World Ocean Database Updates and Seasonal Estimates of Ocean Temperature, Salinity, Heat Content, and Steric Sea Level

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1. Project Summary

The "*World Ocean Database* (WOD) project and resulting products" produces seasonal updates to WOD which is the world's largest collection of vertical ocean profile available internationally without restriction. The database includes: 1) Ocean Station Data profiles of temperature, salinity, and perhaps oxygen, nutrients, tracers; 2) Conductivity (Salinity)-Temperature-Depth profiles; 3) Upper ocean temperature profiles from Expendable Bathythermographs (XBTs) and Mechanical Bathythermograph instruments (MBTs); 4) Profiling floats that provide upper (0-1900 m) ocean profiles of temperature and salinity; 5) Gliders that provide profiles of temperature and salinity (0-2000 m); 6) Moored buoys that provide upper ocean (0-500 m) profiles of temperature and salinity; 7) Drifting buoys that provide upper ocean (0-500 m) profiles of temperature and salinity; 8) Instrumented Marine Mammals that provide profiles of temperature and salinity; 9) Upper ocean temperature and salinity profiles from Expendable Conductivity-Temperature-Depth Bathythermographs (XCTDs). Many of these observational profiles have been funded by NOAA programs.

The seasonally updated WOD is used to produce near-global seasonal estimates of temperature and salinity which are use to produce seasonal estimates of ocean temperature and salinity anomalies as a function of depth. These anomaly fields are used to produce near-global estimates of ocean heat content and the thermosteric and halosteric components of sea level change. These products as well as the original profiles are used by NOAA scientists as well as the international scientific community. NOAA supports the gathering of much of these data and greatly benefits from the data collected by other nations. No single nation can afford to gather all the ocean profile required for many scientific and assessment studies. All data and products are made available online seasonally at www.nodc.noaa.gov.

The scientific, technological, and societal rationale for this is that the world ocean plays a critical role in earth's climate system. Heat being stored in the world ocean will determine the changes in earth's atmosphere, particularly at earth's surface. Changes in the physical and chemical composition of the world ocean will affect fisheries and other parts of the ocean ecosystem, e.g., coral reefs due to changes in temperature (heat content), salinity, and carbon dioxide. There is no more important scientific problem facing earth's population than climate change. Most of our users are the scientific and assessment (*e.g*., the Intergovernmental Program on Climate Change (IPCC)) communities. This is documented by the very large number of scientific citations to our database and products based on our databases.

2. Scientific and Observing System Accomplishments

Please address the following questions:

a. How did your project deliverables serve the observing system's program deliverables (deliverables are noted in the file: OCO_Annual_Report_CoverLetter_14Sep12) If you did not specify deliverables last year, create them now and report on them.

Our project delivered updates of the *World Ocean Database* every three months. Along with these updates we provided quality control information to suppliers of the data such as the NOAA Argo Profiling Float project and the NOAA XBT SEAS program. The updates included NOAA-funded ocean observing programs including:

1) Argo profiling floats;
2) XBT Ship-of-Opportunity profiles;
3) Data from the (a) TAO/Triton (Pacific Ocean- NOAA funded),
   (b) Pirata (Atlantic Ocean- NOAA supplied buoys), and
   (c) RAMA (Indian Ocean- NOAA supplied buoys) arrays of tropical moored buoys

Also included are all other data received and processed such as Ocean Station Data (Bottle), Expandable Bathythermograph profile data, and glider profile data among others from all countries.

What did you achieve during FY 2012?

We produced seasonal updates of the ***World Ocean Database*** and computed and made available online updated estimates of gridded ocean temperature and salinity anomalies at standard depth levels. We also provided updated seasonal gridded heat content and the thermosteric and halosteric components of sea level online. All these fields were available in several compute formats as well as figures.

b. What scientific advances were made and/or facilitated through your activities?

Our FY12 publication on ocean heat content documented that approximately 90% of the warming of the earth system during 1955-2010 has occurred in the world ocean and that

approximately 30% of the heating of the world ocean during this period occurred in the 700-2000 m depth layer. The world ocean continued warming as it has since 1955.

c. What is the significance of these advances?

The amount of heat stored in the world ocean is one of the prime factors that will determine how earths' mean surface temperatures will respond to the increase of greenhouse gases in earth's atmosphere that has been ongoing since the Industrial Revolution began. Ocean heat content is one of, if not ***the***, most important climate quantities to monitor. Heat stored in the world ocean will determine how earth's surface temperature responds to the increase of greenhouse gases in earth's atmosphere. This is important for agriculture, transportation, health and many other human activities.

d. What, if any, information was jeopardized due to a lack of funding, lack of instrumentation, or inability to carry out the work?

