World Ocean Database and related products – Seasonal updates
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1. Project Summary

The World Ocean Database (WOD) is the world’s most extensive collection of uniformly formatted, quality controlled, subsurface ocean profile data available without restriction. Profile data are measurements at multiple depths from the ocean surface to the ocean bottom at a single geographic location during a finite time period – the time it takes to lower and raise the measuring instrumentation. Singly, profiles can provide a snapshot of oceanographic conditions at one location at one time. Combined with other available profiles over discrete time intervals, a view of regional and even global changes in the ocean can emerge. Measurements of different oceanographic variables are often taken at the same time, so a larger picture of the oceanographic environment can be pieced together. Temperature and salinity are most commonly measured concurrently, revealing the density structure of the ocean. Oxygen, nutrients, ocean tracers (such as chlorofluorocarbons), and biological variables (such as chlorophyll) are also measured concurrently with temperature and salinity, revealing the chemical and biological structure of the ocean and how they relate to the physical environment.

Recently, oceanographic profile data has been supplied by international programs intent on measuring as much of the global ocean as possible and providing high quality data in near-real time. Programs such as Argo profiling floats and Ship of Opportunity (SOOP) expendable bathythermographs (XBTs) have sophisticated deployment, data retrieval, and quality control procedures in place across the globe. WOD incorporates these data with historical and recent oceanographic cruise data, preserving the quality control flags set by these programs along with WOD quality flags, providing a uniform format and delivery system for all data from Captain Cook’s second voyage in 1772 through the highly tuned collection programs of 2014 and beyond.

Using temperature and salinity measurements, ocean heat content and freshwater content changes can be calculated against baseline long-term means, utilizing WOD for both the baseline mean and the discrete time period differences (anomalies) from the mean. Ocean heat content is an important component of the Earth’s energy budget, ameliorating to some extent the imbalance...
The WOD is released by the National Oceanographic Data Center every four to five years. The WOD + products project is set up to allow for online updates of WOD every three months and to facilitate the calculation and availability of a variety of scientific products related to ocean heat and freshwater content and for instant online availability of these data as well. The WOD is used by oceanographic and climate researchers for a variety of studies on oceanographic, environmental, and climate studies. Products, which include one-degree global fields of temperature anomalies, salinity anomalies at various depths down to 2000 m, ocean heat content, mean temperature and salinity anomalies, and thermosteric (temperature dependent), halosteric (salinity dependent), and total steric (temperature + salinity dependent) sea level change for the top 700 m and 2000 m of the global ocean, as well as integrated global ocean heat and steric sea level change, are used extensively as well for oceanographic, environmental, and climate research. Further, this project enables scientific research to better understand the calculations of these variables, error statistics, and improvements in technique. Scientific research on improved quality control of data and communication with projects, such as Argo, which are integral to the continued monitoring of ocean heat and freshwater content changes are also important components of the project.

2. Scientific and Observing System Accomplishments

- The WOD updated four times in FY14: November, 2013, January, 2014, April, 2014, and August, 2014. WOD is available through http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html. The updates to WOD included 599,697 casts from the period July 1, 2013 through June 30, 2014, which included 107,801 Argo casts, 25,722 casts (daily means in this case) from the tropical moored buoy arrays, and 63,467 casts from the Global Temperature and Salinity Profile Project (GTSPP). GTSPP is an international project dedicated to aggregating all near-real time profile data from the Global Telecommunications System (GTS) of the World Meteorological Organization (WMO). Near-real time refers to reports which are available within 48 hours of measurement. Argo and the tropical moored buoy data are also available in near-real time from their respective Data Assembly Centers. GTSPP includes casts from the Ship of Opportunity Program (SOOP) expendable bathythermograph (XBT) network, instrumented pinnipeds, gliders, and ship-based conductivity-depth-temperature (CTD) instruments. All near-real time data were put through WOD quality control procedures in addition to the quality control performed by the originators. The near-real time data streams represent data from a number of NOAA investments: Argo, TAO (Pacific), PIRATA (Atlantic), RAMA (Indian) moored buoy arrays, SOOP XBTs. While each of these projects has its own quality control procedures and distribution systems, incorporation into the WOD provides a wider audience, a uniform format, and an extra layer of quality control in addition to the originators own quality control flags. This quality control is unique in that it is specifically geared to tracking down data which may be high quality measurements, but are outliers compared to historical data and in the computations of heat and salt content.

- In addition to the near-real time data sources, 77,259 historical oceanographic casts (plus 402,739 glider cycles) were added to the WOD. These casts were taken in many years from 1898 to 2014.
While this project is not primarily concerned with historical data, these casts can be very helpful in understanding the previous state of the ocean for comparison with the present state to understand long-term change. Further, many of these casts (67,950 + all glider cycles) are from the last 10 years (Figure 1).

