Development of Global Heat and Freshwater Anomaly Analyses

Gregory C. Johnson[1], John M. Lyman[2] and Josh K. Wills[3]
[1]NOAA Pacific Marine Environmental Laboratory, Seattle WA
[2]University of Hawaii/JIMAR, NOAA Pacific Marine Environmental Laboratory, Seattle WA
[3]Jet Propulsion Laboratory, Pasadena CA

Table of Contents

1. Abstract 1
2. Project Summary 1
3. Scientific Accomplishments 2
4. Education and Outreach 4
5. Publications and Reports 4
   5.1. Publications by Principal Investigators 4
   5.2. Other Relevant Publications 4

1. Abstract

We perform analyses of Ocean Heat Content and salinity distributions and variability to assess the role of ocean warming and freshening in climate change. These assessments include quantification of interannual global upper (0-750 m) ocean heat content changes and global ocean surface salinity variability for the annual State of the Climate Report. We also attempt to quantify errors in estimates of upper ocean heat content, and to reduce those errors as feasible. We are also working from regional towards global assessments of decadal abyssal ocean warming. These analyses are important for climate sensitivity, climate commitment, and sea level rise studies.

2. Project Summary

Understanding global climate variability requires knowledge of ocean temperature and salinity fields (or more precisely ocean heat and fresh water content). Accurate estimates of changes in distribution of ocean heat and fresh water content combined with an analysis of how thermohaline (temperature-salinity) anomalies enter, circulate within, and leave the ocean is necessary to monitor and understand interannual to decadal changes in climate. Such fields and analyses help to verify climate models and improve their predictive skill. They also help to diagnose the components of sea level change (ocean temperature variations versus ocean mass variations) and radiative imbalance (net energy through the top of the atmosphere versus rate at which the oceans and rest of the earth warm).

This project is developing, updating, and analyzing global analyses of ocean temperature and salinity using quality-controlled compilations of in situ temperature and salinity data from CTD-equipped autonomous profiling floats (Argo), shipboard Conductivity-Temperature-Depth (CTD) instruments, eXpendable Bathy Thermographs (XBTs), moored buoys, and other sources. These data are used to estimate global ocean temperature and salinity fields, hence upper ocean heat and freshwater content variations, on annual time-scales. Historically, in situ data

distributions are relatively sparse, especially before the advent of Argo. However, variations in upper ocean heat content are closely related to variations in sea-surface height, which has been very well measured since late 1992 by satellite altimeters. By exploiting this close relationship, we are able to quantify sampling errors inherent in estimating a global average of upper ocean heat content from an incomplete data set. We can also exploit the relationship to improve maps of upper ocean heat content from in situ data by using the altimeter data with local correlation coefficients applied as a first guess at upper ocean heat content in poorly measured regions. We exploit recent Argo data to map salinity fields in recent years, helping to assess the roles of ocean salinity in diagnosing and forcing climate variability. Furthermore, we analyze deep ocean temperature changes as data become available, and assess their contributions to global ocean heat content and sea level budgets.

This project, a part of the NOAA Office of Climate Observations Ocean Observing System Team of Experts, by providing analyses of ocean data, helps NOAA to use and assess the effectiveness of the sustained ocean observing system for climate. The work is primarily carried out at NOAA's Pacific Marine Environmental Laboratory by the PMEL and JIMAR investigator, but in very close consultation with the co-investigator at NASA's Jet Propulsion Laboratory.

3. Scientific Accomplishments

In FY2009 we updated maps (e.g. Fig. 1) of annual upper (0-750 m) ocean heat content primarily for the ice-free portions of the globe from 1993 through 2008 combining in-situ and satellite altimetry data (following Willis et al., 2004) to better resolve smaller (sub-gyre) scale spatial variability over shorter (year-to-year) time-scales. We discuss the results in the 2008 State of the Climate Report (Johnson et al., 2009). Prior to making these maps, we removed Argo float profile data with known potential serious pressure biases from our database, and applied the annual fall rate correction estimates for deep and shallow XBT probe data from Wijffels et al. (2008).

