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

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Project Summary

The Ocean Climate Laboratory (OCL) of the National Oceanographic Data Center (NODC) has pioneered the development of a global, integrated ocean profile database with all data in one common format and with a well-defined and documented set of quality control flags provided with each observation. This database is known as the "World Ocean Database" (WOD). WOD has been developed with NODC base funding and funding from the NOAA Climate Program Office (CPO). WOD contains vertical profiles of temperature, salinity, oxygen, nutrients and other variables collected from a variety of instruments and collected at great cost. For example the cost of ship time to gather the data in the WOD is approximately six billion in today's dollars. WOD stores the data measured by scientists at "observed" depth levels. We interpolate the data to "standard" depth levels which we compute by vertical interpolation. All previous releases of the WOD contained 33 standard depth levels from the sea surface to 5500 m depth. **Our next version of the WOD will contain 102 standard levels between the sea surface and 5500 m depth on a ¼ degree horizontal grid.** We are able to increase vertical resolution because of the development of instruments such as profiling floats, gliders, and expendable bathythermographs that have considerably improved vertical resolution compared to older ocean sampling techniques. Such techniques consisted of lowering water bottles and reversing thermometers attached to a wire into the ocean by a winch. Improved vertical ocean analysis resolution is necessary for improved understanding of ocean variability and climate change in diagnostic studies. It has long been known that the historical patterns of relatively coarse vertical sampling could miss important oceanographic features. Improved vertical resolution of ocean data is necessary for diagnostic studies describing the role of the ocean as part of earth's climate system. Numerical models of the ocean are now being run with the vertical resolution that we will be producing in the near-future. These new modeling efforts requires ocean data analyses with improved vertical resolution to better capture topographic features and effects.

The WOD, and products based on the WOD such as the World Ocean Atlas, have proved of great importance to the oceanographic, climate and geodetic communities. These products have been cited at a rate of approximately 400 times per month for the last 12 years. This is shown in figure 1.