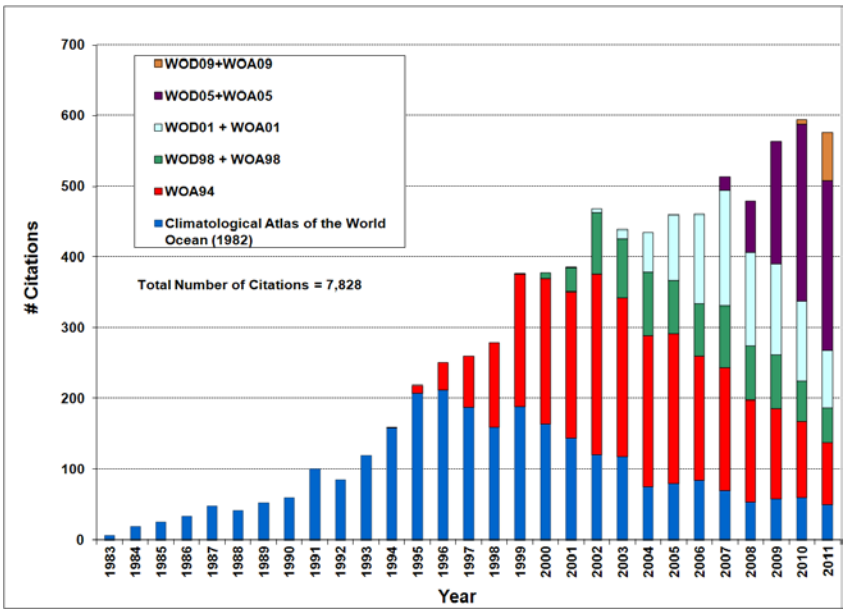
A shortfall in funding will directly affect our ability to process and redistribute ocean profile data to NOAA and the rest of the scientific community. International Assessments such as the IPCC will not have the most comprehensive databases upon which they base their assessments. We have already had to reduce the number of contractors we have by one person due to previous funding cutbacks.

e. What is the web site for your program? www.nodc.noaa.gov

Performance statistics

1) This figure shows that the *World Ocean Database* (WOD) is being cited at a rate of approximately 400 times per year. This is a high citation rate that indicates the importance of the WOD to NOAA and the greater scientific community.

Utility of NODC/WDC profile data as indicated by citations to NODC atlases in the scientific literature

