NOAA Atlas NESDIS 60

WORLD OCEAN DATABASE 2005

Silver Spring, MD
July 2006

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

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For updates on the data, documentation and additional information about WOD05 please refer to:

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PREFACE

The oceanographic databases described by this atlas series expands on the *World Ocean Database 2001* (WOD01) product and its predecessors. We have expanded WOD05 to include data from a new instrument type (gliders) and new variables (tracers). Previous NODC/WDC oceanographic databases and products derived from these databases have proven to be of great utility to the international oceanographic, climate research, and operational environmental forecasting communities. In particular, the objectively analyzed fields of temperature and salinity derived from these databases have been used in a variety of ways. These include use as boundary and/or initial conditions in numerical ocean circulation models, verification of numerical simulations of the ocean, as a form of "sea truth" for satellite measurements such as altimetric observations of sea surface height, and for planning oceanographic expeditions. Increasingly, nutrient fields are being used to initialize and/or verify biogeochemical models of the world ocean. In addition, NODC/WDC products are critical for support of international assessment programs such as the Intergovernmental Program on Climate Change (IPCC) of the United Nations.

It is well known that the amount of carbon dioxide in the earth's atmosphere will most likely double during the next century compared to the CO_2 level that occurred at the beginning of the Industrial Revolution. It is necessary that the scientific community has access to the most complete historical oceanographic databases possible in order to study climate change, as well as for other scientific and environmental problems including ecosystem response to climate change.

In the acknowledgment section of this publication we have expressed our view that creation of global ocean databases is only possible through the cooperation of scientists, data managers, and scientific administrators throughout the international community. In addition, I thank my colleagues at the Ocean Climate Laboratory (OCL) of NODC for their dedication to the project leading to publication of this atlas series. Their commitment has made this database possible. It is my belief that the development and management of national and international oceanographic data archives is best performed by scientists who are actively working with the data.

The production of oceanographic databases is a major undertaking. Such work is due to the input of many individuals and organizations. We have tried to structure the data sets in such a way as to encourage feedback from experts who have knowledge that can improve the data and metadata contents of the database. It is only with such feedback that high-quality global ocean databases can be prepared. Just as with scientific theories and numerical models of the ocean and atmosphere, the development of global ocean databases is not carried out in one giant step, but proceeds in an incremental fashion. The distribution of the *World Ocean Database* series occurs both on-line (www.nodc.noaa.gov) and DVD. Changes made to WOD05 including corrections to data and metadata will be made available on-line as we have done previously.

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June, 2006

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This work was made possible by a grant from the NOAA Climate and Global Change Program which enabled the establishment of a research group, the OCL, at the National Oceanographic Data Center. The purpose of the OCL is to prepare research quality oceanographic databases, as well as to compute objective analyses of, and diagnostic studies based on, these databases.

The international exchange of oceanographic data occurs on a bilateral basis between countries, intergovernmentally through the Intergovernmental Oceanographic Commission (IOC), and also under the aegis of the International Council of Science (ICSU, on a nongovernmental basis) which operates the World Data Center System. The data made available as part of this atlas include data acquired as a result of the IODE/IOC "Global Oceanographic Data Archaeology and Rescue" (GODAR) project. At NODC/WDC, "data archaeology and rescue" projects have been supported with funding from the NOAA Environmental Science Data and Information Management (ESDIM) Program and NOAA Climate and Global Change Program. Support for some of the regional IOC/GODAR meetings was provided by the MAST program of the European Union (EU). Also, the EU MAST program supported the MEDAR/MEDATLAS project which collected, processed, and distributed data for the Mediterranean Sea which are included in WOD05.

We acknowledge the scientists, technicians, and programmers who have submitted data to national and regional data centers as well as the managers and staff at the various data centers. Our database allows for the storage of metadata including information about Principal Investigators to recognize their efforts.

We thank Alexandra Grodsky, Galyna Mishonova, Andrey Pankov, Boris Podrabinnik, and Daniel Smolyar of the OCL for their work in data digitization and their assistance in quality control of the data and metadata in WOD05, to Carla Forgy who performed invaluable work in quality control of data in this database, to Robert Gelfeld, Renee Tatusko, and Charlotte Sazama for their assistance in locating data for rescue in the World Data Center for Oceanography, Silver Spring. John Relph provided outstanding help in advising on web security for the online version of this atlas and database. Tony Piccolo reviewed Chapter 14 and provided many helpful comments. We also thank Todd O'Brien and Cathy Stephens for processing some of the data sets included here. The OCL acknowledges the help received over the last several years from colleagues in other NODC divisions. Francis Mitchell helped with all the code lists and accessions, Melanie Hamilton and Mike Simmons supplied GTSPP data.

The OCL expresses thanks to those who provided comments and helped develop an improved *World Ocean Database 2005* (WOD05) product. Any errors in WOD05 are the responsibility of the Ocean Climate Laboratory.

CHAPTER 1: INTRODUCTION

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ABSTRACT

This atlas describes a collection of scientifically quality-controlled ocean profile and plankton data that includes measurements of temperature, salinity, oxygen, phosphate, nitrate, silicate, chlorophyll, alkalinity, pH, pCO_2, TCO_2, Tritium, Δ^{13}Carbon, Δ^{14}Carbon, Δ^{18}Oxygen, Freons, Helium, Δ^{3}Helium, Neon, and plankton. A discussion of data sources is provided.

1.1. INTRODUCTION

1.1.1. History

The *World Ocean Atlas 1994* (WOA94) represented the first database and analysis product of the National Oceanographic Data Center (NODC) Ocean Climate Laboratory (OCL). WOA94 included vertical profiles of six variables including temperature, salinity, oxygen, phosphate, nitrate, and silicate as well as objective analyses of these variables at standard depth levels. *World Ocean Database 1998* (WOD98) updated WOA94 to include additional data for these six variables as well as data for additional variables such as chlorophyll, nitrite, pH, alkalinity and plankton as well as high-resolution CTD (conductivity-temperature-depth) and high-resolution XBT (expendable bathythermograph) profiles. Products derived from this database, such as objective analyses of the variables that comprise WOD98 were made available as a separate atlas and CD-ROM series entitled *World Ocean Atlas 1998* (WOA98). *World Ocean Database 2001* (WOD01) included data from new instrument types such as profiling floats, Undulating Ocean Recorders (*e.g.,* towed CTDs), and Autonomous Pinniped Bathythermographs (instrumented Elephant Seals) as well as additional data for existing instrument types.

This new release is known as *World Ocean Database 2005* (WOD05) and contains data for the following new variables: Tritium, Δ^{13}Carbon, Δ^{14}Carbon, Freons, Helium, Δ^{3}Helium, Neon, and Δ^{18}Oxygen. In addition it contains profiles of temperature and salinity from a new ocean profiling instrument known as a "glider" (Rudnick *et al.,* 2004).

As with our previous work, users can obtain the latest information on WOD05 (*e.g.* Errata sheet, Frequently Asked Questions and Updates) via the NODC Home Page, http://www.nodc.noaa.gov/ (click on *World Ocean Database 2005*). The purpose of this atlas is to describe the WOD05 database and show the historical distributions of profiles made using the various instrument types included in WOD05 as well as some specific variables that comprise WOD05. This provides users with basic information about the data in the historical ocean profile archives of NODC/WDC. In addition we point users to web sites that represent sources for some of the data sets included in WOD05.

In this atlas, "WDC" stands for the World Data Center for Oceanography, Silver Spring which is collocated with NODC. WDC, was formerly known as "WDC-A for Oceanography". More information about the World Data Center System can be found at http://www.ngdc.noaa.gov/wdc/wdcmain.html.

1.1.2. Goals for World Ocean Database 2005 (WOD05)

Our goal in developing and distributing WOD05 is to make available without restriction, the most complete set of historical ocean profile data and plankton measurements possible in electronic form along with ancillary metadata and quality control flags.

As with earlier versions of NODC/WDC databases, the data contained in WOD05 will find use in many different areas of oceanography, meteorology, and climatology. 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. Oceanography is an observational science. Because of the importance of understanding climate variability and climate change it is necessary to study the role of the ocean as part of the earth's climate system (IPCC, 1996; WCRP, 1995).

It is important to note that WOD05 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. A major contribution of NODC/WDC to the field of oceanography has been to provide centralized databases where all data and metadata are in the same format. This has allowed investigators such as Wyrtki (1971) and Levitus (1982) to construct atlases that have proven to be of great utility to the scientific research and the operational forecasting communities.

1.1.3. Data Organization

Data in WOD05 are organized using the following operational definitions:

Profile: A set of measurements for a single variable (temperature, salinity, *etc.*) at discrete depths taken as an instrument drops or rises vertically in the water column. For surface-only data, the profile consists of measurements taken along a horizontal path. For moored buoys and drifting buoys, the instrument does not move vertically in the water column, so a profile is a discrete set of concurrent measurements from the instruments placed at different depths on a wire attached to the buoy.