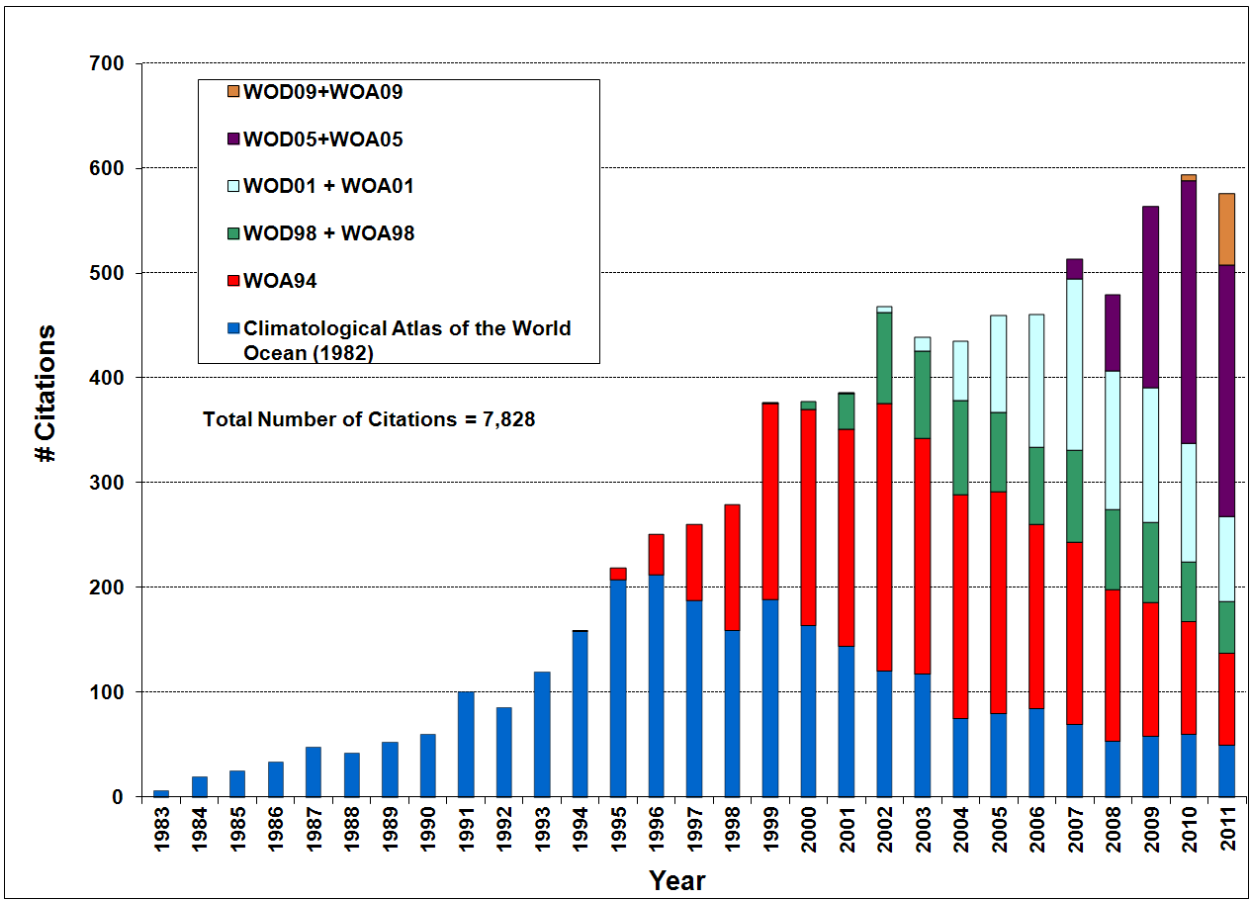

Figure 1. Utility of NODC/WDC profile data as indicated by citations to NODC atlases in the scientific literature (Based on a search of the ISI Scientific Citation Index as of March 2012). The World Ocean Database (WOD) is the world's largest collection of ocean profile-plankton data available internationally 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, …

Fig. 1 shows without question that the WOD serves as one of the basic infrastructures of ocean and climate science for the scientific and forecasting communities.

We document this further by showing the amount of data downloaded by users of NODC WOD data in figure 2.

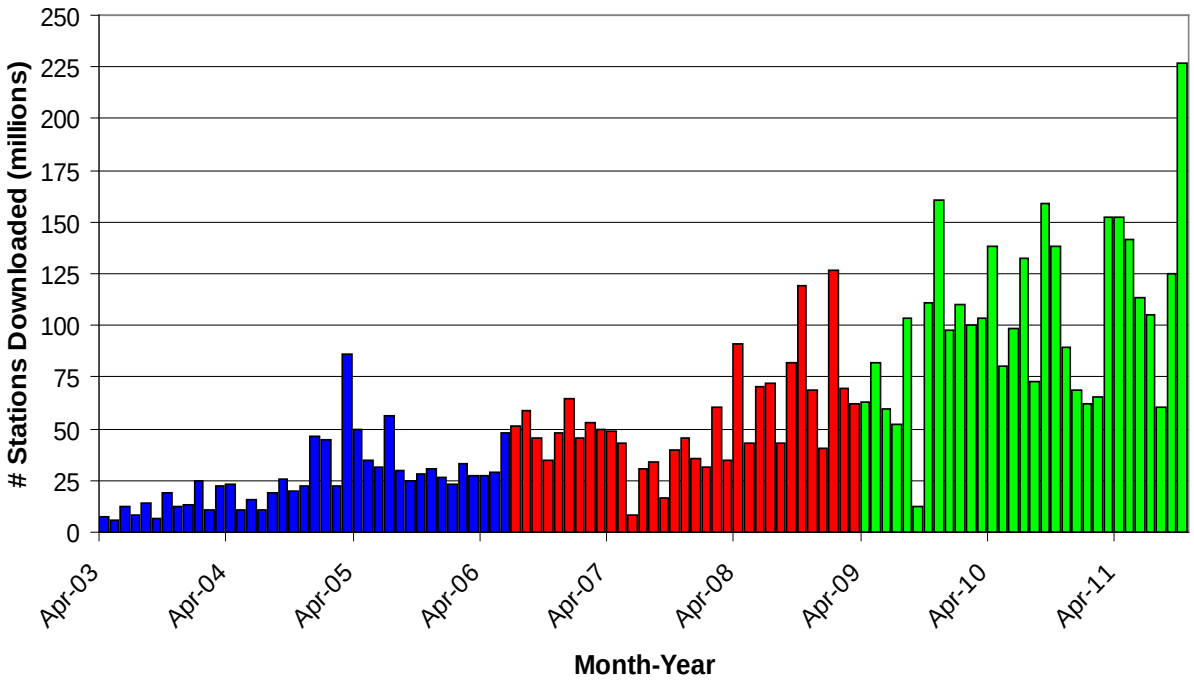

Figure 2. World Ocean Database time series of the number of ocean stations downloaded by month. Since the implementation of WODselect in April 2003, WODselect has responded to 171 thousand database queries, served over 28 billion stations (1493 GB) via the NODC FTP server.
As of April 23, 2011 statistics shows over 114 million (59 GB) stations were downloaded.

