Title: **World Ocean Database 2001 (WOD01)**

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Abstract:

In 1982, the *Climatological Atlas of the World Ocean* was published. This was the first global atlas depicting global objectively analyzed fields of temperature, salinity, and oxygen based on all data available from the NOAA National Oceanographic Data Center (NODC)/World Data Center for Oceanography, Silver Spring (WDC) in electronic as well as paper form. Today, the *World Ocean Database 2001* (WOD01) greatly expands on the 1982 product by including data from new instrument types (such as profiling floats), new variables (such as nutrients, chlorophyll, pCO2, TCO2, plankton), and many more historical as well as modern data.

The goal in developing and distributing WOD01 is to make available in electronic form – without restriction – the most complete set of historical ocean profile-plankton measurements possible along with appropriate metadata and quality control flags. Whether studying the role of the ocean as part of the earth's climate system, conducting fisheries research, or managing marine resources, scientists and managers depend on observations of the marine environment in order to fulfill their mission. The WOD01 is a product based on data submitted to the NODC and the WDC for Oceanography by individual scientists and scientific teams as well as institutional, national, and regional data centers.

Article Text:

INTRODUCTION

In 1982, the *Climatological Atlas of the World Ocean* was published. This was the first global atlas depicting objectively analyzed fields of temperature, salinity, and oxygen based on all data available from the NOAA National Oceanographic Data Center (NODC)/World Data Center for Oceanography, Silver Spring (WDC) in electronic as well as paper form. This was followed in 1994 and 1998 with the publications of the *World Ocean Atlas 1994* (WOA94), the *World Ocean Database 1998* (WOD98), and the *World Ocean Atlas 1998* (WOA98). Today, the *World Ocean Database 2001* (WOD01) and associated *World Ocean Atlas 2001* (WOA01) greatly expands on the 1998 product by including data from new instrument types (such as profiling floats), new variables (such as pCO2 and TCO2), and many more historical as well as modern data for the variables in WOD98.

During the past nine years, the number of temperature profiles electronically archived at NODC/WDC has increased, from approximately 2.5 million to 7 million as a result of projects such as the Intergovernmental Oceanographic Commission (IOC) / NODC *Global Oceanographic Data Archaeology and Rescue project (GODAR),* IOC *World Ocean Database project, Global Temperature-Salinity Profile Project (GTSPP), World Ocean Circulation Experiment (WOCE), Joint Global Ocean Flux Studies (JGOFS), Ocean Margin Experiment (OMEX),* and many others.

Goals for *World Ocean Database 2001* (WOD01)

The goal in developing and distributing WOD01 is to make available in electronic form – without restriction – the most complete set of historical ocean profile-plankton measurements possible along with appropriate metadata and quality control flags. Whether studying the role of the ocean as part of the earth's climate system, conducting fisheries research, or managing marine resources, scientists and managers depend on observations of the marine environment in order to fulfill their mission. It is important to note that WOD01 is a product based on data submitted to NODC/WDC by individual scientists and scientific teams as well as institutional, national, and regional data centers.

Data and instrument (probe) types in WOD01

WOD01 consists of profile data from several oceanographic instrument (probe) types. We present a brief description of some of the major instrument types and/or systems that are (or were) used to make measurements which are included in WOD01:

i) Ocean Station data (OSD)

Ocean Station Data (OSD) has historically referred to measurements made from a stationary research ship using reversing thermometers to measure temperature and making measurements of other variables such as salinity, oxygen, nutrients, chlorophyll, *etc.* on seawater samples gathered using special bottles. WOD01 includes measurements

of temperature, salinity, oxygen, nitrate, phosphate, silicate, pH, alkalinity, chlorophyll, pCo_2, tCO_2 , and plankton.

ii) Conductivity-Temperature-Depth data (CTD)

Conductivity-Temperature-Depth (CTD) instruments measure temperature and conductivity as a function of pressure (depth) at relatively high (often referred to as "continuous") vertical resolution. Salinity is computed from the conductivity measurement. We refer to CTD "stations" or "casts" to recognize that more than one variable is being measured when a CTD instrument is deployed.

iii) Mechanical Bathythermograph data (MBT)

Mechanical Bathythermograph (MBT) instruments were developed in their modern form around 1938 (Spilhaus, 1938). The instrument provides estimates of temperature as a function of depth in the upper ocean.

iv) Expendable Bathythermograph data (XBT)