![Figure 1: Data added to WOD in FY14 from sources other than near-real time for years 2004-2014.](image)

While the Argo program, and to a lesser extent the tropical moored buoy arrays and SOOP, are the main source of oceanographic profile data for monitoring heat and salt, there are areas of the ocean for which other data sources can augment, or in some cases, be the sole source of subsurface temperature and salinity information. These areas include the high Arctic, shelf regions, and Southern Ocean under-ice regions. Further, many of these data represent significant investment from NOAA and other U.S. sources and making them readily accessible through WOD increases their utility. Finally, some of these data represent adjusted, calibrated, and/or higher resolution versions of previous near-real-time data, replacing existing data with higher quality versions. Some of the main sources for the non-real time (delayed-mode) data are the CLIVAR and Carbon Hydrographic Data Office (CCHDO – global coverage), NOAA Northeast Fisheries Science Center (NEFSC, US Atlantic shelf), PIRATA maintenance cruise CTDs (Equatorial Atlantic) and the International Council for the Exploration of the Seas (ICES, international contribution, mainly eastern Atlantic). Further, international data exchanges through official and unofficial agreements carried out routinely by NODC add more data to the WOD, notably on the Patagonian Shelf and off of New Zealand.

A concerted effort to add glider data to WOD in FY14 resulted in a large addition of data from the Integrated Marine Observing System (IMOS, Australia) covering much of the coastal and shelf region surrounding Australia. Glider data will be updated from IMOS quarterly in the future. Also, 22 glider deployments in the Labrador Sea and...
Norwegian Sea from the Applied Physics Lab (APL) at the University of Washington were added to WOD in FY14. Initiated in FY14, collaboration with the U.S. Integrated Ocean Observing System (IOOS) Glider Data Assembly Center (DAC) will shortly result in the inclusion in WOD of U.S. gliders in U.S. coastal and shelf waters as well as in the open ocean. Permission has also been granted by the European Global Ocean Observing System (EuroGOOS) glider DAC to upload their data into WOD. At the moment, WOD is unique in bringing all these sources of glider data together in one dataset. Gliders will be a significant source of data in the coming year and making these data available in the WOD will represent an additional return on NOAAs investment in this instrumentation.

![World Ocean Database time series of gigabytes of ocean stations downloaded by month (September 2013 through September 2014)](chart)

**Figure 2 Oceanographic Casts downloaded from WODselect in FY13**

It is difficult to present statistics on the utility of WOD for research, as it can be downloaded from NODC in a number of forms (sorted by year, sorted by geographic area – 10 degree squares) as well as subset through the WODselect tool. Further, other international databases such as ENACT use WOD as their main data source, and so WOD data are disseminated (with different quality control flags and formats) through many secondary sources. To give some idea of the utility of WOD, **Figure 2** shows the number of casts downloaded through WODselect subsetting tool by month for FY14 (plus September 2013). For perspective, there are approximately 13.5 million casts (collocated profiles of oceanographic variables) in the entire WOD. 1GB casts is about 76 times the entire WOD. Some users do download the entire WOD through WODselect, while others subset just a few hundred or a few thousand casts. There were more than 2,000 new unique users who downloaded from WODselect in FY14 in addition to
downloads from the nearly 10,000 previous users of WODselect. Many more used WODselect as a tool to inventory oceanographic data without downloading their subsets. As stated above, WODselect is just one of a number of ways to access WOD data through NODC and other sources.

- The Global Ocean Heat and Salt Content Dataset was updated four times in FY14, in the same months as the WOD (see above). Data and figures are available at http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/. The four quarterly updates consist of seasonal temperature anomalies at 26 discrete levels from the surface to 2000 m depth, salinity anomalies at the same discrete levels, seasonal integrals of heat content for the upper 700 m and 2000m, seasonal averages of thermosteric (Figure 3), halosteric, and total steric sea level change for the upper 700m and upper 2000m, and seasonal averages of temperature and salinity anomaly for the upper 100m, upper 700m and upper 2000m. All fields are on one-degree latitude/longitude grids and include error statistics. In addition, global integrals of ocean heat content (in Joules) and global averages of thermosteric, halosteric, and total steric sea level change (in millimeters), and global average temperature and salinity change were calculated and made available. In FY14, yearly (2013) and pentadal (2009-2013) fields were also calculated for all above noted variables. Calculating these fields involved significant quality control of the underlying data, quality control information which was fed back into the WOD.