Cast: A set of one or more profiles taken concurrently or nearly concurrently. Meteorological and other ocean data, *e.g.* Secchi disk data, are also included in a cast if measurements were taken concurrently with the profile(s). Observations and measurements of plankton from net-tows are included if taken concurrently or in close time proximity to profiles. If there are no profiles in close proximity, a net-tow by itself will constitute a cast. Each cast in the WOD05 is assigned a unique cast number. If the cast is subsequently replaced by higher quality data, the unique cast number is inherited by them. If any alteration is made to a cast, this information is noted in comments to the monthly database update, referenced by the unique cast number. For surface-only data in dataset SUR, a cast is defined as a collection of concurrent surface measurements at discrete latitudes and longitudes over an entire cruise (see definition of cruise below). Latitude, longitude and julian year-day values are included with each set of measured oceanographic variables.

Station: Data from one or more casts at one geographic location.

Cruise: A set of stations is grouped together if they fit the "cruise" definition. A cruise is defined as a specific deployment of a single platform for the purposes of a coherent oceanographic investigation. For an oceanographic research vessel, this deployment is usually well-defined with a unique set of scientific investigators collecting data for a specific project or set of projects. In some cases different legs of a deployment with the same equipment and investigators are assigned different cruise numbers, as per the investigators designation. In the case when merchant ships-of-opportunity (SOO) are used for data collection, a cruise is usually defined as the time at sea between major port calls. Profiling floats, moored buoys, and drifting buoys are assigned the same cruise number for the life of the platform. For surface-only data in dataset SUR, a cast and cruise are the same, except for 27 cruises which were split into 2 casts each due to the large number of sets of measurement (> 24,000).

In WOD05, a cruise identifier consists of two parts, the country code and the unique cruise number. The unique cruise number is only unique with respect to the country code. The country code is usually assigned based on the flag of the data collecting ship. If the platform from which data were collected was not a ship, (*e.g.* a profiling float, drifting or moored buoy), the country of the primary investigator or institute which operates or releases the platform is used (See Johnson *et al.*, 2006; Appendix for a list of country codes). For data for which no information on country is present, a country code of 99 is used. For data for which there is no way to identify a specific cruise, a cruise number of zero (0) is used.

The present cruise identifier definition is slightly different from previous releases of the *World Ocean Database* (WOD94, WOD98, WOD01). Previously, bathythermograph (BT) data were assigned unique cruise numbers without regard to country in keeping with prior convention at the U.S. NODC. This made assigning the same cruise number to BT data and other data collected on the same cruise impossible. Now cruise identifiers for BT are assigned in the same manner as for other data types. To facilitate this change, approximately 5,300 Mechanical Bathythermograph (MBT) and 22 Expendable bathythermographs (XBT) cruise numbers were reassigned.

All data grouped as cruise are listed under one unique country code/unique cruise number combination. It is possible to get all bottle, high-resolution Conductivity-Temperature-Depth (CTD), BT, and towed-CTD data for a cruise using one unique cruise identifier. However, there are still cases for which BT data have a different cruise identifier.

It is an ongoing project to match these BT data with the correct bottle and high-resolution CTD data.

Accession Number: A group of stations received and archived at the U.S. NODC. Each collection submitted to NODC is given a unique "accession number". Using this number, a user can get an exact copy of the original data sent to NODC as well as information about the data itself (*i.e.* metadata) from NODC through the Accession Tracking Database (ATDB, available online). Cruises are not always subsets of accession numbers, as data from the same cruise may have multiple accession numbers. Each cast has an associated accession number (with a few exceptions). If data from a cast is replaced by higher quality data, the accession number will reflect the new source of the data while the unique station number will remain unchanged. If a profile for a variable not previously stored with a station becomes available, the profile will be added to the existing station, and a variable-specific accession number will be added to the station to record the source of the new profile.

Dataset: All casts from similar instruments with similar resolution. For instance, all data acquired by bathythermographs (BTs) which are dropped over the side of a ship on a winch and recovered reside in the MBT dataset, all CTD data collected at high vertical depth resolution (relatively small depth increments) are stored in the CTD dataset. For convenience, each dataset is stored in a separate file in WOD05.

1.1.4. Datasets

The WOD05 datasets group together data acquired in a similar manner. So, bottle data and low vertical resolution CTD casts are grouped together since bottle casts often include temperature and salinity measurements from CTDs only at the depths at which bottles were tripped. High resolution CTD data are stored in a separate dataset because of their high volume. The low-resolution version of the data is often available as well, in casts which include bottle data. Cases where high and low-resolution CTD data are available in different datasets are identified in the data themselves.

The WOD05 datasets are briefly described below and in more details in followings chapters. A list of datasets in WOD05 is shown in Table 1.1.

The three-letter notation for each dataset is the abbreviation used for the naming of the output data files. Note that not every particular instrument used for data acquisition has a dedicated separate dataset to hold the data, and that the three-letter dataset notation does not always reflect all diversity of instrumentation used for gathering the data found in the dataset. More detailed data descriptions and relevant oceanographic information can be found in chapters 2-16 of this document, and in the bibliographies and references provided for each chapter. For a description of the instrument codes as well as for other codes embedded in the data format, see Johnson *et al.* (2006).

The WOD05 database includes oceanographic variables measured at "observed" depth levels as well as interpolated to a set of 33 "standard" depth levels. All climatic fields in the atlas are produced based on "standard" depth levels data.

OSD Dataset – Ocean Station Data, low-resolution CTD, low-resolution XCTD, plankton tows

i.) *Ocean Station Data*

Ocean Station Data has historically referred to measurements made from a stationary research ship using reversing thermometers and water samples collected from bottles tripped at depths of interest in the water column. The water samples are analyzed to measure variables, including water salinity, oxygen, nutrients (phosphate, silicate, nitrate plus nitrite), chlorophyll, pCO_2, TCO_2, and tracers (Tritium, Δ^{13}Carbon, Δ^{14}Carbon, Freons, Helium, Δ^{3}Helium, Δ^{18}Oxygen, and Neon) concentrations. The two most commonly used bottle types are the Nansen and Niskin (See Chapter 2.)

ii.) *Low-resolution CTD data*

Conductivity-Temperature-Depth (CTD) instruments are a combination of a pressure sensor (measured pressure is converted to depth), a resistance temperature measurement device (usually a platinum thermometer), and a conductivity sensor used to estimate salinity. CTDs are usually mounted on a metal frame and lowered through the water column suspended from a cable. The frame is often used to hang bottles for collecting water samples. Low-resolution here refers to a limited number of temperature and/or salinity measurements made along the vertical profile. Usually, but not always, these measurements are recorded at the depths at which bottles are tripped to collect water samples. This dataset also include data from the older Salinity-Temperature-Depth (STD) instruments - the precursor to the CTD. About 7.7% of all data in the OSD dataset are listed as containing temperature and/or salinity data measured by CTD/STD. (See Chapter 3.)

iii.) *Low-resolution Expendable CTD* (see description below under CTD, Chapter 5.)

iv.) *Plankton tow* – net tows or bottle casts from which plankton counts and/or biomass observations were taken (see Chapter 14.)

CTD Dataset – High-resolution CTD (CTDs and XCTDs recorded at high depth/pressure frequency)

i.) *High-resolution Conductivity-Temperature-Depth (CTD) data*

High-resolution CTD data consist of temperature and salinity profiles recorded at high frequency with respect to depth or pressure. These records are usually binned (averaged) in 1 to 5m depth interval mean values by the data submitter, although some means are calculated using smaller depth intervals. Often the high-resolution CTD cast has a low-resolution counterpart in the OSD dataset with accompanying measurements from bottle samples. In these cases, both the high-resolution CTD and the OSD data have a marker identifying these data as coming from the same station ('hi-res pair' - second header code # 13 in the WOD native format). High-resolution measurements of dissolved oxygen, chlorophyll (from a fluorometer), and beam attenuation coefficient (BAC) from a transmissometer are also included in this dataset when available. Note that in many cases the dissolved oxygen and chlorophyll data are uncalibrated and not of high quality. Information on whether these variables are calibrated is not usually supplied by the data submitter. (See Chapter 3.)

ii.)   High-resolution Expendable Conductivity-Temperature-Depth (XCTD) data

Expendable Conductivity-Temperature-Depth (XCTD) probes are similar to XBT instruments (described below) - they are a torpedo-shaped device attached to a spool of copper wire. Along with the thermistor found in the XBT, a conductivity sensor is used to estimate salinity. XCTD instruments are produced by Sippican, Inc. (Sippican, U.S.A.) and The Tsurumi Seiki Co., Ltd. (TSK, Japan). The standard XCTD has a manufacturer-specific drop-rate equation error (Johnson, 1995; Mizuno and Watanabe, 1998). Depth corrections for both manufacturers are incorporated in the standard level dataset. Air dropped and submarine discharged XCTDs have no known drop-rate problems. XCTD casts make up less than 1% of the CTD dataset. Data from XCTD instruments are included in the CTD dataset. (See Chapter 5.)