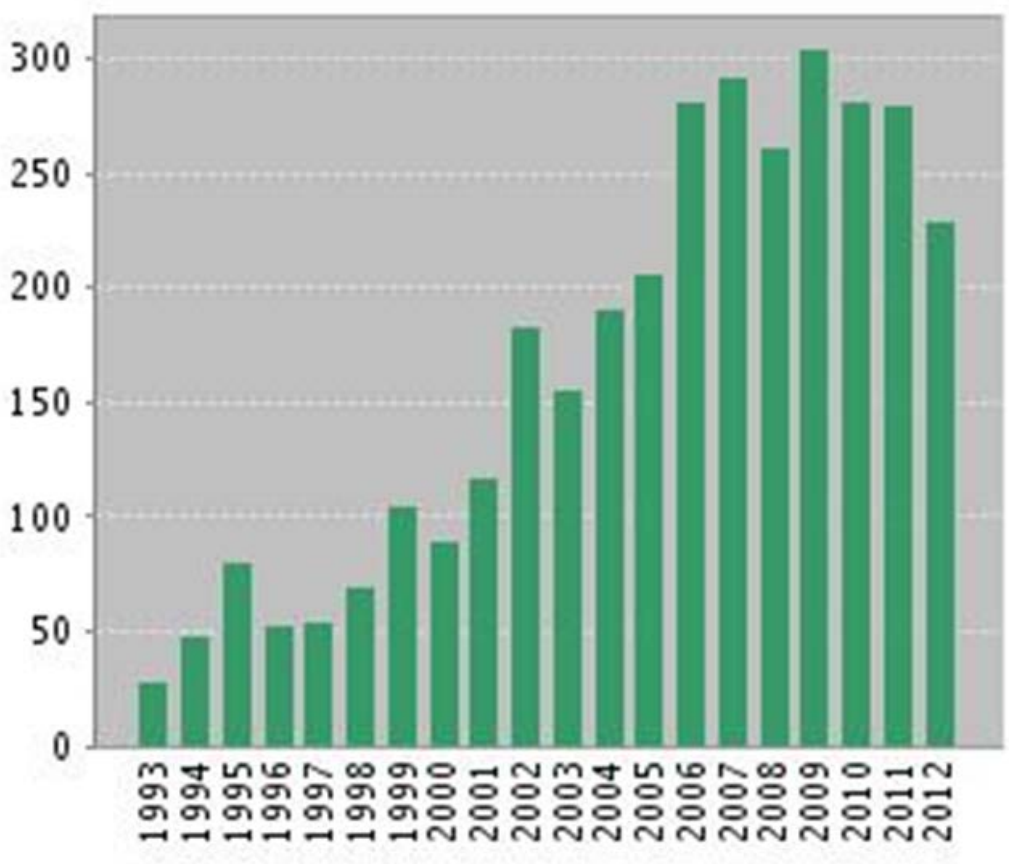


The *World Ocean Database* (WOD) is the world's largest collection of ocean profile-plankton data available internationally without restriction. All data are quality controlled and in one format. The WOD is a product, it is not an archive. Not all data that scientists submit to NODC/WDC are put into the WOD, *e.g.* amino acids, …

***Based on a search of the ISI *Scientific Citation Index* as of March 2012.**

1

2) This figure shows citations in the peer-reviewed scientific literature for the P.I.s Sydney Levitus and Timothy P. Boyer (and colleagues). This documents the importance of the scientific work published by Levitus and Boyer which is based on the *World Ocean Database*.



For projects involved with data collection, please address the following questions:

All of our data and products reside and are available at www.nodc.noaa.gov
Our database (World Ocean Database) is updated every three months and made available online.

a. Are your data distributed in real time on the Global Telecommunications System? We receive data via the GTS.

b. Where do your real time data reside? NODC/NOAA. Are the data available online? Yes.

c. Where do your delayed mode data reside? (www.nodc.noaa.gov) Are the data available online? Yes. What is the date of the most recent data available publicly? Updated online every 3 months.

d. Where are your data archived and with what frequency? www.nodc.noaa.gov Every 3 months

e. Have you successfully retrieved your program's data from the website or Data Assembly Center where your data reside, just to ensure the accessibility of the data? Yes.

f. Do you have a data management plan for the data collected as part of your project? Yes.

g. Is your observing project compliant with the National Environmental Policy Act (NEPA) and other NOAA Environmental Statutes (e.g. Marine Mammal Protection Act (MMPA), Endangered Species Act (ESA), Essential Fish Habitat (EFH), and the National Marine Sanctuaries Act (NMSA)? Yes, we are simply archiving all ocean profile data.

2.1. Outreach and Education

Levitus has been frequently cited in the media about ocean heat content and has given interviews on CBS, NPR as well as major newspaper. We have hosted foreign scientists for training and summer students such as NOAA Knauss Fellows. Our works are used by university professors as well as high school teachers. We have worked with Ms. LuAnn Thompson of NOAA the CPO on her NOAA web presentation about ocean warming. John Antonov and I worked with LuAnn of NOAA/CPO on this slide presentation (she put the presentation together, John and I checked it for accuracy: http://www.climate.gov/#understandingClimate/presentationLibrary .

3. Publications and Reports

3.1. Publications by Principal Investigators

This section includes publications on which one of the project investigators is a lead or contributing author. **Please follow the *Bulletin of the American Meteorological Society* style (http://www.ametsoc.org/pubs/Refstyl.pdf) when listing your publications and include an**

electronic copy of each cited publication. Under this heading list your publications under the following subheadings:

Published:

1) Giese, B. S., G. A. Chepurin, J. A. Carton, T. P. Boyer, and H. F. Seidel. 2011: Impact of Bathythermograph Temperature Bias Models on an Ocean Reanalysis. J. Clim., 24, 84-93.

2) Helber, R. W. A. Birol Kara, J. G. Richman, M. R. Carnes, C. N. Barron, H. E. Hurlburt, and T. Boyer, 2012: Temperature versus salinity gradients below the ocean mixed layer J. Geophys. Res., 117, C05006, doi:10.1029/2011JC007382.

3) T. P. Boyer, V. V. Gopalakrishna, F. Reseghetti, A. Naik, V. Suneel, M. Ravichandran, N. P. Mohammed Ali, M. M. M. Rafeeq and R. A. Chico (2011): "Investigation of XBT and XCTD biases in the Arabian Sea and the Bay of Bengal with implications for climate studies". J Atmosph. Oceanic Tech., 28, DOI: 10.1175/2010JTECHO784.1, 266-286.

4) 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, and 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.

5) Gleckler, P. J., B. D. Santer, C. M. Domingues, D. W Pierce, T. P. Barnett, J. A. Church, K. E. Taylor, K. M. AchutaRao, T. P. Boyer, M. Ishii, and P. M. Caldwell (2012): Robust evidence of human-induced global ocean warming on multi-decadal time scales. Nature: Climate Change, published online, doi:10.1038/nclimate1553.