![Figure 3 Thermosteric component of sea level change from in situ profile data from http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/](http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/)

**Figure 3** Thermosteric component of sea level change from in situ profile data from http://www.nodc.noaa.gov/OC5/3M_HEATCONTENT/.
• Tim Boyer was a contributing author to the 5th IPCC (International Panel on Climate Change) Assessment. Tim Boyer and Syd Levitus were reviewers for the 5th IPCC Assessment. The 5th Assessment Ocean Scientific Basis Chapter was released December, 2013.

• The World Ocean Database 2013 (WOD13) and a portion of the World Ocean Atlas 2013 (WOA13 one-degree temperature and salinity climatologies for 6 decades and a decadal average) were released in FY13. The release of the WOD13 represents all the data assembled during this project through January 2012 with the extra quality control which goes into the World Ocean Atlas 2013. While all subsequent quality control and data additions are available through the main WOD site, WOD13 is valuable to present the exact data quality control needed to reconstruct the World Ocean Atlas 2013. WOA13 quarter-degree fields for 6 decades and a decadal average were released in FY14. This represents a significant improvement over previous World Ocean Atlas versions with increased resolution in the horizontal and in the vertical. The release of WOA13 and its benefits to the oceanographic community were reported recently in Eos (Boyer et al., 2014).

• More emphasis was placed this year on developing an understanding and utilization of calculated salinity content (and freshwater content) anomaly fields. In partnership with NOAAs National Center for Environmental Prediction (NCEP), routines were developed for blending the sea surface salinity anomaly fields calculated under the WOD project and Aquarius and SMOS satellite fields of sea surface salinity (Xie et al., 2014). Fields of monthly sea surface salinity are now generated routinely using WOD algorithms and GTSPP near-real time data and sent to NCEP by the 4th of each month for blending. The blended fields are then used for medium to long-term climate prediction. Comparisons between Aquarius and WOD sea surface salinity were also performed to examine the utility of both the Aquarius and WOD fields (Reagan et al, 2014, Figure 4) for monitoring salinity changes.
3. Outreach and Education

- The Global Ocean Heat Content is now one of the climate variables available through NOAAs climate.gov website dashboard. This brings our work from this project to the main public access point of NOAA for climate change information.

- Tim Boyer helped organize the IQUD (International Quality Controlled Data Set) meeting in Silver Spring, MD, June, 2014 and the 4th XBT Science meeting set for November, 2014 in Beijing, China. These activities provided a forum for exploring quality control best practices for oceanographic data and for correcting a bias in XBT.
(expendable bathythermograph) data which is critical for more accurately estimating ocean heat content changes.

- Tim Boyer participated in compilation of a FAQ for the climate.gov site on global climate change as an expert on ocean heat and salt content on the climate.gov scientific advisory panel. This FAQ will offer answers to many questions from the general public on climate change. While the FAQ was initiated in FY13, its refinement and release occurred in FY14.

- Meeting attendance provided outreach for our work on this project. Tim Boyer presented the following:
  - a poster on WOD13/WOA13 at the Ocean Science meeting, February 2014 in Honolulu, HI
  - 3 oral presentations on WOD at the IQUOD meeting, June, 2014 in Silver Spring, MD.
  - an oral presentation on WOD at the CLIMAR IV meeting, June, 2014 in Asheville, NC.
  - a seminar on the WOD/heat content/global warming hiatus at the University of Delaware, September, 2014.

Jim Reagan presented the following:
  - an oral presentation on WOD sea surface salinity anomalies at the Aquarius SAC-D meeting, Buenos Aires, Argentina, November, 2013
  - an oral presentation on WOD sea surface salinity anomalies at the Ocean Science meeting, February, 2014 in Honolulu, HI.

- WOD is part of the effort to put together a CTD reference database for Argo quality control.

- WOD help desk (OCLhelp@noaa.gov, OCL= Ocean Climate Lab) answered numerous questions from users from the elementary school through graduate school level and from the general public regarding oceanographic profile data, ocean heat and salt content, and climate change in general. The help desk also generated custom figures and special format data sets for users.

4. Publications and Reports

4.1. Publications including Principal Investigators

- Published


- Accepted.


4.2. Other Relevant Publications

The publications resulting from the work involved in this project have been cited numerous times, demonstrating the utility of the work for scientific research.
Figure 5: Citations in peer-reviewed journals since 2000 for publications of Syd Levitus and or Tim Boyer


As of November 20, there are more than 200 citations for Levitus and or Boyer in calendar year 2014 (Figure 5) in addition to more than 300 citations of the WOD and resultant World Ocean Atlas in calendar year 2014 (Figure 6).