XBT Dataset – low and high-resolution Expendable Bathythermographs

Expendable Bathythermograph (XBT) probes are torpedo-shaped devices attached to a spool of copper wire. The instrument is launched over the side of a moving ship, from an airplane, or from a submarine. Temperature is estimated by measurements of the resistance in a semi-conductor (called a thermistor). For recording the information is sent back to the command unit over the copper wire. Depth is calculated as a function of time since launch using a manufacturer-supplied equation. When the wire has unspooled, the copper wire breaks. There are two manufacturers of XBTs, Sippican in the United States (was the first manufacturer), and TSK in Japan. A third manufacturer, Sparton, is no longer in business. XBTs have been deployed since 1966. Seaver and Kuleshov (1982) and Heinmiller *et al*. (1983) reported a systematic error in the recorded depths for XBT drops. Hanawa *et al*. (1995) published depth corrections for XBT types T-4, T-6, and T-7. Kizu *et al*. (2005) published revised drop-rate equations for T-5 XBTs manufactured by TSK (T5 probes manufactured by Sippican do not have a drop-rate problem). The recommended practice for exchanging and archiving XBT data (UNESCO, 1994) state these data should not be corrected or altered so as to provide a known base for a user to apply necessary depth correction. In 1996, both TSK and Sippican began distributing software which used the amended depth equation as the default. In the present dataset, all data prior to January 1, 1996 are assumed to have depths as calculated with the original manufacturer's depth equation, unless otherwise noted, in keeping with established convention. For data taken on or after January 1, 1996 to the present, no assumption is made about the depth equation used. The data are marked as either using the original manufacturer's depth equation, the amended depth equation, or unknown depth equation, based on information provided by the data submitter. These distinctions are quite important for many areas of oceanographic research. There are more than 78,000 XBT temperature profiles taken since January 1, 1996, for which no drop-rate equation information is available. The present database applies all listed corrections only during the interpolation to standard depth levels. The observed level XBT data are not altered. (See Chapter 4.)

MRB Dataset – Moored buoys

Moored buoys are platforms which are anchored or otherwise stabilized to measure oceanographic and atmospheric data in a small area around a fixed geographic location.

Measurement devices are suspended at subsurface levels from a chain attached to the buoy. Temperature is measured using thermistors. Salinity is measured using conductivity sensors similar to those in standard CTDs. The moored buoy dataset include data from the Tropical Atmosphere-Ocean (TAO) buoy array (in the tropical Pacific), the TRITON buoy array (in the western tropical Pacific and Indian Ocean), the PIRATA buoy array (in the tropical Atlantic), MARNET buoys and light-ships (in the North Sea and the Baltic Sea). The data in WOD05 from the TAO, PIRATA, and most of the TRITON buoys are daily averages acquired from the TAO webpage http://www.pmel.noaa.gov/tao/index.shtml. The remainder of the TRITON buoys, the MARNET buoys and light-ships data were acquired from the Global Temperature and Salinity Profile Project (GTSPP, http://www.nodc.noaa.gov/GTSPP/gtspp-home.html) database. (See Chapter 9.)

PFL Dataset – Profiling floats

Profiling floats are platforms which are drift at a predetermined subsurface pressure level in the water column, rising to the surface at set time intervals. Pressure, temperature, salinity, and sometimes dissolved oxygen measurements taken on the ascent or previous descent are relayed to the satellite. Most profiling floats are now operated as part of the Argo project (http://www.argo.ucsd.edu/). Profiling float data were taken mainly from the Global Ocean Data Assimilation Experiment (GODAE, http://www.usgodae.org/) server, with smaller contributions from WOCE and GTSPP. (See Chapter 6.)

DRB Dataset – Drifting buoys

Drifting buoys are platforms which are advected by ocean currents, either at the surface, or at predetermined (usually shallow) depths. Drifting buoy data included in WOD05 were acquired from GTSPP database and from Arctic Buoy program archive. The GTSPP data are from the subset of oceanic drifting buoys which have multiple subsurface temperature measurement devices (thermistors) suspended from a chain. For more information on the ocean drifting buoys, see http://www.drifters.doe.gov/ or http://www.aoml.noaa.gov/phod/dac/dacdata.html. (Also see Chapter 10.)

MBT Dataset – Mechanical Bathythermographs, Digital Bathythermographs (DBT), and Micro-bathythermographs (μBT).

i.) Mechanical Bathythermographs

Mechanical Bathythermographs (MBT) 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. Earlier versions of the instrument were limited to making measurements in the upper 140 m of the water column. The last U.S. version of this instrument reached a maximum depth of 295 m. MBTs recorded temperature as a function of depth by scratching a line on a smoked glass plate with a stylus. Pressure was determined from a pressure-sensitive tube known as a Bourdon tube. MBTs could be dropped from a ship moving at low speed. The accuracy of an MBT is about 0.3°C. (See Chapter 7.)

ii.) Digital Bathythermographs

A bathythermograph (developed in Japan) digitally records depth-temperature pairs as it is lowered in the water column. These instruments were used mostly by the Japanese in the mid-1970s and the 1980s in the Pacific Ocean, and less extensively by the Canadians in the North Pacific and North Atlantic. (See Chapter 8.)

iii.) Micro-Bathythermograph

Bathythermographs designed to record depth-temperature pairs at high vertical or temporal resolution. (See Chapter 13.)

UOR Dataset – Undulating Oceanographic Recorders (Towed CTDs)

Undulating Oceanographic Recorders are specific types of oceanographic vehicle which are towed behind a vessel while ascending and descending in the water column, recording temperature, salinity, and other variables at high vertical and horizontal resolution. (See Chapter 11.)

GLD Dataset - Gliders

The Glider (GLD) dataset is new in this *World Ocean Database* release. It contains data collected from reusable autonomous underwater vehicles (AUV) designed to glide from the ocean surface to a programmed depth and back while measuring temperature, salinity, depth-averaged current, and other quantities along a sawtoothed trajectory through the water. The source of the GLD data is the Pacific Rim Military Exercises (RIMPAC) project courtesy of Marc Stewart of the University of Washington Applied Physics Laboratory. (See Chapter 15.)

APB Dataset – Autonomous Pinniped Bathythermographs

Bathythermographs attached to sea elephants. Temperature information is recorded during dives taken while feeding and transmitted to satellite upon surfacing. (See Chapter 12.)

SUR Dataset – Surface-only data

Surface-only data are either data taken using some type of bucket, or data from thermosalinographs. These data are not the focus of WOD05. Only selected surface datasets which contained data from specific time periods and ocean areas which were not otherwise well covered by profile data are included in WOD05. Note that a "cast" here refers to an entire cruise of surface-only measurements. (See Chapter 16.)

Table 1.1. Instrument types in the WOD05

DATASET	SOURCE
OSD	Bottle, low-resolution Conductivity-Temperature-Depth (CTD), low-resolution XCTD data, and plankton data
CTD	High-resolution Conductivity-Temperature-Depth (CTD) data and high-resolution XCTD data

MBT	Mechanical Bathythermograph (MBT) data, DBT, micro-BT
XBT	Expendable (XBT) data
SUR	Surface only data (bucket, thermosalinograph)
APB	Autonomous Pinniped Bathythermograph - Time-Temperature-Depth recorders attached to elephant seals
MRB	Moored buoy data from TAO (Tropical Atmosphere-Ocean), PIRATA (moored array in the tropical Atlantic), MARNET, and TRITON (Japan-JAMSTEC)
PFL	Profiling float data
DRB	Drifting buoy data from surface drifting buoys with thermistor chains
UOR	Undulating Oceanographic Recorder data from a Conductivity/Temperature/Depth probe mounted on a towed undulating vehicle
GLD	Glider data

1.1.5. 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 WOD05 Ocean Station Data (OSD) dataset.

The computation we describe was first performed in 1982 by Mr. Rene Cuzon du Rest, of NODC. We use an average operating cost estimate 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, WOD05 contains approximately 1.8 million shallow casts so that the cost of the ship time to perform these measurements is approximately $3.7 billion. In addition, WOD05 contains 0.3 million profiles deeper than 1000 m depth, so the cost in ship time to make these "deep" measurements is approximately $3.1 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, technicians, or any other costs.

1.1.6. Data fusion

It is not uncommon in oceanography that measurements of different variables made from the same sea water samples, are often maintained as separate databases by different principal investigators. In fact, data from the same oceanographic cast may be located at different institutions in different countries. From its inception, NODC recognized the importance of building oceanographic databases in which as much data from each station and each cruise as possible are placed into standard formats, accompanied by appropriate metadata that make the data useful to future generations of scientists. It was the existence of such databases that allowed the *International Indian Ocean Expedition Atlas* (Wyrtki, 1971) and *Climatological Atlas of the World Ocean* (Levitus, 1982) to be produced without the time-consuming, laborious task of gathering data from many different sources. Part of the development of WOD05 has been to expand this data fusion activity by increasing the number of variables that NODC/WDC makes available as part of standardized databases.

1.1.7. Distribution media

WOD05 is being distributed on-line (http://www.nodc.noaa.gov/OC5/indprod.html) and on DVD with all data compressed. 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. To further minimize storage space requirements, the data have been compressed with the GZIP utility. For more information on data format see Johnson *et al.* (2006).

1.1.8. Application software interfaces

We have included software conversion routines so that users of software packages, databases, and programming languages such as MATLAB, IDL, GS-Surfer™, C, and FORTRAN can access the data in WOD05. In response to user requests, we have defined the WOD05 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 or instrument types are added or increases in data precision occur. We do not envision any substantial changes to our present data format.

1.2. COMPARISON OF WOD05 WITH PREVIOUS GLOBAL OCEAN PROFILE DATABASES

Table 1.2 shows the amount of data available from different dataset types that were used in earlier global oceanographic analyses. During the past three years, the archives of historical oceanographic data have grown due to special data management and data observation projects that we discuss in section 3.1 of this atlas, as well as due to normal submission by scientists and operational ocean monitoring programs. With the distribution of WOD05 there are now approximately 7.9 million temperature profiles and 2.7 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 0.9 million temperature profiles since publication of *World Ocean Database 2001*.

