THE WORLD OCEAN DATABASE

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ABSTRACT

The World Ocean Database (WOD) is the most comprehensive global ocean profile-plankton database available internationally without restriction. All data are in one well-documented format and are available both on DVDs for a minimal charge and on-line without charge. The latest DVD version of the WOD is the World Ocean Database 2009 (WOD09). All data in the WOD are associated with as much metadata as possible, and every ocean data value has a quality control flag associated with it. The WOD is a product of the U.S. National Oceanographic Data Center and its co-located World Data Center for Oceanography. However, the WOD exists because of the international oceanographic data exchange that has occurred under the auspices of the Intergovernmental Oceanographic Commission (IOC) and the International Council of Science (ICSU) World Data Center (WDC) system. World Data Centers are part of the ICSU World Data System.

Keywords: World Ocean Database, Ocean profile data, Intergovernmental Oceanographic Commission (IOC), International Council of Science (ICSU), National Oceanographic Data Center, World Data Center

1 INTRODUCTION

The World Ocean Database (WOD) is the largest collection of ocean profile and plankton data available internationally without restriction and with all data made available in a common format. The WOD is available both on DVD and online (http://www.nodc.noaa.gov/). The WOD is a product of the U.S. National Oceanographic Data Center (NODC) and its co-located World Data Center for Oceanography (WDC). The WOD is a product built by merging thousands of originators data sets from many different countries and organizations. These data sets, which are sent to NODC/WDC in many different formats, are put into a common database and quality control is performed on the data (Boyer & Levitus, 1994; Conkright et al., 1994). Each data value has quality control (QC) flags associated with it. The data are made available in formats including ASCII and netCDF.

The WOD exists because of the international oceanographic data exchange that has occurred under the auspices of the IODE (International Oceanographic Data and Information Exchange committee) of the Intergovernmental Oceanographic Commission (IOC) and the International Council of Science (ICSU) World Data Center (WDC) system. We emphasize that it is the originators' data sets that represent the archive of oceanographic data maintained by the U.S. National Oceanographic Data Center (NODC). All originators data and accompanying metadata are archived electronically (saved to disk).

It is important to note that the WOD is a product derived from the originators' data stored in the Ocean Archive System (OAS) at NODC. NODC archives the complete originators' data and metadata, exactly as submitted, in the OAS. The original data can be retrieved at any time. The WOD does not completely represent all data in the OAS. The WOD contains profile data for 23 oceanographic variables, but the OAS archives many kinds of ocean data that the WOD does not currently store (measurements of metal concentrations, amino acids, etc). In the future, additional variables may be added to the WOD and processed from data in the OAS. Another reason for archiving originators' data exactly as they are sent to NODC/WDC is that if a mistake in processing data into WOD is identified, we can access originators' data from the OAS and reprocess these data. WOD is serving a need for a standardized, quality-controlled scientific ocean data product. However, it is still critical to archive originators' data as it was sent to NODC/WDC.

In order for the international scientific community to develop climate system forecast capability for seasons, to determine the role of the world ocean as part of the earth's climate system, and to improve climate assessments for decadal and longer time-scales, the most complete databases of historical oceanographic data such as the

WOD are required. These databases, and scientific products based on these databases, represent the infrastructure on which much ocean and climate research and assessments are now based. Specifically:

a) Objective analyses of data in the WOD provide gridded climatologies that are used as initial and boundary conditions for ocean climate simulations and to verify simulations of the climate system;
b) The data are used to prepare diagnostic studies, particularly for estimating interannual-to-decadal ocean variability of ocean heat content (Levitus et al., 2000);
c) In recent years the data have been used as the input for ocean data assimilation efforts (Carton & Giese, 2008);
d) The international scientific community advises national and international bodies on such issues as climate change, e. g., the Intergovernmental Program on Climate Change (IPCC). Hence, the international oceanographic and climate communities should have access to the most complete electronic oceanographic databases possible. Regardless of one's views about the origins of observed changes of the Earth's climate system (anthropogenic, internal, or natural), the scientific community needs the best scientific databases possible to perform scientific research on this topic;
e) Substantial resources have been, and continue to be, allocated for national and international ocean and climate programs such as Tropical Ocean and Global Atmosphere (TOGA), World Ocean Circulation Experiment (WOCE), Global Ocean Ecosystems Dynamics (GLOBEC), Joint Global Ocean Flux Study (JGOFS), Climate and Global Change, Climate Variability and Prediction (CLIVAR), and for the establishment of a Global Ocean Observing System (GOOS). Planners of such programs should have access to all historical oceanographic data in order to optimize measurement strategies for these programs. Scientists analyzing data from such programs need historical data in order to study interannual-to-decadal variability. Operational forecast centers need historical data in order to perform quality control of synoptic data;
f) The data are a crucial tool to understand fisheries variability and to manage fisheries and other marine resources;
g) More specifically, the data in the WOD have been used in a variety of products including the production of global climatologies of temperature, salinity, oxygen, and nutrients at ocean depths from the sea surface down to 5,500 m depth (Locarnini et al., 2010; Antonov et al., 2010; Garcia et al., 2010a,b). Regional atlases have also been prepared (Matishov et al., 2004), and studies of the frequency distribution of ocean variables computed (Levitus & Sychev, 2002). These climatologies are used in a variety of ways including initialization of ocean models and ocean data assimilation studies among others;
h) The data in WOD have also been incorporated into other atlases including the International Comprehensive Ocean-Atmosphere-Data-Set (Woodruff et al., 2011).

2 WHAT IS INCLUDED IN THE WOD

The following table (Table 1) is a list of the oceanographic variables included in the WOD:

Table 1. List of the oceanographic variables included in the WOD

1. temperature;
2. salinity;
3. oxygen;
4. phosphate;
5. nitrate;
6. nitrate + nitrite;
7. silicate;
8. chlorophyll;
9. pH;
10. alkalinity;
11. CO_2 mole concentration;
12. DIC (Dissolved inorganic carbon);
13. Plankton (Biomass, abundance etc.);
14. chlorofluorcarbon-11;
15. chlorofluorcarbon-12;
16. chlorofluorcarbon-113;
17. Tritium [^3H] (isotope);
18. ΔHe^3 (isotope);

19. ΔC^{13} (isotope);
20. ΔC^{14} (isotope);
21. ΔO^{18} (isotope);
22. Argon (noble gas);
23. Neon (noble gas);
24. Helium (noble gas);
25. Beam Attenuation Coefficient (transmissivity);
26. Meteorological data observed (measured approximately at the sea surface) during the oceanographic measurements may include barometric surface air pressure, wind speed and direction, wave height and direction, and dry and wet bulb temperatures.

The following table is a list of the instrument types used to collect the data included in the WOD:

Table 2. List of the instrument types used to collect the data included in the WOD

1) Ocean Station Data (OSD) (bottles, reversing thermometers);
2) Conductivity-Temperature-Depth (CTD);
3) Expendable Bathythermograph (XBT);
4) Mechanical Bathythermograph (MBT);
5) Towed (CTD);
6) Profiling Floats (PFL);
7) Drifting buoy (DRB) (thermistor chains);
8) Moored buoy (MRB) (e.g., TAO, PIRATA, TRITON);
9) Autonomous Pinniped (APB) (instrumented elephant seals) (Boehlert et al., 2001);
10) Gliders (GLD);
11) Surface only data (SUR).

3 THE WOD IS A COMPLEX, HETEROGENOUS, AND LABOR-INTENSIVE DATABASE TO DEVELOP

Consider the last release of the WOD, which is known as the World Ocean Database 2009 (WOD09) (Boyer et al., 2009; Johnson et al., 2009). The WOD09 is a global, comprehensive, integrated, scientifically quality-controlled database with all data in one well-documented format. We characterize WOD09 as a "heterogeneous" database. As an example, the Ocean Station Data (OSD) component of WOD09 contains data from 65,840 cruises, 3,465 ships and other platforms (buoys, profiling float, etc), 564 institutes, 70 countries, and 653 Principal Investigators (P.I.s). Populating the database with these metadata and many other metadata (e.g., instrument codes, scientific methods used, etc) is labor intensive. Populating the database with the actual data is labor-intensive because the data come from so many different sources in so many different formats. Also, both the metadata and data we receive frequently have problems associated with them such as misreported units, locations, etc., which we attempt to fix with the assistance of the data originators.

