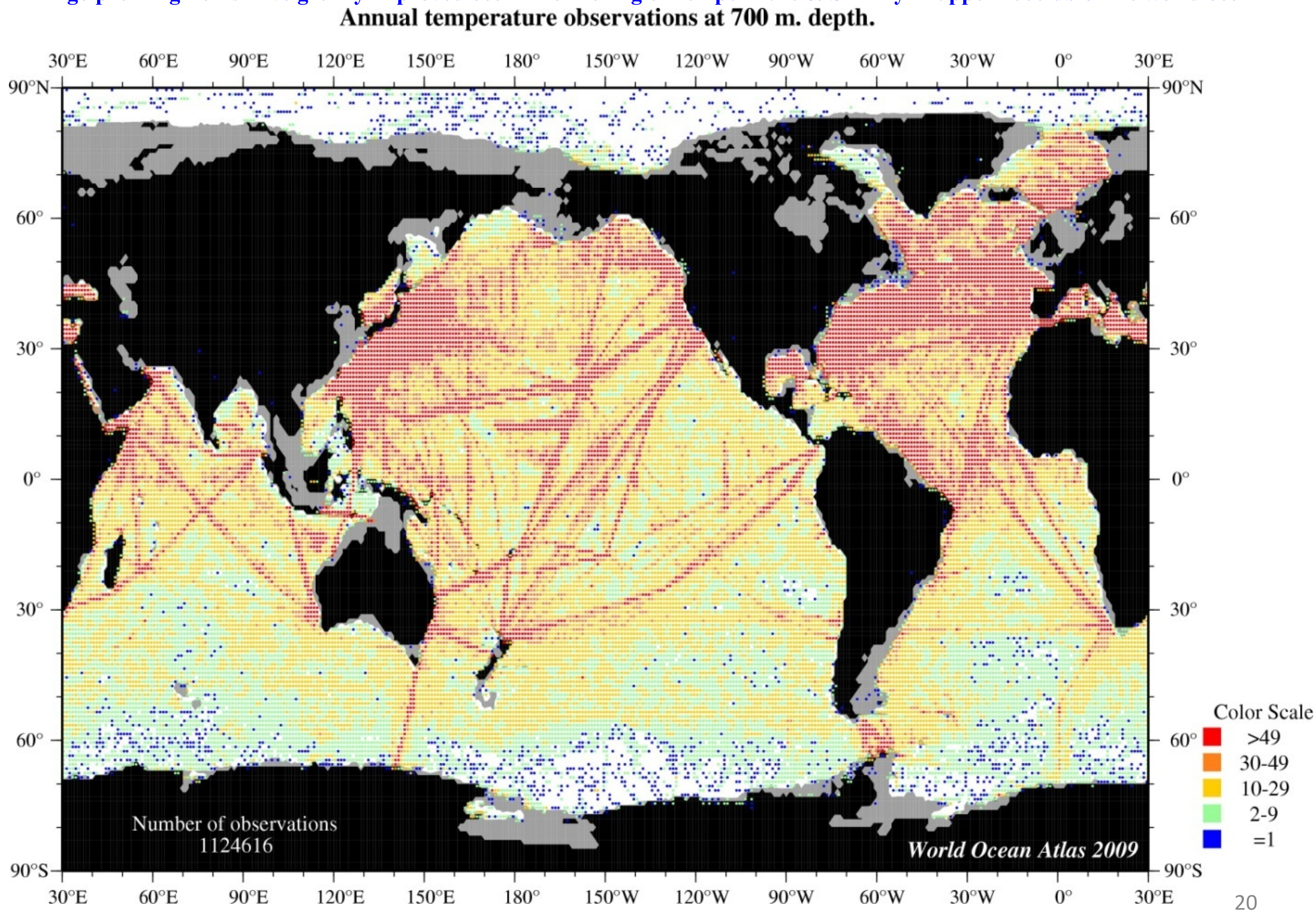
www.nodc.noaa.gov

Web page developed by Olga Baranova and Tim Boyer



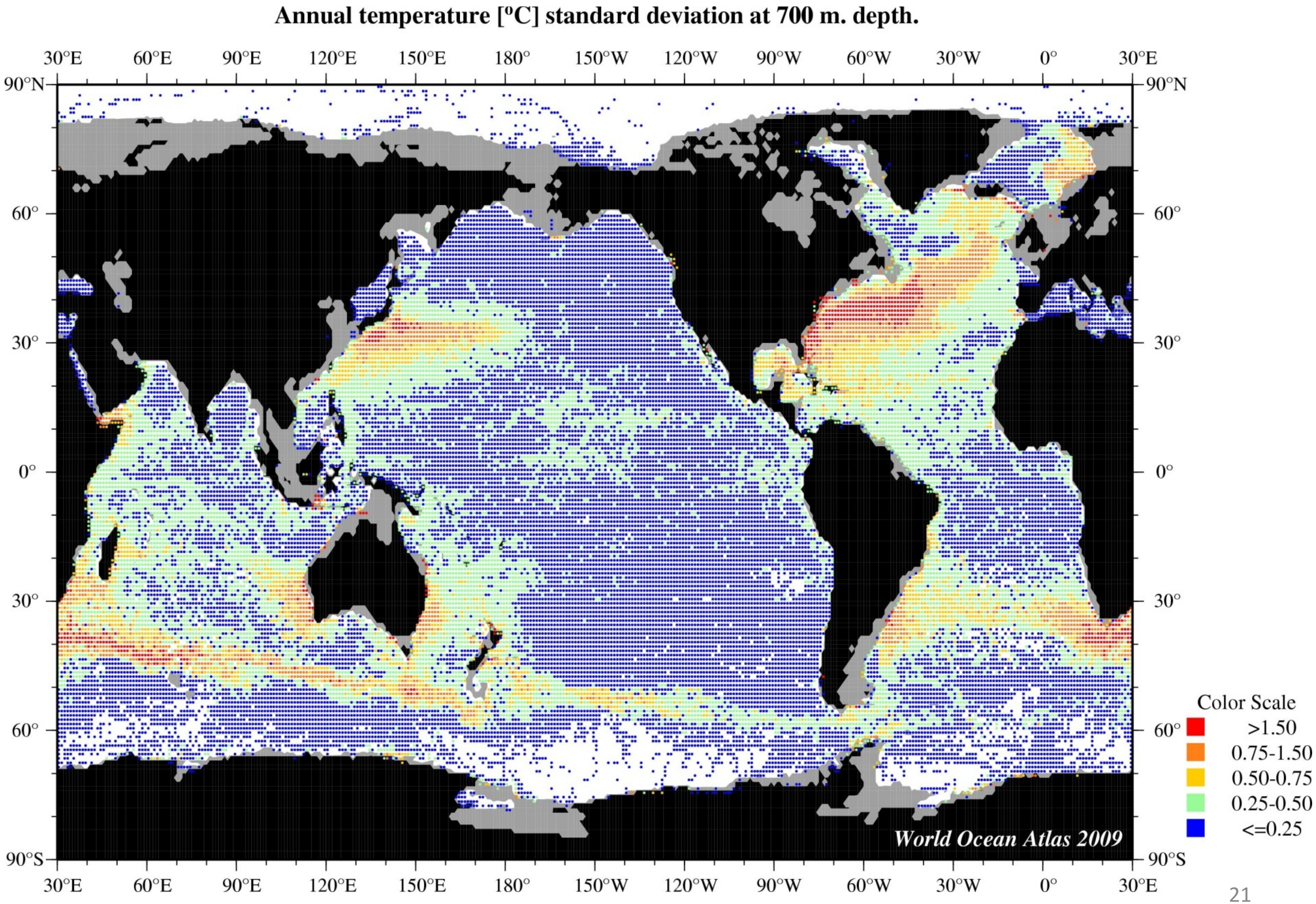
Distribution of all temperature observations used in this study at 700 m depth