Table 1.2. Comparison of the amount of data in WOD05 with previous ocean databases.

Dataset	NODC (1974)[1]	NODC (1991)[2]	WOA94	WOD98	WOD01	WOD05
OSD [3]	425,000	783,912	1,194,407	1,373,440	2,121,042	2,258,437

CTD [4]	na	66,450	89,000	189,555	311,943	443,953
MBT [5]	775,000	980,377	1,922,170	2,077,200	2,376,206	2,421,935
XBT	290,000	704,424	1,281,942	1,537,203	1,743,590	1,930,399
MRB	na	na	na	107,715	297,936	445,371
DRB	na	na	na	na	50,549	108,564
PFL	na	na	na	na	22,637	168,988
UOR	na	na	na	na	37,645	46,699
APB	na	na	na	na	75,665	75,665
GLD	na	na	na	na	na	338
Total Stations	**1,490,000**	**2,535,163**	**4,487,519**	**5,285,113**	**7,037,213**	**7,900,349**
Plankton				83,650	142,900	150,250
SUR [6]	na		na	na	4,743	9,178

[1] Based on statistics from *Climatological Atlas of the World Ocean* (1982).
[2] Based on NODC Temperature Profile CD-ROM.
[3] WOD05 OSD dataset includes data from 121,625 low-resolution CTD casts and 864 low-resolution XCTD casts.
[4] WOD05 CTD dataset includes data from 2,478 high-resolution XCTD casts.
[5] WOD05 MBT dataset includes data from 80,212 DBT profiles and 5,659 Micro-BT profiles.
[6] Surface data are represented differently from profile data in the database – all observations in a single cruise have been combined into one "station" with zero depth, value(s) of variable(s) measured, latitude, longitude, and Julian year-day to identify data and position of individual observations.

1.3. DATA SOURCES

The oceanographic data that comprise WOD05 have been acquired through many sources and projects as well as from individual scientists. Some of the international data exchange organizations are described.

The International Council for the Exploration of the Sea (ICES) was established in 1902 and began collecting and distributing oceanographic data at that time.

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. The IOC was established to support international oceanographic scientific needs including data exchange on an intergovernmental basis (UNESCO, 1979). Additional information about IODE can be found on their Web Page, http://www.iode.org/.

The World Data Center System was set up during the International Geophysical Year under the auspices of the International Council of Scientific Unions (ICSU, 1996; Rishbeth, 1991; Ruttenberg and Rishbeth, 1994). Contributions of data from scientists, oceanographic institutions, and countries have been sent to WDC for Oceanography, Silver Spring since its inception. There are two other World Data centers for Oceanography. WDC for Oceanography, Obninsk (formerly WDC-B for Oceanography) is located in Russia and WDC for

Oceanography, Tianjin is located in China. Additional information about the World Data Center System can be found on the following Web Page, http://www.ngdc.noaa.gov/wdc/ hosted by the National Geophysical Data Center located in Boulder, Colorado.

The MAST (Marine Science and Technology Programme) program of the European community promoted international oceanographic data exchange by emphasizing that MAST funded projects must contribute data to appropriate data centers.

It has become more common for all data from a particular project to be released on CD-ROM as a project data set. We have incorporated data from these CD-ROMs into the WOD05. Examples include: the British Ocean Flux Study (BOFS) and Ocean Margins Experiment (OMEX) datasets produced by the British Oceanographic Data Center and the North Sea Project Database sponsored by the MAST program of the European Community.

1.3.1. IOC Global Oceanographic Data Archaeology and Rescue Project

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. Results from the first phase of this project were described by Levitus *et al.* (1994). With the publication and distribution of WOD05, approximately 3.7 million temperature profiles have been added to the historical archives of oceanographic data since inception of various national data archaeology and rescue projects and the IOC/GODAR project in 1991, and the NODC/WDC "Global Ocean Database Project" in 1996. The status of these projects to date has been described by Levitus *et al.* (1994), Smolyar *et al.* (2004), and Levitus *et al.* (2005).

1.3.2. World Ocean Database 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. After receipt at NODC/WDC, the data in these databases are compared to existing data holdings and duplicates and "near duplicates" are eliminated before data are added to the NODC/WDC archives. A substantial effort is involved, but improvements to the archives greatly serves the user community.

The response to WDC requests for data has been excellent. We emphasize that some of, and in some cases the majority of, the data submitted by these institutions may have already existed in NODC/WDC databases. However, we have frequently found that there are large numbers of casts that were thought to be in these databases that were in fact not present. In addition, there were large number of Ocean Station Data casts for which the NODC/WDC databases had temperature and salinity data but not data for other variables (*e.g.*, chlorophyll, nutrients). These additional data were merged in with the profiles from the existing stations. There were also cases for which the NODC/WDC databases had data only at standard or selected levels. We replaced these data profiles with the corresponding observed level profiles.

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.

1.3.3. IOC Global Temperature-Salinity Profile Program

The Global Temperature-Salinity Profile Program (GTSPP) (Searle, 1992; IOC, 1998) is a project sponsored by the Intergovernmental Oceanographic Commission to develop databases of temperature-salinity profiles reported in "real-time". [The GTSPP files include data from moored buoys (identified in WOD98 as "fixed platforms") such as the NOAA Tropical Atmosphere-Ocean (TAO) array of buoys (Hayes *et al.,* 1991; McPhaden, 1993, 1995) in the Pacific Ocean and from other buoy programs such as TRITON and PIRATA]. We incorporated XBT and TAO buoy profiles from this database into WOD05 for the period inclusive through February 2005.

Users wanting GTSPP data after this date can acquire the data over the Internet via the NODC website www.nodc.noaa.gov or by contacting the NODC User Services group (NODC.Services@noaa.gov).

Users wanting the complete TAO buoy database comprised of data that have had the benefit of additional PMEL processing and quality control, can find instructions for acquiring these data via the Home Page of the Pacific Marine Environmental Laboratory (http://www.pmel.noaa.gov/).

1.3.4. International Research Projects Data

Data from the WOCE DVD version 3.0 (CTD and OSD profiles) are included in WOD05. Some WOCE XBT profiles are also part of WOD05. Data from the Joint Global Ocean Flux Study (JGOFS) and the Global Ocean Ecosystem Dynamics (GLOBEC) are also included.

1.3.5. ICES Contribution

The International Council for Exploration of the Sea (ICES) has collected data from participating countries for many years. ICES data are included in WOD05. The ICES website is www.ices.dk .

1.3.6. Declassified Naval Data Sets

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. It should be recognized that some navies have policies of declassifying substantial amounts of data in real-time or with relatively short time delays. For example, the U.S. Navy has contributed approximately 435,000 mechanical bathythermograph (MBT) profiles and the U.S. Coast Guard approximately 217,000 MBT profiles to the NODC/WDC databases. Recent U.S. Navy data have been acquired from the U.S. Navy MOODS database. Also, the Australian Navy reports profile data in real-time including data from their Exclusive Economic Zone (EEZ).

1.3.7. Integrated Global Ocean Service - Volunteer Observing Ship programs

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. (Scripps Institute of Oceanography) and France (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). A description of the status of many of these programs can be found in the report, IOC (1989). As described in this report, Australia, Canada, Chile, Germany, Japan, United Kingdom, and Russia have conducted such programs in addition to France and the U.S. A summary of the status of the system is given by Joint IOC-WMO Committee for IGOSS (1996).

1.3.8. NOAA Ship-of-Opportunity Program (SOOP)

The NOAA SOOP program acquires surface meteorological data and XBT profiles from instruments placed on Volunteer Observing Ships participating in the program. The automated system for acquiring and transmitting these data is known as SEAS (Shipboard Environmental Acquisition System). Data are transmitted via satellite and eventually stored at NODC/WDC. Approximately 20,000 XBT probes are deployed each year as a result of this effort.

1.3.9. SURTROPAC

The SURTROPAC program is a French Ship-of-Opportunity Program that uses Volunteer Observing Ships (VOS) to make measurements of sea surface temperature, salinity, and chlorophyll (Dandonneau, 1992). These data are in the SUR dataset in WOD05.

1.3.10. Underway CO_2

Surface measurements of pCO_2 and TCO_2 have been included from SOOP programs (Murphy *et al.,* 2001; Zeng *et al.,* 2002) and research cruises (Inoue and Sugimura, 1998; Keeling *et al.,* 1965; Murphy *et al.,* 1995; Takahashi *et al.,* 1980; Wanninkhof and Thoning, 1993; Weiss *et al.,* 1992; Wong and Chan, 1991; Wong *et al.,* 1995).

1.4. QUALITY CONTROL FLAGS

Each individual data value and each profile in WOD05 has quality control flags associated with it. A description of these flags and general documentation describing software to read and use the WOD05 database are found in Johnson *et al.* (2006). WOD05 now includes Quality Control Flags assigned by data submitters. 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 questionable or unrepresentative when in fact they are not. There are some data that have been flagged as being “acceptable” based on our tests which in fact may not be the case. In addition, the scarcity of data, non-normal frequency distributions, and presence of different water masses in close proximity results in incorrect assignment of flags. Oguma et al. (2003; 2004) discuss skewness of oceanographic data.