4 TIME SERIES HISTORY OF INSTRUMENTAL DATA WITH TEMPERATURE DATA IN WOD09

The history of the ocean temperature profile data set available in electronic form from NODC/WDC contained in WOD09 is shown in Figure 1.

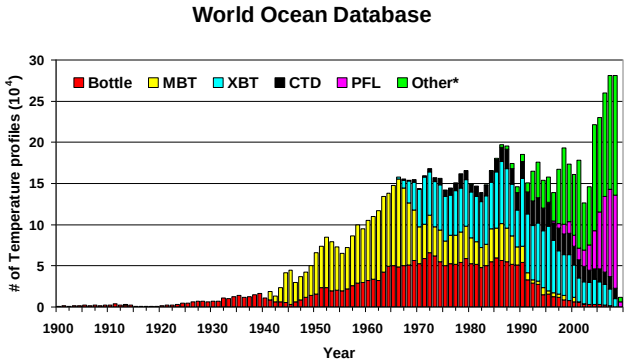
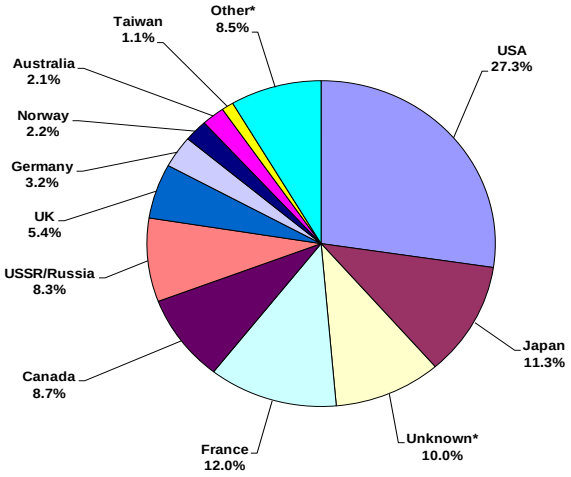


Figure 1. The history of the ocean temperature profile data set available in electronic form from NODC/WDC contained in WOD09. "MBT" is the abbreviation for mechanical bathythermographs, "XBT" represents expendable bathythermographs, "CTD" represents Conductivity-Temperature-Depth, and "PFL" represents profiling floats. The category "Other" includes data from gliders, moored buoys, drifting buoys, undulating ocean recorders (e.g., towed CTDs), and instrumented elephant seals.

5 NATIONAL CONTRIBUTIONS TO WOD09

National contributions to WOD09 are shown in Figure 2. This figure clearly documents that the WOD is a multinational product. The Intergovernmental Oceanographic Commission (IOC) and the International Council of Science (ICSU) have played major roles in facilitating the international exchange of oceanographic data that have been incorporated into the WOD. The percentages shown are based on the total amount of data in five major datasets (OSD, MBT, XBT, CTD, SUR).



*Other – countries contributing < 1%.
*Unknown – country name not provided with originator's metadata.

Figure 2. Percentage of country's contribution in WOD09. The Intergovernmental Oceanographic Commission (IOC) and the International Council of Science (ICSU) have played major roles in facilitating the international exchange of oceanographic data. The percentages shown are based on the total data in five datasets (OSD, MBT, XBT, CTD, SUR).

6 WOD UPDATING SCHEDULE

The WOD is updated online every three months with all of the data that we have processed for that quarter. Corrections are made for data and metadata reported or found to have been in error and reported to data originators. We compute seasonal temperature anomaly fields for 0-700 m depth, and these are placed online (http://www.nodc.noaa.gov/) as well as the 0-700 m ocean heat content field and time series of the global integral of this field. We plan to extend these products to include salinity and extend all of the analyses and computations down to 2,000 m depth. Approximately every four years, the data in the WOD are subjected to additional quality control, and a new database is released on DVD and on-line.

7 DATA AVAILABILITY AND ACCESS

As part of its commitment to the scientists, institutions, and countries that have made their oceanographic data available, the IOC/GODAR (Global Oceanographic Data Archeology and Rescue) and the IOC/WOD (World Ocean Database) projects through NODC/WDC have made all data available on DVD media as well as on-line via the Internet from the NODC/WDC website (http://www.nodc.noaa.gov/). Beginning with *World Ocean Database 1998*, all data have been made available on-line.