Argo profiling floats have greatly improved ocean monitoring of Temperature & Salinity in upper 2000 db of the world ocean



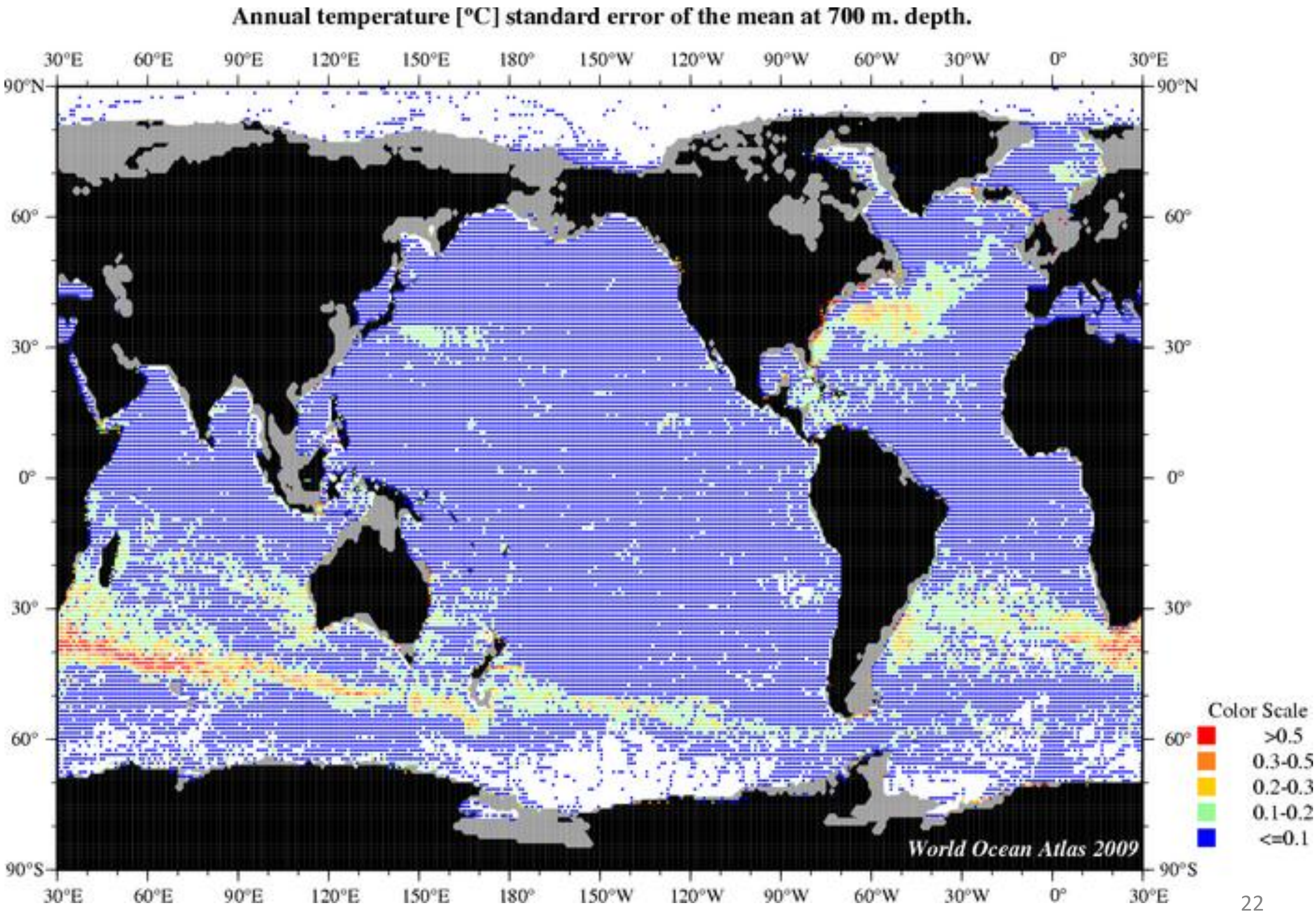
From Locarnini *et al.* (2010). Atlas is available online at www.nodc.noaa.gov