6) Johnson, G.C., J. M. Lyman, J. K. Willis, S. Levitus, T. Boyer, J. Antonov, (2012) [Global Oceans] Ocean heat content, [in State of the Climate in 2011]. Bull. Amer. Meteor. Soc., 93 (7), S62-S65.

7) Boyer, T., S. Levitus, J. Antonov, J. Reagan, C. Schmid, R. Locarnini, (2012), [Global Oceans] Subsurface salinity, ([n State of the Climate in 2011]. Bull. Amer. Meteor. Soc., 93 (7), S72-S75.

8) Levitus, S., 2012: The UNESCO/IOC/IODE Global Oceanographic Data Archaeology and Rescue (GODAR) project. CODATA Data Sci. J., 11, 46-71, published online at https://www.jstage.jst.go.jp/browse/dsj/11/0/_contents.

9) Xue, Y., M. A. Balmaseda, T. Boyer, N. Ferry, S. Good, I. Ishikawa, A. Kumar, M. Rienecker, A. J. Rosati, and Y. Yin, 2013: A Comparative Analysis of Upper Ocean Heat Content Variability from an Ensemble of Operational Ocean Reanalyses. J. Clim., 6905-6929, doi:10.1175/JCLI-D-11-00542.1.

10) Gouretski, V., J. Kennedy, A. Kohl, T. Boyer, 2012: Consistent near-surface ocean warming since 1900 in two largely independent observing networks, Geophys. Res. Lett., 39, 19, doi:10.1029/2012GL052975.

11) Preliminary version of “Oceanographic Atlas of the East Asian Seas” placed online (www.nodc.noaa.gov).

Accepted for publication: None as of this date.

Submitted for publication:

12) Cowley, R., S. Wijffels, L. Cheng, T. Boyer, S. Kizu, "Biases in Expendable Bathythermograph data: A new view based on historical side-by-side comparisons". Submitted to J. Atmosph Oceanic Tech.

In Preparation:

13) Boyer, T., 2013” "Evolution of the Ocean Observing System for Subsurface Temperature" finished and submitted to J. Abraham (U. of St. Thomas) for inclusion in a review article on climate, ocean heat content and observational challenges.

14) Roemmich, D., G. J. Johnson, T. Boyer, "Recent progress and current status of global observations of subsurface temperature, heat content, and thermosteric sea level", IOOS Summit White Paper, completed and prepared for submission.

15) Levitus., S. Antonov, J. I., Boyer, T.P., Locarnini, R. A., Garcia, H. E., Seidov, D., Mishonov, A. V, M. M. Zweng, J. R. Reagan, 2012: Multidecadal variability of temperature, salinity, density, and oxygen of the North Atlantic subarctic gyre, 1955-2010. Geophys. Res. Lett., 39, In prep.

16) Cheng, L. J. Zhu, R. Cowley, T. Boyer, S. Wijffels, 2012, Time, Probe Type, and Temperature Variable Biases Corrections on Historical Expendable Bathythermograph Observations, In prep.

17) T. P. Boyer is a contributing author to the ocean observations section of the next IPCC report.

18) S. Levitus and T.P. Boyer are official reviewers for the next IPCC report.

3.2. Other Relevant Publications

Paper	# Citations* As of 10/16/12
Levitus, S., J. I. Antonov, T. P. Boyer, C. Stephens, 2000: Warming of the World Ocean. Science, 287, 2225-2229.	559
Levitus, S., J. I. Antonov, T. P. Boyer, 2005: Warming of the World Ocean, 1955-2003. Geophys. Res. Lett., L02604, doi:10.1029//2004GL021592.	405
Levitus, S., J. Antonov, J. Wang, T. L. Delworth, K. W. Dixon, A. J. Broccoli, 2001: Anthropogenic warming of Earth's climate system. Science, 292, 267-270.	252
Boyer, T.P., J. I. Antonov, S. Levitus, R. Locarnini, 2005: Linear trends of salinity for the world ocean, 1955-1998. Geophys. Res. Lett., 32, L01604, doi:1029:2004GL021791.	84
Boyer, T., S. Levitus, H. Garcia, R. A. Locarnini, C. Stephens, J. Antonov, 2005: Objective analyses of annual, seasonal, and monthly temperature and salinity for the world ocean on a 0.25° degree grid. Int. J. Clim., 25, 931-945.	81
Antonov, J. I., S. Levitus, T. P. Boyer, 2002: Steric sea level variations during 1957-1994: Importance of salinity. J. Geophys. Res.-Ocean, 107, 8013, doi:10.1029/2001JC000964.	78

Total Citations by Year for Sydney Levitus and Tim Boyer