The obvious advantage of flagging data is that users can choose to accept or ignore all or part of the flags we assign to data values. The most important flags we set are those that are set based on unusual features produced during objective analyses of the data at standard levels. This is because standard statistical tests may be biased for the reasons described above. Data from small-scale ocean features such as eddies and/or lenses are not representative of the large-scale permanent or semi-permanent features we attempt to reproduce with our analyses and will cause unrealistic features such as bull’s-eyes to appear. Hence, we flag these data, and other data that cause such features, as being unrealistic or as questionable data values. It is important to note that an investigator studying the distribution of mesoscale features in the ocean will find data from such features to be the signal they are looking for. As noted by Levitus (1982), it is not possible to produce one set of data analyses to serve the requirements of all possible users. A corollary is that it is not possible to produce one set of quality control flags for a database that serve the exact requirements of all investigators. As data are added to a database, investigators must realize that flags set for having violated certain criteria in an earlier version of the database may be reset solely due to the addition of new data which may change the statistics of the region being considered. Even data that have produced unrealistic features may turn out to be realistic when additional data are added to a region of sparse data. Conkright *et al.* (1994) present the objectively analyzed field of silicate at 1000 m depth using all silicate data available as part of WOA94 and using only data flagged as being acceptable. The differences are obvious.

1.4.1. Levels of Quality Control

Different oceanographic variables in the WOD05 datasets have various levels of quality control performed to them. Those oceanographic variables in datasets used for calculating climatological means had the highest level of quality control. This included all preliminary and automatic quality control checks and subjective checks performed in evaluating the quality of the resultant climatological fields. The automatic checks included minimum/maximum range assessment for 28 ocean areas at 33 standard levels.

Values of temperature in all datasets except APB received the highest level of quality control. Values of salinity received the highest level of quality control for all datasets.

Values of oxygen, phosphate, silicate, and nitrate concentrations in the OSD dataset received the highest quality control. Values of phosphate, silicate, and nitrate concentrations are only present in the OSD dataset.

Oxygen data in the CTD and PFL datasets received a slightly lower level of quality control. Since these data were not used to calculate climatologies subjective checks were not performed on them. After calculation of climatologies using oxygen data from the OSD dataset only, the newly calculated five-degree statistics (mean and standard deviation) were used to perform a standard deviation quality control check on oxygen in the CTD and PFL datasets. The reason for not using the oxygen data from the CTD dataset is that many of these oxygen data are not calibrated. Oxygen sensors for profiling floats are still a developing technology therefore there are very few oxygen data in the PFL dataset.

Chlorophyll, pH, and alkalinity values received a lower level of quality control than oxygen for the CTD and PFL datasets. There are no chlorophyll, pH, or alkalinity climatologies calculated for WOA05, so no standard deviation checks were performed. All other checks were done as for oxygen in the CTD and PFL datasets.

A lower level of quality control was done on pCO_2, DIC, Tritium, Helium, Δ^3Helium, Δ^{14}Carbon, Δ^{13}Carbon, Argon, Neon, CFC-11, CFC-12, CFC-113, and Δ^{18}Oxygen concentrations. Only initial range checks were applied to these variables in the OSD dataset. These ranges, a single minimum and maximum for all oceans were taken from the WOCE Data Reporting Requirements (WOCE Publication 90-1 *Revision* 2).

BAC data in the CTD dataset was subject to this lowest level of quality control as well. The minimum and maximum values were set by A. Mishonov.

For more information about the quality control procedures, see Johnson *et al*. 2006.

Plankton data have a different set of quality control detailed in Chapter 14 of this document as well as Johnson *et al*. 2006.

1.5. XBT DROP RATE ERROR

The XBT instrument does not measure pressure or depth directly. The depth of an XBT instrument as it falls through the water column is computed from the elapsed time from when the probe enters the water through use of a drop-rate equation. There are several models of the

Sippican Expendable Bathythermograph instrument. The manufacturer's drop rate equation for the T4, T-6, and T-7 models are known to contain a systematic error. The systematic error in calculated depth can be as large as 25-30 m at depths of 750 m. To correct for this error a new drop rate equation has been computed (Hanawa *et al.,* 1995; UNESCO, 1994). By international agreement (UNESCO, 1994), XBT profile depths are supposed to be reported to and archived at data centers using the "old' drop-rate equation. This policy is to avoid possible confusion as to whether the profiles have been converted or not. NODC/WDC archives the XBT data as submitted. In fact, some data are submitted using the new drop-rate formula although none of these data are in WOD05. This fact can be demonstrated by using a code in the observed level profile metadata (Johnson *et al.,* 2006). (See chapter 4).

The observed level XBT profiles are the same data as submitted by originators. However, in preparing standard level data for WOD05, the NODC/OCL corrected the depths of the originator's XBT profiles using the new drop-rate equation, before interpolating to standard levels.

1.6. STATISTICS OF INDIVIDUAL INSTRUMENT TYPES

We present a series of figures and tables which document the status of the archives of historical ocean profile through the presentation of summary statistics. More detailed information is presented in the individual chapters of this volume, each describing the historical distributions of an individual instrument or measurement type (*e.g.* CTD, MBT, XBT, OSD temperature and salinity, nutrients, chlorophyll, pH, alkalinity, pCO_2, and TCO_2 and plankton data).

Table A.1 (see Appendix) shows the number of stations or profiles in WOD05 submitted by individual countries for the OSD, CTD, MBT, and XBT datasets. This table is sorted by NODC country code. Table A.2 (see Appendix) shows the same information sorted alphabetically by country name.

1.7. OUTLOOK FOR FUTURE ACQUISITIONS OF HISTORICAL OCEAN PROFILE AND PLANKTON DATA AND INTERNATIONAL COOPERATION IN THE "WORLD OCEAN DATABASE PROJECT"

Substantial amounts of historical ocean data continue to be transferred to NODC/WDC for archiving and 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. Examination of the distribution of high-resolution CTD profiles presented in Figure 3.2 and by Boyer *et al.* (2002) documents the lack of such data for global scale analyses. There is a need for additional historical chlorophyll, nutrient, oxygen, 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 been excellent. This response 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.

1.8. LAYOUT OF THE REST OF THIS DOCUMENT

The rest of this document, Chapters 2-16 describe in more detail the oceanographic instrumentation used to collect the data which are contained in WOD05 and the nature of the measurements themselves. Chapter 2 describes the OSD dataset, with an emphasis on Ocean Station Data. However, not all chapters neatly fit into one dataset. For instance, Chapter 5 is about the XCTD data, which are spread over the OSD and CTD datasets. Chapters 7, 8, and 13 all details the data which are collected by different instruments and stored in the MBT dataset.

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CHAPTER 2: OSD - OCEAN STATION DATA, LOW-RESOLUTION CTD, LOW-RESOLUTION XCTD, AND PLANKTON TOWS

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2.1. INTRODUCTION

Data from Ocean Station Data (OSD) casts have historically referred to surface and sub-surface oceanographic measurements of temperature made from sea-going research ships using deep-sea reversing thermometers and measurements of dissolved and particulate constituents in seawater at depths of interest in the water column. Data that are in the OSD dataset are also frequently referred to as "bottle data" and the entire OSD collection may be alternatively referred to as the "Bottle Dataset". Here we adopt the term OSD to refer collectively to serial (discrete) water column measurements (bottles, buckets), plankton (bottles, net-tows), and to relatively low vertical resolution Conductivity-Temperature-Depth (CTD) data in the *World Ocean Database 2005* (WOD05**)**. Computer storage was still a scarce resource at the time salinity-temperature-depth (STDs) and CTDs were introduced (about the mid-1960s). As a result many data from the mid-1960s and even from later years were archived at relatively low vertical resolution. These low depth resolution data are stored in the OSD dataset as opposed to the high-resolution CTD dataset. Low-resolution here refers to a limited number or a subset of measurements as a function of depth or pressure. At a minimum, these low-resolution CTD and STD measurements are recorded at the depths at which water samples have been collected and usually data at some additional depths are recorded.

The OSD dataset include a number of the most frequently measured *in situ* physical, chemical, and biological oceanographic observations as a function of depth or pressure. We believe that the OSD dataset provides the most comprehensive collection of discrete oceanographic observations available to date. The description that follows is a general note on the data in the OSD dataset.

2.2. COMMONLY USED LOW AND LARGE VOLUME WATER COLUMN SAMPLERS

Most of the historical seawater samples of the ocean's water column in the OSD dataset were obtained from oceanographic research cruises occupying a number of selected oceanographic station locations (sometimes called hydrographic stations) along pre-selected cruise tracks. For each station, water samples from the ocean surface to some selected depth of the water column were obtained by means of a variety of specially designed sampling bottles. Some of the early historical oceanographic measurements of the water column were collected by means of wood or metal buckets. Many types of water sampling devices have been invented since the early days of oceanographic research starting with the H.M.S. Challenger expedition in the late-1800s (1872 to 1876). The Nansen and Niskin bottles are arguably the most commonly used samplers for the serial collection of relatively small volumes of seawater. It is worth noting that a majority of the most commonly analyzed constituents dissolved in seawater in the OSD dataset were obtained from a relatively small sample volume of seawater. The stainless steel Gerard-Ewing bottle samplers are the most commonly used sampler for the serial collection of relatively large volumes of seawater (approximately 270-liter). Large volumes of seawater are needed for the analysis of chemical constituents in trace concentrations present in seawater such as isotopes (*e.g.*, argon-39 [^{39}Ar], kripton-85 [^{85}Kr], and carbon-14 [^{14}C]). Present day analytical techniques for measuring ^{85}Kr in seawater, for example, require a sampling volume of about 1200 liters (Smethie and Mathiew, 1986; Smethie, 1994). The Gerard-Ewing samplers were first used during the Geochemical Ocean Sections Study (GEOSECS) program in the early 1970s (Bainbridge, 1980; Craig, 1972; 1974; Craig and Turekian, 1980) and subsequently used during several research cruises such as the Transient Tracers in the Ocean (TTO, Williams, 1986), South Atlantic Ventilation Experiment (SAVE, Smethie and Jacobs, 1992), and the World Ocean Circulation Experiment (WOCE) programs. Water sampling collection and analysis is a labor intensive process. Below we describe briefly the main features of the Nansen and Niskin bottles.