All-data temperature standard deviation (°C) at 700 m depth



From Locarnini *et al*. (2010)

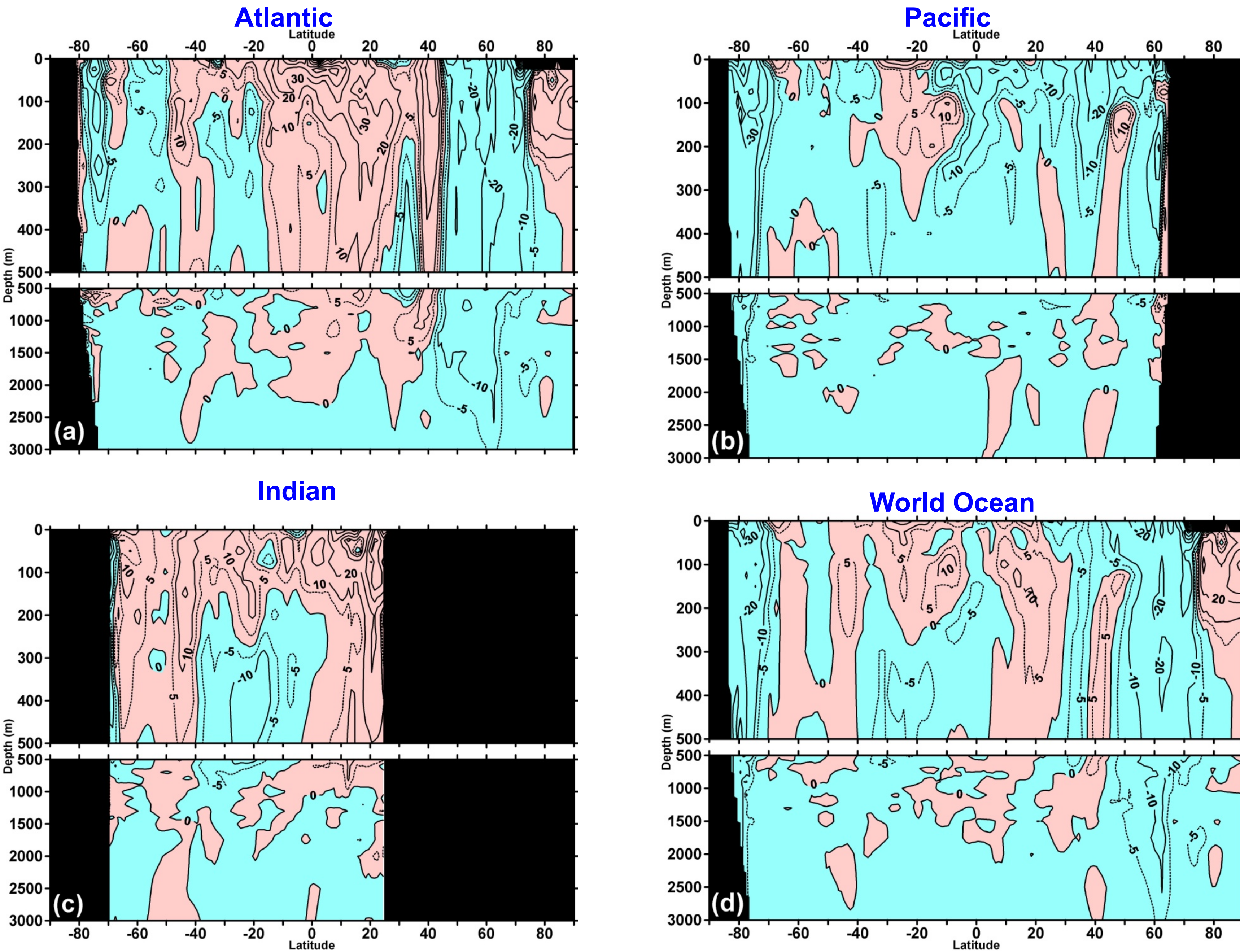
All-data temperature standard error of the mean (°C) at 700 m depth



From Locarnini *et al*. (2010)

One slide on salinity trends

Basin Linear trends of zonally averaged salinity (10^{-04} year^{-1})   Boyer *et al.* (2005)



Thank you.