The Expendable Bathythermograph (XBT) was deployed beginning in 1966 and has replaced the MBT in most measurement programs. The XBT is an electronic instrument with a thermistor used to measure temperature versus depth.

v) Moored Buoy data (MRB)

Temperature and salinity measurements are collected from moored buoy arrays comprised mostly of TAO (Tropical Atmosphere-Ocean), PIRATA (moored array in the tropical Atlantic), MARNET, and TRITON (Japan-JAMSTEC). The source of these data is mostly from GTSPP.

vi) Profiling Float data (PFL)

Temperature and salinity data are collected from drifting floats such as Profiling Autonomous Lagrangian Circulation Explorer (P-ALACE) subsurface drifting floats; PROVOR (free-drifting hydrographic profiler), SOLO (Sounding Oceanographic Lagrangian Observer), and APEX (Autonomous Profiling Explorer). The source of this data is the GTSPP project.

vii) Drifting Buoy data

Temperature data are collected from surface drifting buoys with thermister chains. The source of this data is the GTSPP project.

viii) Surface only data (SUR)

Surface only data from underway or ship of opportunity have been collected. Each cruise is considered a station, therefore each measurement will have an associated latitude, longitude, and julian year-day within the station. Variables in the Surface Only Data Files (SUR) include: temperature (*in situ)*, salinity, pH, chlorophyll, alkalinity, pCO_2, CO_2warming, xCO_2atmosphere, air pressure.

ix) Undulating Ocean Recorder data (UOR)

Data from TOGA, JGOFS, PRIME and OMEX projects are collected from a Conductivity/Temperature/Depth probe mounted on a towed undulating vehicle. Variables include: temperature, salinity, oxygen, chlorophyll, pressure.

x) Autonomous Pinniped Bathythermograph (APB)

Temperature data are collected from time-Temperature Depth recorders attached to elephant seals. The source of this data is the Pacific Fisheries data off of California and Washington (Boehlert *et al.*, 2001).

Economic justification for maintaining archives of historical oceanographic data: the value of stewardship

Oceanography is an observational science and it is not possible to replace historical data that have been lost. From this point of view, historical measurements of the ocean are priceless. However, in order to provide input to a "cost-benefit" analysis of the activities of oceanographic data centers and specialized data rescue projects, we can estimate the costs incurred if we wanted to resurvey the world ocean today, in the same manner as represented by the WOD01 Ocean Station Data (OSD) profile archive.

The computation we describe was first performed in 1982 by Mr. Rene Cuzon du Rest, of NODC. We use an average operating cost of $20,000. per day for a medium-sized U.S. research ship with a capability to make two "deep" casts per day or 10 "shallow" casts per day. We define a "deep" cast as extending to a depth of more than 1000 m and a "shallow" cast as extending to less than 1000 m. This is an arbitrary definition but we are only trying to provide a coarse estimate of replacement costs for this database. Using this definition, WOD01 contains approximately 1.8 million shallow casts so that the cost of the ship time to perform these measurements is approximately $3.6 billion. In addition WOD01 contains 323,000 profiles deeper than 1000 m depth, so the cost in ship time to make these "deep" measurements is approximately $3.2 billion. Thus, the total replacement cost of the OSD archive is about $6.8 billion, a figure based only on ship-time operating costs, not salaries for scientists or any other costs.

Distribution

WOD01 is being distributed on-line (www.noaa.nodc.gov) and on CD-ROMs with all data compressed in DOS format. Based on requests by users of our earlier products, the OCL developed a new ASCII format to make the most efficient use of space on storage

media used to transfer data to users. We have included 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.

With the distribution of WOD01 there are now approximately 7.1 million temperature profiles and 1.5 million salinity profiles (as well as other profile data and plankton data) available to the international research community in a common format with associated metadata and quality control flags. There has been a net increase of about 1.7 million temperature profiles since publication of *World Ocean Database 1998.*

DATA SOURCES

The oceanographic data that comprise WOD01 have been acquired through many sources and projects as well as from individual scientists. Some of the international data exchange organizations include:

The International Council for the Exploration of the Sea (ICES) was established in 1902 and began collecting and distributing oceanographic data. The pioneering and excellent work in international oceanographic data management and exchange of ICES continues.

The International Oceanographic Data Exchange (IODE) activities of the Intergovernmental Oceanographic Commission (IOC) have been responsible for the development of a network of National Oceanographic Data Centers in many countries. This network greatly facilitates international ocean data exchange.