Nansen bottles commonly used prior to the late 1960s and first invented by Fridtjof Nansen in 1910, are cylindrical pressure-resistant metal (usually made of brass) containers with plug valves at each end that allow the collection of small volumes of seawater (about 1.2 liters) at selected depths in the water column (Sverdrup *et al.,* 1942). The bottles with the ends open are sequentially attached to a metal wire in serial numbers at selected vertical intervals (typically about 12 bottles) and lowered to the desired depths in the water column. Then the bottles are closed in succession by the tripping action of a metal messenger that slides down the metal wire. Another messenger is typically arranged on the wire to be released by the inverting mechanism of each Nansen bottle, and slides down the cable until it reaches the next Nansen bottle. By fixing a sequence of bottles and messengers at intervals along the cable, a series of water samples at increasing depth are collected. When the bottles are brought back on deck, water samples are sequentially collected from each bottle and then analyzed at a later time for a variety of dissolved and particulate constituents. Because of their relatively small sampling volume, sampling is generally restricted to a small number of dissolved or particulate constituents present in seawater. The Nansen bottles often included two or more specially designed protected and un-protected mercury-filled glass reversing thermometers inside a small metal case exposed to the water column attached to the outside of each bottle. These thermometers allowed the estimation of the *in situ* temperature and pressure at which each bottle closed in the water column.

Though the Nansen bottle was the sampling device of choice of oceanographic field research in the early 20th century, it had several practical disadvantages: (1) its relatively small sampling volume limited the analysis to a small number of constituents (*i.e.*, salinity, dissolved oxygen, and the most abundant inorganic nutrients), (2) its relatively poor metal seals had a tendency for sample water leakage resulting in degassing, and (3) its metal construction was thought to interfere with some seawater constituents (*i.e.*, inorganic and organic nutrients, gases such as oxygen, transition metals such as iron, *etc.*). Nansen bottles are no longer manufactured commercially. The Nansen bottles were generally replaced by the Niskin bottles beginning in the late 1960s. Niskin bottles helped minimize some of the problems associated with the collection of Nansen bottle samples (Worthington, 1982).

Niskin bottles are cylindrical pressure-resistant plastic containers (to minimize contamination between the bottle and the water sample) with rubber spring-loaded end-caps that allow the collection of a variety of volumes of seawater (about 1.2 to 10 liters depending on the Niskin bottle size) at selected depths in the water column. Shale Niskin invented the Niskin bottle in 1966 based on the general idea of the Nansen bottle. Like the Nansen bottles, one or more Niskin bottles can be sequentially attached to a metal wire at selected vertical intervals and each bottle may often include two or more deep-sea glass mercury-filled reversing thermometers. In more recent years, the Niskin bottles are frequently mounted around a circular rosette sampler metal frame with the capacity to hold as many as 36 bottles depending on the size of the bottles. The rosette frame is attached at the end of a wire with (or without) an electrical conductor. The bottles can then be closed at any depth or pressure by an electrical command from deck or from pre-set depth (pressure) values for research ships with or without an electrical conductor wires, respectively. When the closed Niskin bottles are brought back on deck, water samples can be collected from each bottle and then analyzed for different dissolved and particulate constituents. The rosette frame may include a CTD and other high-frequency sampling instruments (*e.g.*, fluorometers, polarographic oxygen sensors, transmissometers, *etc.*).

2.3. VARIABLES AND METADATA INCLUDED IN THE OSD DATASET

The OSD include a large number of the most frequently measured *in situ* physical (temperature, salinity), chemical (dissolved gases, carbon variables, nutrients, tracers), and biological (total chlorophyll and plankton) historical oceanographic observations as a function of depth or pressure. The OSD dataset includes several new tracer variables which were not available in previous releases of the World Ocean Database Series. Table 2.1 lists the nominal names, number of profiles (or stations in the case of plankton data), and sampled years of the parameters or variables included in the OSD dataset. Each oceanographic station data record may contain simultaneous profiles of one or more of these variables as a function of depth or pressure. The user can extract data from the OSD dataset both at observed depths and up to 33 nominal standard depth levels. The observed level values in the OSD dataset are the measurements submitted by the data originator as a function of depth or pressure. The profiles at standard levels in the OSD dataset are the measurements submitted by the data originator vertically interpolated to selected depth levels. The profiles include quality flags for observed and standard depth level data. Johnson *et al.* (2006) describe the WOD05 data format.

Table 2.1. Variables present in the Oceanographic Station Data (OSD) and low-resolution Conductivity-Temperature-Depth (CTD) dataset.

Parameter [nominal abbreviation]	WOD05 reporting unit (nominal abbreviation)	Number of profiles (sampled years)
Temperature [t]	Degree centigrade (°C)	2,082,770 (1772-2004)
Salinity [S]	Dimensionless or unit less	1,883,461 (1874-2004)
Dissolved oxygen [O_2]	Milli-liter per liter (ml l^{-1})	638,888 (1893-2004)
Phosphate [HPO_4^{-2}]	Micro-mole per liter (µM)	400,399 (1922-2004)
Silicate [$Si(OH)_4$]	Micro-mole per liter (µM)	287,256 (1921-2004)
Nitrate [NO_3]	Micro-mole per liter (µM)	233,125 (1925-2004)[1]
pH [pH]	Dimensionless	152,911 (1904-2003)
Total Chlorophyll [Chl]	Micro-gram per liter (µg l^{-1})	136,034 (1900-2004)
Total Alkalinity [TALK]	Milli-equivalent per liter (meq l^{-1})	30,419 (1921-2004)
Partial pressure of carbon dioxide [pCO_2]	Micro-atmosphere (µatm)	3,036 (1967-2003)
Dissolved inorganic carbon [DIC]	Milli-mole per liter (mM)	9,093 (1958-2004)
Tritium [^3H]	Tritium Unit (TU)[1]	1,326 (1984-1997)
Helium [He]	Nano-mol per liter (nM)	1,807 (1984-1997)
Delta Helium-3 [Δ^3He]	Percent (%)	1,769 (1985-1997)
Delta Carbon-14 [$\Delta^{14}C$]	Per-mille (‰) deviation	878 (1991-2001)
Delta Carbon-13 [(13(13C]	Per-mille (‰)deviation	697 (1991-2001)
Argon [Ar]	Nano-mol per liter (nM)	75 (1993-1993)
Neon [Ne]	Nano-mol per liter (nM)	1,131 (1989-1997)
Chlorofluorocarbon-11 [CFC-11]	Pico-mole per liter (pM)	8,286 (1985-2004)
Chlorofluorocarbon-12 [CFC-12]	Pico-mole per liter (pM)	8,225 (1985-2004)
Chlorofluorocarbon-113 [CFC-113]	Pico-mole per liter (pM)	1,795 (1990-2004)
Delta Oxygen-18 [(18O]	Per-mille (‰)deviation	29 (1996-1996)
Pressure [P]	Decibar	73,135 (1911-2004)
Plankton taxonomy and Biomass	Various units	150,250 (1905-2004)[3]

Notes:
[1] profile count includes 10,577 profiles of Nitrate+Nitrite;
[2] One tritium unit (TU) equals 1 tritium atom in 1018 hydrogen atoms;
[3] Count refers to the number of plankton stations (not profiles; see Chapter 14).
Units: 1 mol = 10^3 mmol = 10^6 µmol = 10^9 nmol =10^{12} pmol; 1 µM = 1 µmol l^{-1}.