The *World Ocean Database* products come with software conversion routines so that users of software packages, databases, and programming languages such as MATLAB, IDL, PC-Surfer, C, and FORTRAN can access the data. In response to user requests, we have defined the WOD format to be as 'self-defining' as possible so as to eliminate, or at least minimize, the need for any structural changes to the format when new data types are added. All code tables, documentation, and software containing metadata are available on-line as well as on the CD-ROMs and DVDs that are used to distribute the WOD series. When a new database is released (every 3-4 years), users can acquire the new database or simply acquire data for those ocean stations that have been added or modified since the previous release. In addition, as corrections are made to the database after a release of WOD, users can acquire any modified data several days after the end of every month. For users there is a "Help Desk" and "Frequently Asked Questions" support for the database available on-line.

Selection software, (WODSelect) (developed by Mr. Tim Boyer, Dr. Hernan Garcia, and Ms. Olga Baranova),

allows users to access data on-line by specifying geographic area, observation dates, instrument type, measured variables, deepest measurement, country, ship/platform, project name, and institute. Data are made available in a Comma-Separated-Values format. WODSelect supports the goals of the IOC, ICSU WDC, and United States data exchange systems to promote open access to scientific data. Additionally, it supports the United Nations Framework Convention on Climate Change to "promote and cooperate in the full, open, and prompt exchange of relevant scientific, technological, technical, socio-economic, and legal information related to the climate system and climate change".

8 WOD DATA DOWNLOADED

All the data in WOD are available online at http://www.nodc.noaa.gov/. Figure 3 shows the time series of the number of ocean stations downloaded by month since April 2003. Since the implementation of WOD*select* in April 2003, WOD*select* has responded to 171 thousand database queries and served over 28 billion stations (1493 GB) via the NODC FTP server. As of April 23, 2011, statistics show that over 114 million (59 GB) stations were downloaded. It is impractical to be limited to downloading one profile at a time. For example, the WOD09 contains approximately 9 million temperature profiles and 3.5 million salinity profiles as well as profiles of other variables. Therefore a user must be able to easily download multiple profiles.

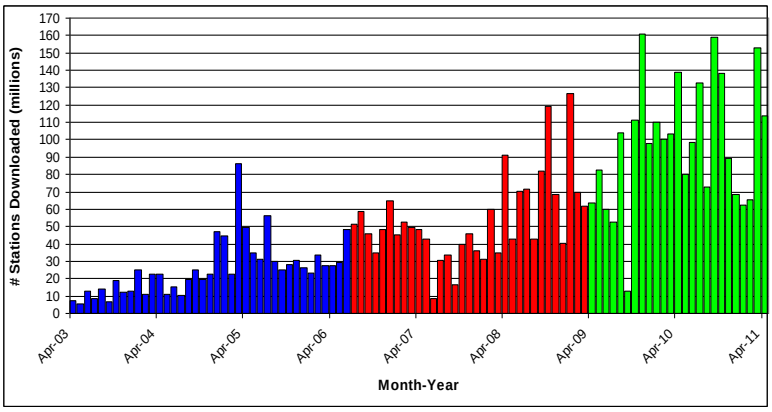


Figure 3. Time series of the number of ocean stations downloaded via the Internet by month from the World Ocean Database. Since the implementation of WODselect in April 2003, WODselect has responded to 171 thousand database queries and served over 28 billion stations (1493 GB) via the NODC FTP server. As of April 23, 2011, statistics show over 114 million (59 GB) stations were downloaded. Scientists do not want to be limited to downloading one profile at a time. WOD09 contains approximately 9 million temperature profiles, 3.5 million salinity profiles as well as profiles for other ocean variables; therefore a user must be able to easily download multiple profiles.

9 FUTURE WORK

The WOD project continues incorporating as much historical as well as modern oceanographic data as possible. The outlook for continued international cooperation is excellent. The WOD and products and papers based on it are frequently cited in the scientific literature. We plan to continue our work with the cooperation of the international scientific and data management communities to improve the WOD and products based on it.

10 ACKNOWLEDGMENTS

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Data Center system).

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