I am retiring from NOAA as of June 29, 2012.

I will be teaching and doing research starting September, 2013 at the:

Department of Atmosphere and Ocean Sciences, University of Maryland.

Supplemental slides

Recent Research on Ocean Heat Content

Levitus, S., J. I. Antonov, T. P. Boyer, O. K. Baranova, H. E. Garcia, R. A. Locarnini, A. V. Mishonov, J. R. Reagan, D. Seidov, E. S. Yarosh, M. M. Zweng, 2012: World Ocean heat content and thermosteric sea level change (0-2000 m) 1955-2010. *Geophys. Res. Lett*., 39, L10603, doi: 10.1029/2012GL051106.

Building on earlier work:

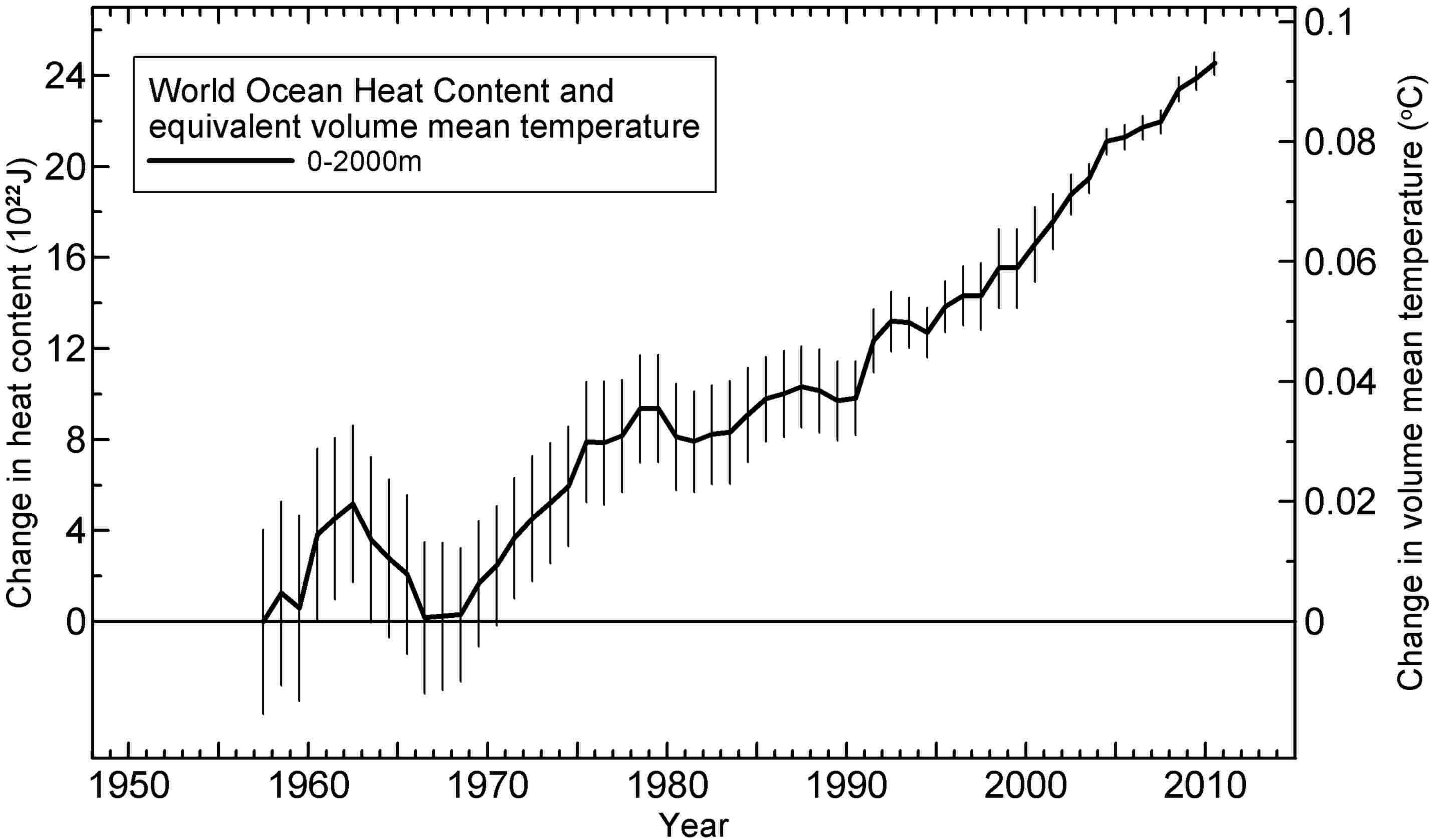
Levitus, S., J. Antonov, and T.P. Boyer, C. Stephens, 2000: Warming of the World Ocean. Science, 287, 2225-2229.