Physical variables such as temperature, salinity, and pressure are conservative variables which define the equation of state of seawater (Millero and Poisson, 1981). By conservative variables we mean measurements which are not affected directly by biochemical processes. Historical temperature measurements have been obtained by means of manual (*i.e.*, visual readings of temperature from reversing thermometers) and automated (*i.e.*, digital recordings of temperature from STDs and CTDs) instruments. Temperature measurements have been obtained following several International Temperature Scales (ITS) definitions dating back from to early 1900s (*i.e.*, ITS-1927; ITS-1948, ITS-1968) to the present ITS-1990 (Preston-Thomas, 1990). Similarly, salinity measurements have been obtained by manual (*i.e.*, chemical titrations with silver nitrate, chlorinity to salinity formulae, refractometer, salinograph, inductive salinometer, *etc.*) and automated (*i.e.*, conductivity to salinity from CTDs) methods. For the past few decades, bottle salinity sampling and analyses are normally conducted to calibrate the conductivity to salinity measurements of CTDs. Salinity measurements have been obtained using reference standard seawater samples of known salinity (within uncertainty). In 1978 the practical salinity scale (PSS-1978) was adopted defining salinity in terms of electrical conductivity ratio (UNESCO, 1981; Lewis and Perkins, 1981; Culkin and Ridout, 1998). Under the PSS-1978 definition, salinity measurements are dimensionless (Millero, 1993). Seawater standards provide a means to test the calibration of salinity measurement instruments and facilitate the inter-comparison of ocean salinity measurements against samples of known electrical conductivity ratio (UNESCO, 1981; Mantyla, 1980; 1987; 1994; Culkin and Smed, 1979; Aoyama *et al.,* 2002; Kawano *et al.,* 2005). It is important to note that low-resolution CTD profiles present in the OSD dataset may be associated with high-resolution CTD profiles in the CTD dataset. This is done so that users of the OSD dataset have access to CTD values collected at the same time and depth or pressure that water samples are collected and to maintain a more or less concise size for the OSD dataset. WOD05 salinity data are not corrected for "standard sea water" changes (Mantyla, 1994) or converted to any salinity scale other than the scale the measurements were reported in.

Geochemical variables such as dissolved oxygen (O_2), major dissolved inorganic nutrients (reactive phosphate [HPO_4^{-2}], nitrate and nitrite [NO_3+NO_2 or N+N], nitrate [NO_3], nitrite [NO_2], and silicate or silicic acid [$Si(OH)_4$], carbon species (total alkalinity [TALK], dissolved inorganic carbon [DIC or TCO_2], partial pressure of carbon dioxide [pCO_2]) and pH are non-conservative variables. Their concentrations result from diffusion and advection of waters with varied preformed concentrations, by biogeochemical processes, and by oceanic atmospheric inputs (Redfield *et al.,* 1963; Sarmiento *et al.,* 1998; Falkowski *et al.,* 1998; Broecker and Peng, 1982).

The WOD05 includes NO_3+NO_2 and NO_3 data only. The concentrations of reactive NO_3+NO_2 and NO_2 are often estimated by independent photometric analyses where in one case NO_3 is measured indirectly by effectively reducing NO_3 to NO_2 while in the other only NO_2 is measured directly (Strickland and Parsons, 1972; Atlas *et al.,* 1971; Whitledge *et al.,* 1986; Gordon *et al.,* 1993). The concentration of NO_3 is then obtained by difference between the estimated concentrations of NO_3+NO_2 and NO_2 (*i.e.*, $NO_3 = NO_3+NO_2 - NO_2$). However data reported as NO_3 in the *WOD05* should be used with caution because it is difficult to verify that the NO_3 data is NO_3+NO_2 or NO_3. When reported by the originator of the data, *WOD05* includes information about whether the labeled nitrate measurement is reported as NO_3+NO_2 data. Historical DIC, TALK, pCO_2, and pH data seldom includes information about the methods, buffers, or scales used (Millero *et al.,* 1993a, 1993b; Ramette *et al.,* 1977; Robert-Baldo *et al.,* 1985; Bradshaw and Brewer, 1988; Byrne and Breland, 1989; Dickson, 1981; 1984; 1993; DOE, 1994). For example, little information exists in the *WOD05* about the scales used to measure pH in seawater (*i.e.*, NBS pH Scale, total pH Scale, free pH Scale, TRIS Buffer, *etc.*)

The dissolved oxygen concentration is often analyzed following various modifications of the Winkler titration followed by end-detections by visual, amperometric, or photometric methods (Winkler, 1888; Carpenter, 1965; Culberson and Huang. 1987; Knapp *et al.,* 1990; Culberson *et al.,* 1991; Dickson, 1994). Carpenter (1965) outlined a whole bottle titration method that minimized the amount of error that was introduced during the O_2 titration from the volatization of iodine and the difference between the titration end point and the equivalence point. It is worth noting that the CTD dataset contains high-resolution O_2 data obtained from electronic sensors mounted on the CTD rosette frame. For example, polarographic O_2 electronic sensors estimate seawater O_2 concentration by estimating the flux of oxygen molecules per unit time that diffuse through a permeable membrane. These high-resolution O_2 profiles obtained by electronic sensors can be subject to sensor drift problems resulting in relatively lower data quality (precision) than O_2 profiles which have been obtained by chemical analysis of serial water samples. The CTD O_2 data are often calibrated using discrete O_2 measurements of the water column (Owens and Millard, 1985). For these reasons, the O_2 profiles in the CTD dataset are kept separate from the O_2 profiles in the OSD dataset.

Dissolved noble gases and tracers in seawater are conservative variables. These help in the interpretation of how ocean surface properties are transmitted into the ocean's interior, the dynamics of ocean circulation, biochemical cycles, ocean-atmosphere interactions, and to help infer paleo-temperatures (Broecker and Peng, 1982). The WOD05 OSD dataset includes noble gases such as neon [Ne], argon [Ar], and helium [He]. The distributions of these gases are useful, for example, to further our understanding of the ocean circulation and air-sea gas flux interactions (Schlosser, 1986; Weiss, 1971; Broecker and Peng, 1982). The distributions of tracers (chlorofluorocarbons [CFC-11, CFC-12, and CFC-113], tritium [hydrogen-3 or ^3H], helium-3 [^3He], delta carbon-13 [$\Delta^{13}C$], delta carbon-14 [$\Delta^{14}C$], and delta oxygen-18 [$\Delta^{18}O$]) provide estimates of oceanic ventilation rates (a measure of water mass spreading rates from the surface to the ocean interior). Specifically, transient tracers such as bomb-fallout radionuclides (^3H) and natural isotopes (^3He) function as "clocks" recording the elapsed time since a parcel of water was last in contact with the oceanic surface layer [Broecker *et al.,* 1986; 1991; Schlosser *et al.,* 1991; Jenkins, 1982; 1987; Jenkins and Rhines, 1980; Östlund and Rooth, 1990]. For example, tritium was delivered to the atmosphere as a result of the atmospheric thermonuclear weapon tests in the late 1950s and early 1960s. Chlorofluorocarbons (also called CFCs or freons) are man-made gases with high greenhouse potential (Bach and Jain, 1990). Their time history within the water column provides important clues regarding the oceanic uptake of atmospheric gases (Bullister and Weiss, 1988; Smethie, 1993; Weiss *et al.,* 1985; Haine *et al.,* 1995). There is a large number of freons produced and dissolved in the ocean. The most commonly sampled CFCs in the ocean are CFC-11 (R-11, freon-11, or trichlorofluoromethane [CCl_3F]), CFC-12 (R-12, freon-12, or dichlorodifluoromethane [CCl_2F_2]), and CFC-113 (1,1,2-Trichloro-1,2,2-trifluoroethane or trichlorotrifluoroethane [$Cl_2FC\text{-}CClF_2$]). CFCs were used worldwide as refrigerants, propellants, and cleaning solvents. The temporal evolution of the CFC concentrations in oceanic waters is essentially controlled by the atmospheric record. Most of the tracer data in the OSD dataset were collected as part of WOCE program in the 1990s. Additional sources of historical tracer data have been identified but were not included in time for the release of WOD05.

OSD chemical variables received at NODC are reported by originators of the data in a variety of concentration units that may differ from the international system of units in oceanography (UNESCO, 1985). When originator's units differ from a set of adopted WOD05 common units, the data are converted from the originator's units to a common set of concentration units to facilitate the use of the WOD05 data. For example, originator's chemical concentration units reported in per-mass units were converted to per-volume units assuming a constant density of seawater equal to 1025 kg·m^{-3} (arbitrary choice). Chemical concentration units reported in mass-per-volume basis were converted to mole-per-volume units using the standard element atomic weights of 1989 (CRC, 1993 and previous editions). Dissolved oxygen originator units reported in molar-per-volume units were converted to volume-per-volume (ml-per-liter) using a molar volume of O_2 of ~22.392 liters-per-mole. This molar volume is only slightly smaller than the ideal gas volume (22.4 liters-per-mole) by about 0.04% (Garcia and Gordon, 1992). Though OSD chemical data are nominally expressed in per-volume units, it is of practical importance to express chemical concentrations in per-mass units which are independent of temperature and pressure.

In addition to the observed data (profiles as a function of depth of each sampled variable), OSD casts may include additional information (commonly referred to as "station header information") such as, but not limited to, ocean surface conditions (*i.e.*, wave direction and height, sea state), meteorological observations (*i.e.*, cloud cover and type, visibility, wind speed and direction, barometric pressure, dry and wet bulb temperature), water color and transparency (*i.e.*, Secchi disk depth), originator's information about the data collected (instrumentation, methods, units, quality flags, stations and cruise labels, institutions, platforms, principal investigators, *etc.*). Johnson *et al.* (2006) describes the WOD05 cast header information and data format. We refer collectively to this information as station metadata. The cast metadata included in the OSD dataset are not meant to substitute in whole or in part data for information included with any oceanographic cruise data reports or scientific manuscripts which may be associated with any particular OSD subset. Metadata are included in the OSD dataset as a means to quickly identify additional information about the measurements that may be available with each cast. Metadata are included with each OSD station in the form of cast header information when metadata or sources to metadata are included with data received at NODC.