Contributions of data from scientists, oceanographic institutions, and countries have been sent to World Data Center for Oceanography, Silver Spring since its inception. WDC-B for Oceanography is located in Obninsk, Russia and WDC-D for Oceanography is located in Tianjin, China.

Data Archaeology and Rescue

NODC and several other oceanographic data centers initiated “data archaeology and rescue” projects around 1991. Based on the success of these projects, the Intergovernmental Oceanographic Commission of UNESCO initiated a project in 1993 known as the “Global Oceanographic Data Archaeology and Rescue”(GODAR) project with the goal of “locating and rescuing” oceanographic data that are stored in manuscript and/or digital form, that are at risk of being lost due to media decay. The international scientific and data management communities have strongly supported this project.

During 1995, World Data Center for Oceanography, Silver Spring initiated a project entitled “*Global Ocean Database*” with support from the NOAA/ESDIM program. This project was instituted because it was recognized that there are substantial oceanographic data in digital form at oceanographic institutes around the world, that while not at risk of being lost due to media degradation or neglect, have not been submitted to the WDC

system. WDC for Oceanography has begun requesting institutions to transfer their entire ocean profile and plankton archives to WDC for Oceanography.

In 2001 the IOC initiated a "*World Ocean Database Project*". The goals of this project are to encourage more rapid exchange of modern oceanographic data and to encourage the development of regional oceanographic databases, regional quality control procedures for oceanographic data and regional atlases.

As a result of the end of the Cold War, the navies of several countries have declassified substantial amounts of oceanographic data that were formerly classified, in some cases at the request of the Intergovernmental Oceanographic Commission. The U.S. Navy has contributed approximately 435,000 MBT profiles and the U.S. Coast Guard approximately 217,000 MBT profiles to the NODC/WDC databases. Also, the Australian Navy reports profile data in real-time including data from their Exclusive Economic Zone (EEZ).

Since the pioneering work of Mathew Maury beginning in 1854, there have been programs in existence to gather meteorological and oceanographic data from merchant ships. These ships are sometimes referred to as Voluntary Observing Ships (VOS) and the programs called Ship-of-Opportunity Programs (SOOP). During the 1970's, the U.S. and France (Scripps Institute of Oceanography and ORSTOM, New Caledonia) began a SOOP program that focused on the deployment of XBT instruments from VOS platforms in the Pacific Ocean (White, 1995). This program expanded to include the Atlantic and Pacific Oceans and is now supported by NOAA Ship-of-Opportunity Program. Several countries are conducting SOOPs or have conducted them. These programs are coordinated internationally by the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC).

QUALITY CONTROL FLAGS

Each individual data value and each profile in WOD01 has quality control flags associated with it. Users can choose to accept or ignore these flags. It is clear that there are both Type I and Type II statistical errors (for normal distributions) associated with these flags. There are some data that have been flagged as being "acceptable" based on our tests which in fact may not be the case, but they are not necessarily in error. In addition, the sparsity of data, non-normal frequency distributions, and presence of different water masses in close proximity results in incorrect assignment of flags.

Future Goals

Substantial amounts of historical ocean data continue to be transferred to NODC/WDC for inclusion into databases. The outlook for continuing to be able to increase the amount of such data available to the scientific community is excellent. Based on the positive results of the *IOC/GODAR* project and the *World Ocean Database Project*, we have requested the continued cooperation of the international scientific and data management communities in building the historical ocean data archives. There is a particular need for

high resolution CTD data so that we can resolve smaller scale features in the vertical and thus provide objective analyses of variables at greater vertical resolution than present. There is a need for additional historical chlorophyll and plankton data so we can improve understanding of ocean biogeochemical cycles.

Improving the quality of historical data and their associated metadata is an important task. Corrections to possible errors in data and metadata is best done with the expertise of the principal investigators who made the original observations, the data center or group that prepared the data, or be based on historical documents such as cruise and data reports (however, one has to also consider that these documents may contain errors). The continuing response of the international oceanographic community to the GODAR project and the Global Ocean Database Project has resulted in global ocean databases that can be used internationally without restriction for the study of many environmental problems.

As the amount of historical oceanographic data continues to increase as a result of international cooperation, the scientific community will be able to make more and more realistic estimates of variability and be able to place confidence intervals on the magnitude of temporal variability of the more frequently sampled variables such as temperature.