Levitus, S., Antonov, J. Wang, T. L. Delworth, K. W. Dixon, and A. J. Broccoli, 2001: Anthropogenic warming of earth's climate system. Science, 292, 267-270.

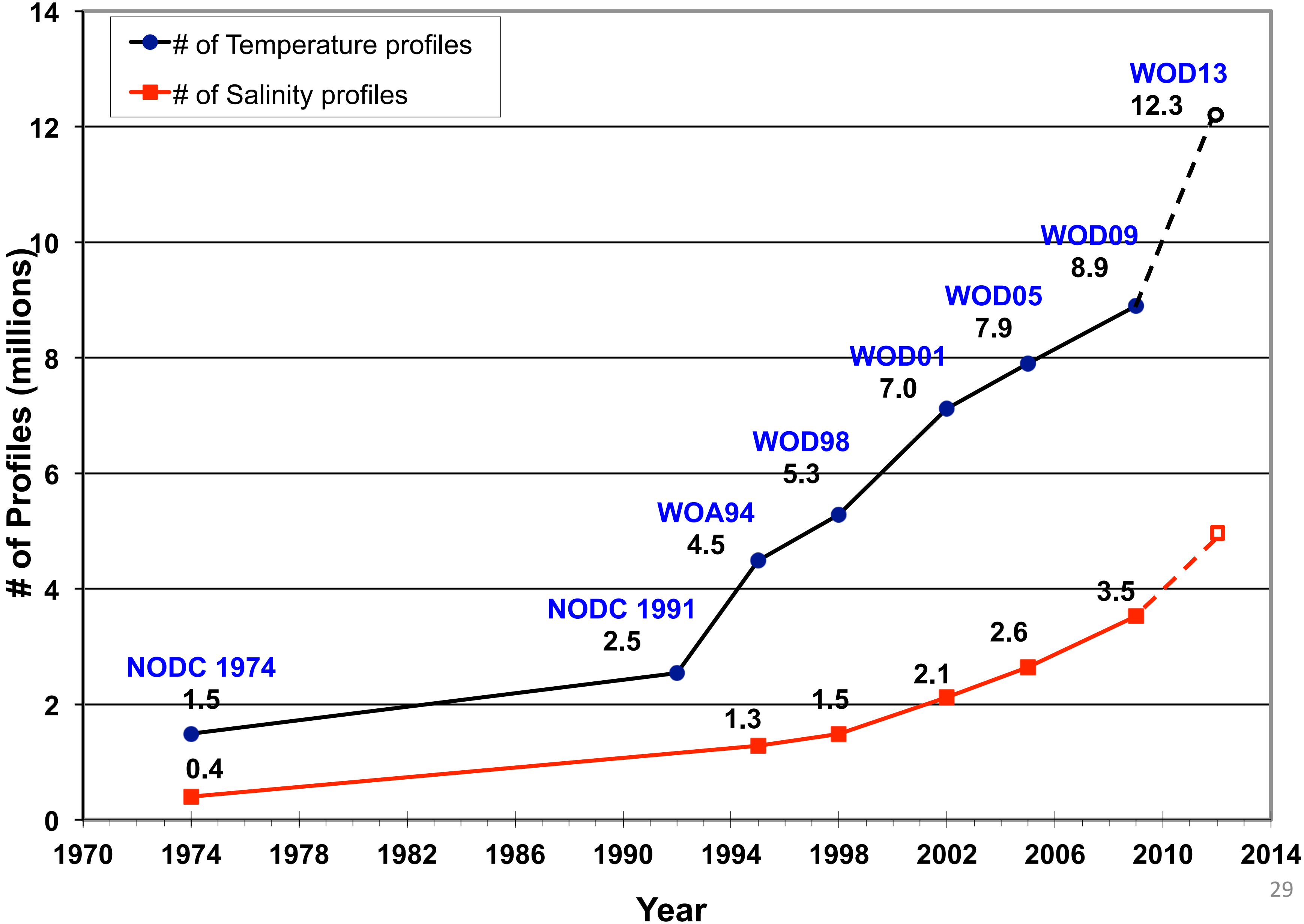
Levitus, S., J. I. Antonov, T. P. Boyer, 2005: Warming of the World Ocean, 1955-2003. Geophys. Res. Lett., L02604, doi:10.1029/2004GL021592.

Levitus, S., J. I. Antonov, T. P. Boyer, H. E. Garcia, R. A. Locarnini, and A.V. Mishonov, 2009: Global Ocean Heat Content 1955-2008 in light of recently revealed instrumentation problems. Geophys. Res. Lett., 36, L07608, doi:10.1029/2008GL037155.