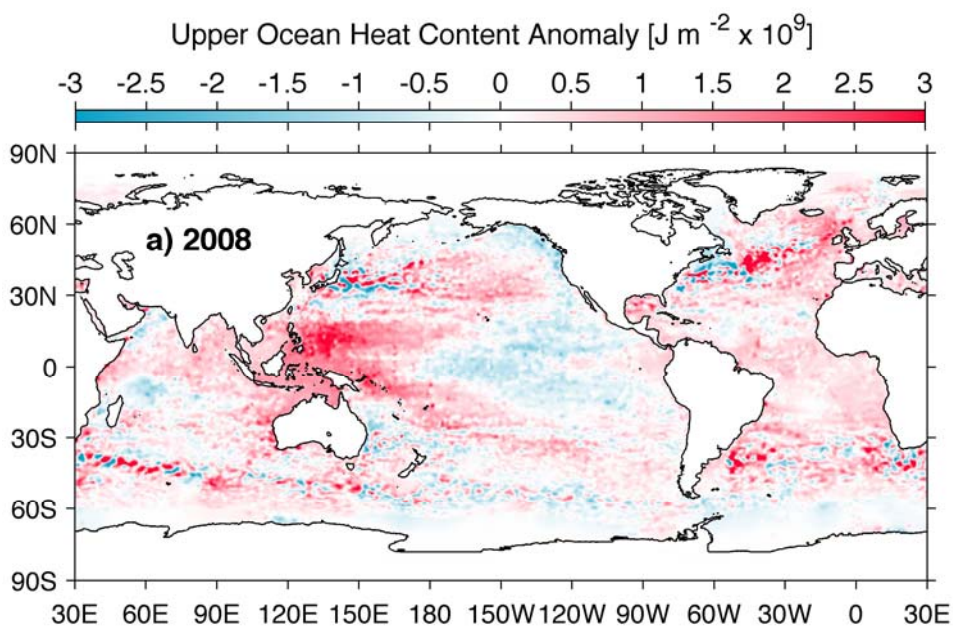

Figure 1. Combined satellite altimeter and in situ ocean temperature data upper (0 – 750 m) ocean heat content anomaly OHCA (J m^{-2}) map for 2008 analyzed following Willis et al. (2004), but relative to a 1993 – 2008 baseline. Figure after Johnson et al. (2009).

We also updated annual average maps of Sea-Surface Salinity (SSS) anomalies with respect to the World Ocean Atlas 2001 Climatology for the 2008 State of the Climate Report (Johnson and Lyman, 2009). These maps (e.g. Fig. 2) are only robust for 2005 through 2009, when Argo provided near-global coverage of SSS data.

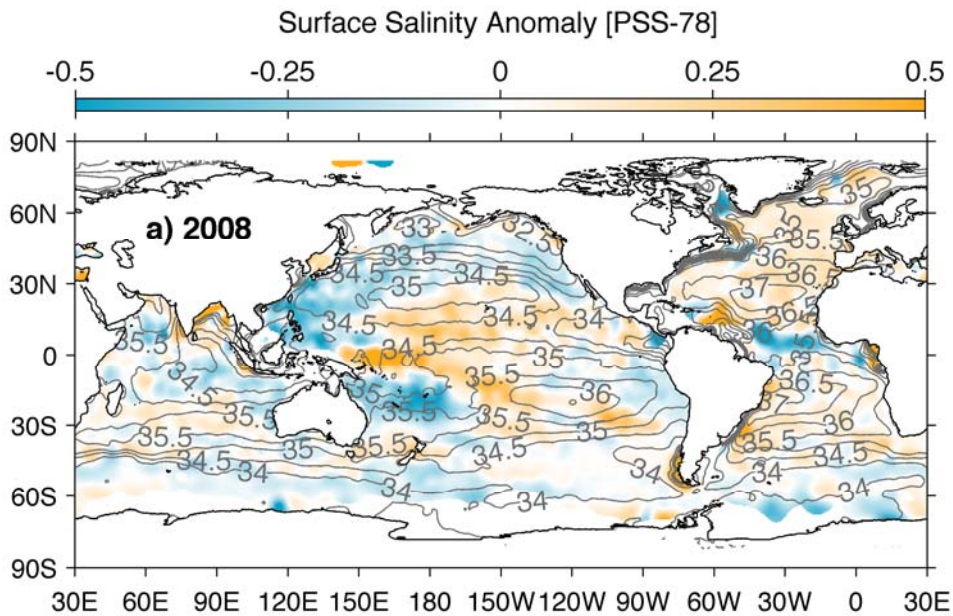

Figure 2. Map of the 2008 annual surface salinity anomaly estimated from Argo data [colors in PSS-78] with respect to a climatological salinity field from WOA 2001 [gray contours at 0.5 PSS-78 intervals]. White areas are either neutral with respect to salinity anomaly or are too data-poor to map. While salinity is often reported in practical salinity units, or PSU, it is actually a dimensionless quantity reported on the 1978 Practical Salinity Scale, or PSS-78. Figure after Johnson and Lyman (2009).

In FY2009 we published a study on the effects of sparse historical in situ ocean temperature sampling patterns on global integrals of upper ocean heat content changes (Lyman and Johnson, 2008) as well as work on quantifying and documenting two sets of instrument errors, XBT fall rate errors and misreported Argo float pressures (Willis et al., 2009). In addition we published work on constraining ocean heat content from sea level and geodetic changes (Dickey et al. 2008), and observing systems for meridional overturning variability (Willis, 2009). We also began work on a comparison of global annual upper ocean heat content curves from different international research groups to quantify errors and their magnitudes.