Part of the work in maintaining the WOD is supported by base funds. Funding from the Ocean Climate Observation Program supports additional personnel who provide seasonal updates of the World Ocean Database and the work described in the next paragraph. In particular, they perform quality control of the profile data for each seasonal period. This quality control work is critical in providing a quality product to the WOD user community. Additional funding is needed to produce monthly updates of the WOD and the quantities we derive from the WOD such as ocean heat content and steric component of sea level change.

Base funding of WOD only allowed updates approximately every four to five years. Funding from the CPO has allowed online updating of the WOD every three months. This has also allowed us to prepare seasonal estimates of important climate system variables. The NODC/OCL has been preparing seasonal estimates of near-global ocean temperature and salinity anomalies ocean heat content, and the components of sea level change (thermosteric and halosteric) associated with these anomalies. We do this with support from the NOAA CPO. NODC/OCL prepares gridded fields (a one-degree latitude-longitude grid) of temperature and salinity anomalies every three months based on all oceanographic vertical profile data received at NODC. Many of these data are gathered as a result of observing programs (*e.g.*, profiling floats deployed as part of the Argo project, Expendable Bathythermographs (XBTs) deployed by the Ship-of-Opportunity Program (SOOP)) supported by the NOAA CPO/OCO. All data received are quality-controlled at NODC. Derived quantities such as ocean heat content and the temperature and salinity components of sea level change are computed from the three-month

temperature and salinity anomaly fields that we compute. All anomaly and derived fields are made available online at www.nodc.noaa.gov.

Table 1 quantitatively documents the impact our work has had on the research community. In fact our work has motivated several other groups to address the problem of determining ocean heat content.

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

Table 1. Citation counts of some relevant NODC/OCL papers.

At a minimum, the results we have described are critical for monitoring the health of the ocean climate observing system. For example, our work has been important for documenting time-varying biases found in XBT observations. Our work has also played a role in identifying that some profiling floats had systematic biases. Most importantly, as we have shown in previously published work, approximately 90 percent of the heat added to earth's climate system since 1955 has been sequestered in the world ocean. See the figures at the end of this report to see the scientific figures we update and make available online every 3 months.

SOCIETAL BENEFIT

The societal benefit of our work is twofold. First, our work represents a monitoring of the ocean observing system since systematic biases in instruments tend to appear quickly in the derived fields we compute every 3 months. Thus we and others can relatively identify and find the source of these problems instead of archiving the data and having decades pass by before problems are identified such as happened with XBT profile data. Deployment of an ocean climate observing system is expensive and so it needs to be monitored to ensure that it is producing the highest quality data. Second, we have pioneered the quantification of the amount of heat being stored by the world ocean. This improves understanding of earth's climate system thus advancing both ocean and climate sciences and improves assessments of climate variability and change. Some

droughts such as the late 20th century Sahel drought (*e.g.*, Lu, J., and T. L. Delworth (2005), Geophys. Res. Lett., 32(22), among others) have been related to anomalous sea surface temperature conditions. Such conditions are most likely linked to anomalous subsurface temperate conditions which we provide on a seasonal basis.

The world ocean is a major part of earth's climate system because of its enormous ability to store heat. The response of earth's climate to increasing greenhouse gases will be determined in part by how much heat the world ocean has already, and will in the future, sequester. Thus societal impact of our work could not be greater.

The scientific community is the main user of our database and products based on the database. For example our database products have been cited approximately 400 times per year for the past twelve years. Our four papers on ocean heat content have been cited more than 1200 times since the first paper was published in 2000. Our papers on steric sea level variability have also been frequently cited. Our work is critical to understanding sea level variability which is of critical importance to society.

In summary our proposed work will:

a) Develop and maintain long time-series indicators of climate variability and change (see Table 1).

b) Develop and maintain standard data sets for initialization and evaluation of climate forecast models, assessments of climate change, and informed risk management. (See, for example, Carton, J. A., and B. S. Giese (2008), A reanalysis of ocean climate using simple ocean data assimilation (SODA), Mon. Wea. Rev., 136, 2999-3017)

c) Perform diagnostic studies of observed patterns of climate variability and change on global to regional scales (e.g., Table 1).