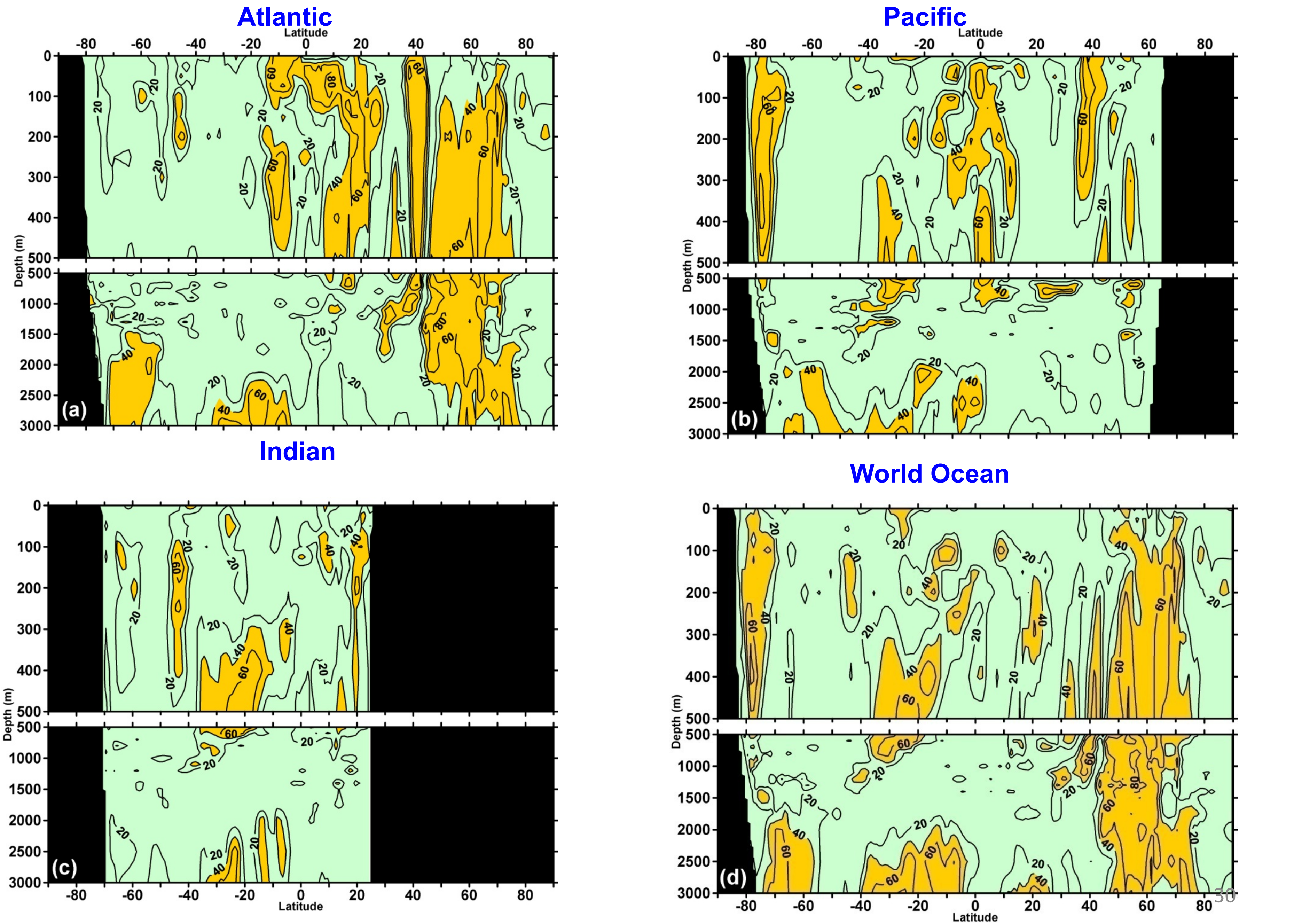
World Ocean OHC and equivalent volume mean temperature anomaly (1955-2010) based on running pentads (5-year periods)