We also published observational analyses of Antarctic Bottom Water warming and freshening in the Southeast Indian Ocean (Johnson et al., 2008a) and reduced Antarctic Bottom Water

signatures in the western North Atlantic (Johnson et al., 2008b), as well as continued warming in the deep Caribbean Sea (Johnson and Purkey, 2009). We discussed these and other abyssal studies of abyssal warming and freshening at an invited talk at the scientific conference in Copenhagen this spring billed as a lead-in to COP-15 (Johnson, 2009), as well as in two sections of the 2008 State of the Climate report (Baringer et al., 2009; Johnson et al., 2009). This work is germane to both this activity and the Global Repeat Hydrographic/CO2/Tracer Survey work.

We also submitted an analysis of the effects of salt fingering (vigorous double-diffusive mixing) on interior ocean climate change signals that are used to diagnose variations in the atmospheric hydrological cycle (Johnson and Kearney, 2009). These results suggest that such diagnoses might benefit from improved mixing physics. In addition, we analyzed subsurface eddies off Chile containing anomalously warm and salty water that previously flowed poleward from the equator along the west coast of South America (Johnson and McTaggart, 2009). These eddies modify the characteristics of the much colder and fresher subsurface water in the interior after they propagate westward and eventually mix their anomalous properties into their surrounding waters.

The project web page is http://oceans.pmel.noaa.gov/.

4. Education and Outreach

G. Johnson is currently advising U. of Washington Oceanography graduate student S. Purkey. She is working on quantifying global abyssal temperature changes and their contributions to global heat and sea level budgets. G. Johnson is also advising NRC postdoctoral fellow S. Schmidtko, working with him on ocean oxygen changes and observational analysis global southern ocean water mass formation and variability.

5. Publications and Reports

5.1. Publications by Principal Investigators

Baringer, M. O., C. S. Meinen, G. C. Johnson, T. O. Kanzow, S. A. Cunningham, W. E. Johns, L. M. Beal, J. J.-M. Hirschi, D. Rayner, H. R. Longworth, H. L. Bryden, and J. Marotzke, 2009: Global Oceans: The Meridional Overturning Circulation. *In* State of the Climate in 2008, T. C. Peterson and M. O. Baringer, Eds., *Bulletin of the American Meteorological Society*, **90**, *8*, S59–S62, doi:10.1175/BAMS-90-8-StateoftheClimate.

Dickey J. O., S. L. Marcus, J. K. Willis, 2008: Ocean cooling: Constraints from changes in Earth's dynamic oblateness (J 2) and altimetry. *Geophys. Res. Lett.*, **35**, L18608, doi:10.1029/2008GL035115.

Johnson, G. C., 2009. Recent decadal warming and freshening of Antarctic-derived abyssal waters. The IARU Scientific Congress "Climate Change: Global Risks, Challenges and Decisions", Copenhagen, Denmark, 10 – 12 Mar., invited, *IOP Conf. Ser.: Earth Environ. Sci.*, **6**, 032006, doi:10.1088/1755-1307/6/3/032006.

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Johnson, G. C., J. M. Lyman, J. K. Willis, S. Levitus, T. Boyer, J. Antonov, C. Schmid, and G. J. Goni, 2009: Global Oceans: Ocean Heat Content. *In* State of the Climate in 2008, D. H. Levinson and J. H. Lawrimore, Eds., *Bulletin of the American Meteorological Society*, **90**, *8*, S49–S52, doi:10.1175/BAMS-90-8-StateoftheClimate.

Johnson, G. C., and K. E. McTaggart. 2009. Equatorial Pacific 13°C Water eddies in the eastern subtropical South Pacific Ocean. *Journal of Physical Oceanography*, in press, doi:10.1175/2009JPO4287.1.

Johnson, G. C., and S. G. Purkey. 2009. Deep Caribbean Sea warming. *Deep-Sea Research I*, **56**, 827–843, doi:10.1016/j.dsr.2008.12.011.

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Lyman, J. M., and G. C. Johnson. 2008. Estimating global upper ocean heat content despite irregular sampling. *Journal of Climate*, **21**, 5629–5641, doi:10.1175/2008JCLI2259.1.

Willis, J. K., J. M. Lyman, J. M., G. C. Johnson, and J. Gilson. 2009. In situ data biases and recent ocean heat content variability. *Journal of Atmospheric and Oceanic Technology*, 26, 846–852, doi:10.1175/2008JTECHO608.1.

Willis, J. K., 2009: The "Day after Tomorrow" Scenario: Can In-Situ Floats and Satellite Altimeters Detect the Impact of Global Warming on Atlantic Ocean Overturning? *Nature*, in review.