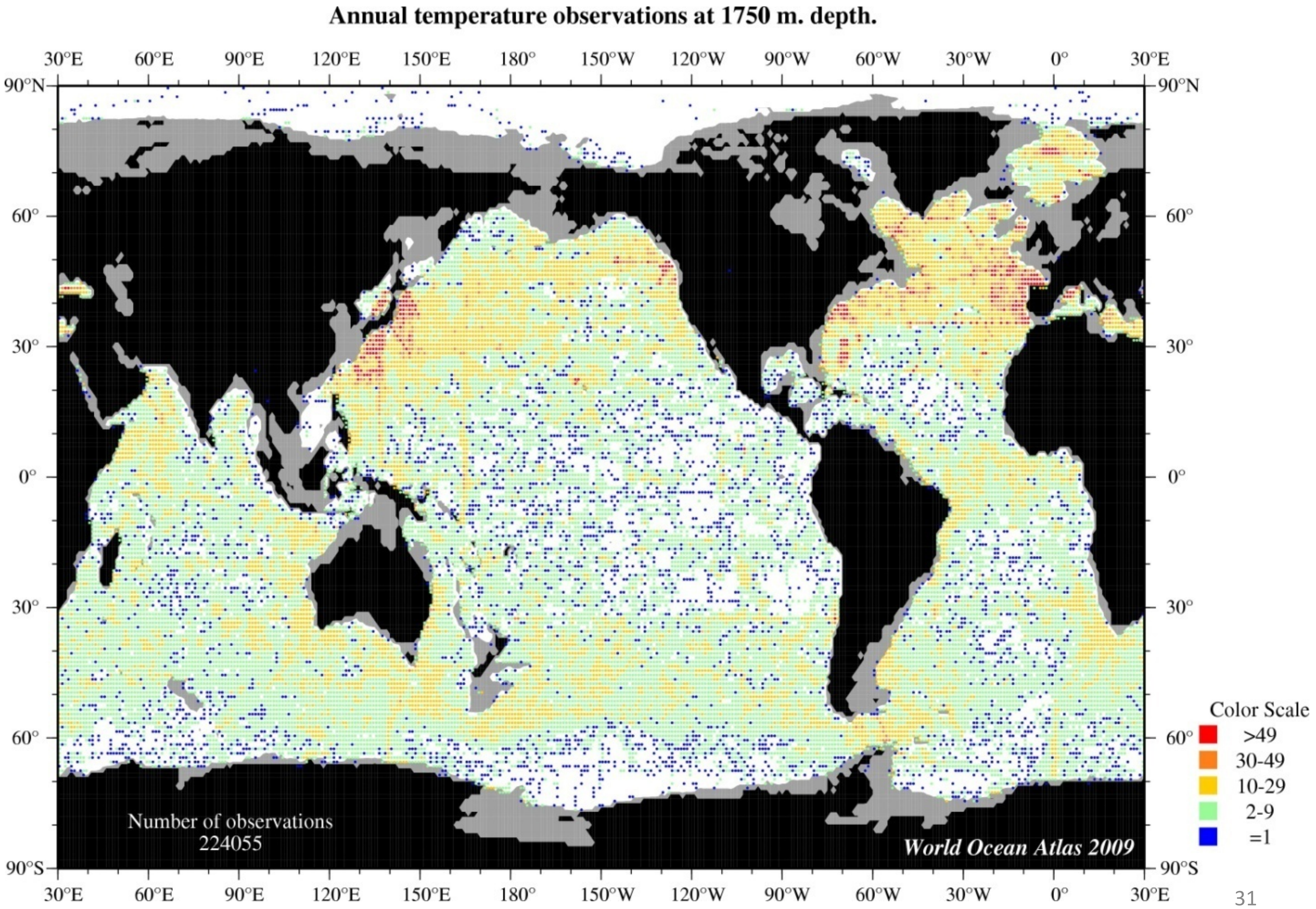
Growth of the *World Ocean Database*



% variance accounted for by linear trends of zonally averaged salinity- Boyer et al. (2005)

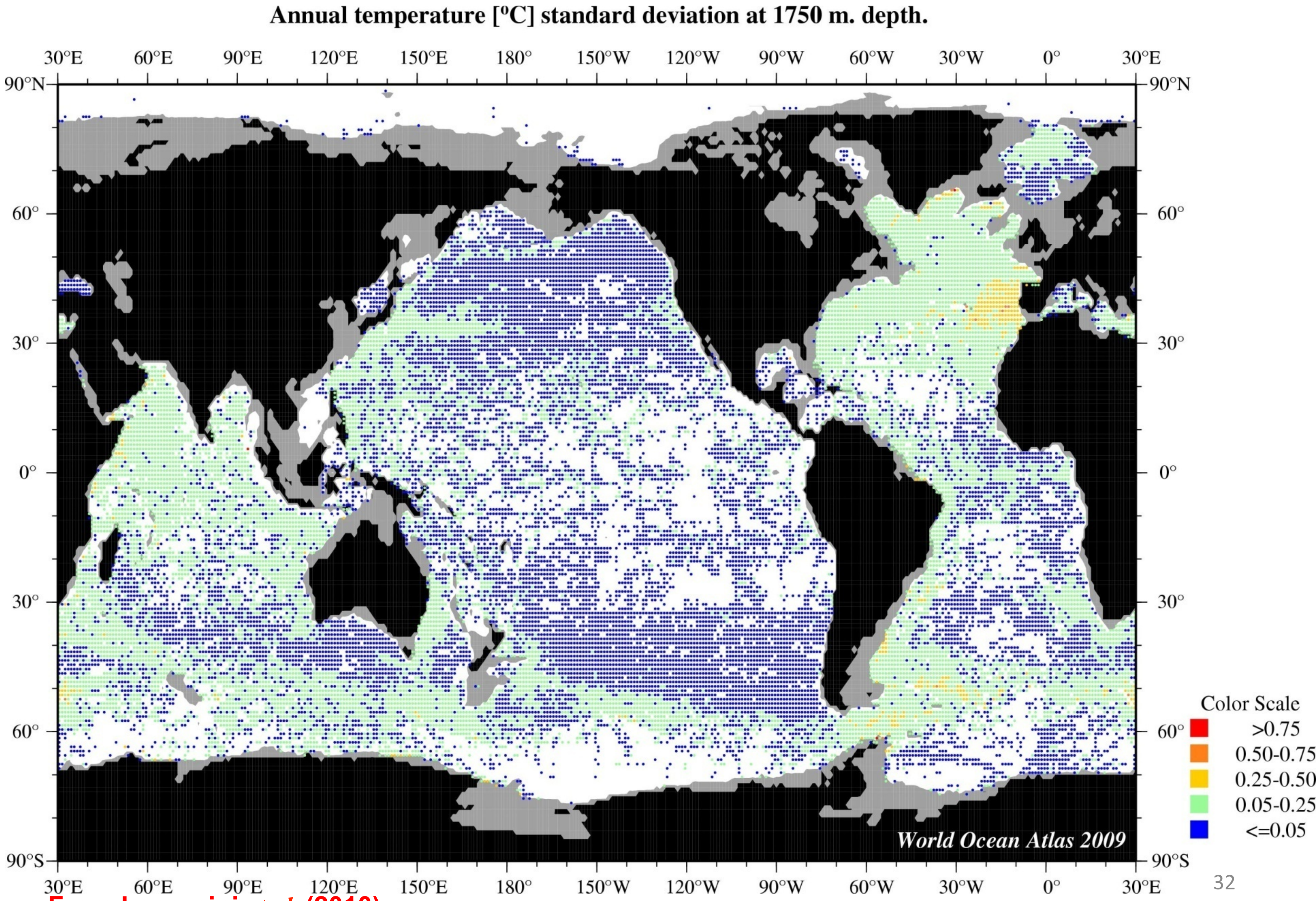


Distribution of all temperature observations at 1750 m depth



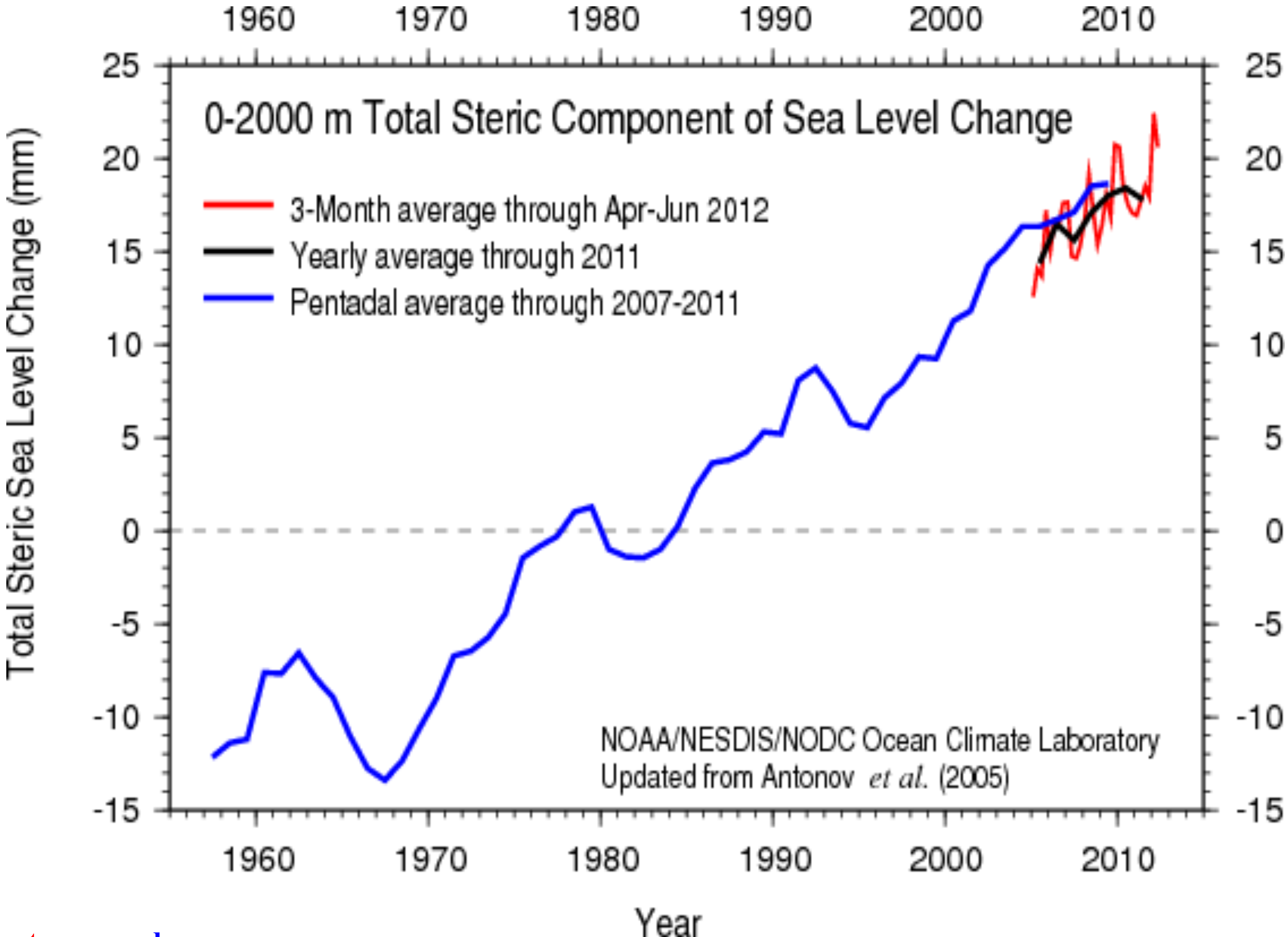
From Locarnini *et al*. (2010)

All-data temperature standard deviation (°C) at 1750 m depth



From Locarnini *et al*. (2010)

0- 2000 m steric component of sea level change



Online at www.nodc.noaa.gov

It is the thermosteric component of sea level change that is the main contributor to the total change.

Halosteric component can be very important regionally.