The historical biochemical data in the OSD dataset have been measured using a variety of manual and automated analytical methods. It is beyond the scope of this work to describe the evolution and inter-comparison of the precision and accuracy of historical oceanographic chemical measurements and methods for several reasons. Not all data received at NODC contain complete metadata information. For example, less than 20% of the OSD profiles contain variable specific metadata information about the analytical methods and instruments used.

The historical chemical methods arguably provide measurements with varying degrees of within-laboratory and inter-laboratory precision, reproducibility, and accuracy which are difficult to quantify. It is difficult to estimate the precision and accuracy of the historical chemical data in part because (1) there has not been a generally accepted set of standard international analytical oceanographic methods, (2) the continuous availability over time of new or improved analytical techniques for the determination of the concentration of dissolved and particulate constituents in seawater, (3) the practical difficulty of periodic comparison of the precision and accuracy of oceanographic data collected by oceanographic institutions worldwide. At present, there is no suitable program for the periodic and systematic comparison of analytical instruments, measurements, and certified reference standards used by international or national research institutions or universities to collect oceanographic observations. Some major international oceanographic sampling programs have adopted sample and measurement protocols such as the WOCE and the Joint Global Ocean Flux Study

(JGOFS) programs. These protocols are believed to provide relatively consistent high-quality measurements. In the past few years certified reference materials (CRMs) of known chemical concentrations have been used for the analysis, for example, of DIC and TALK (DOE, 1994). It is believed that adoption of CRM's can facilitate the inter-laboratory comparison of measurements and estimation of the calibration accuracy of oceanographic systems. Farringtion (2000) provides a summary of advances in chemical oceanography for the 1950-2000 period.

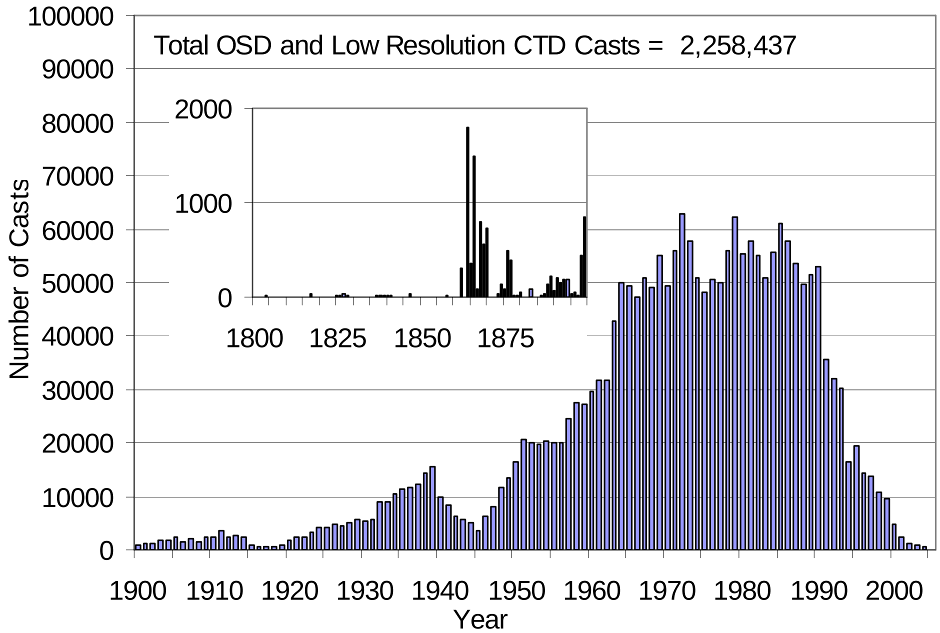

Figure 2.1. Time series of OSD and low-resolution CTD casts in WOD05.

The OSD dataset includes data from 121,625 low-resolution CTD casts, 864 low-resolution XCTD casts, and 150.250plankton casts.

2.4. OSD DATA COVERAGE

The sampling coverage of the OSD variables is worldwide and for some variables spans approximately 230 years (Table 2.1). However the coverage for each variable is non-uniform in space and time. The largest numbers of oceanographic profiles present in the OSD dataset are due to temperature, salinity, and dissolved oxygen measurements. This non-uniformity of the number of profiles can be attributed to different reasons. First, historical oceanographic cruises typically sampled individual or a limited suite of tracers to deduce specific physical, chemical, biological or geological aspects of the ocean. In other words, oceanographic cruises in general have a specific research goal which may require sampling of a limited number of variables. Second, the sampling and analysis of biochemical variables is more labor intensive when compared to temperature or conductivity measurements obtained by CTD instruments.

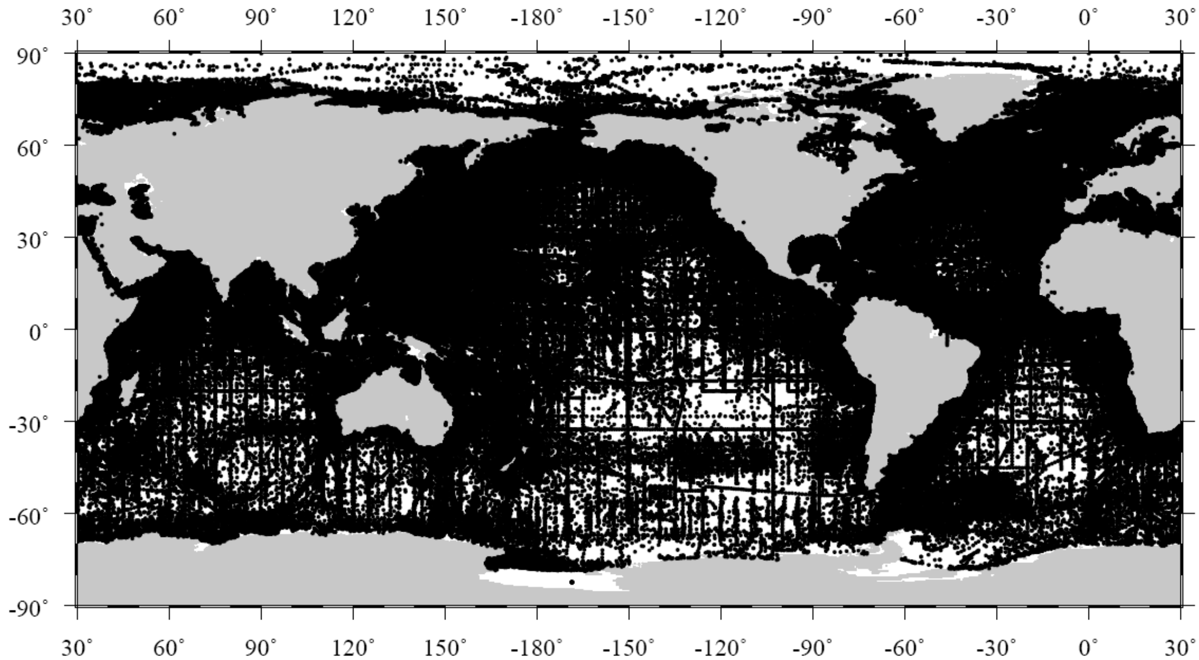

Figure 2.2. Geographic distribution of OSD and low-resolution CTD casts in WOD05.

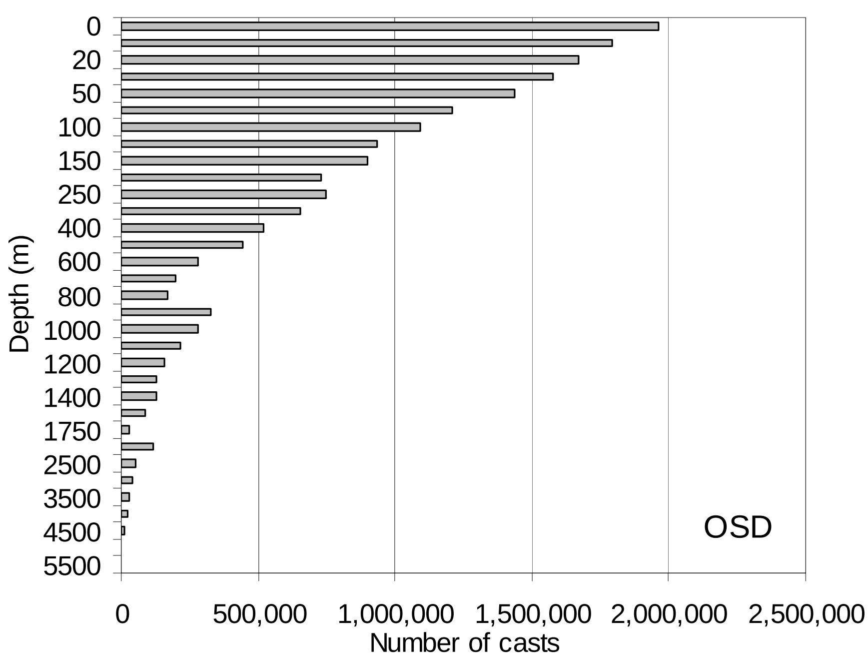

Figure 2.3. Distribution of Ocean Station Data (OSD) and low-resolution CTD data at standard depth levels in WOD05.

2.5. VARIABLES AND METADATA NOT INCLUDED IN THE OSD DATASET

The *World Ocean Database* includes data for other biochemical variables not available as part of the WOD05. These variables were not released as part of the WOD05 because a minimum of data quality control was not performed on these measurements. The variables not present in the WOD05 include dissolved and particulate organic carbon, nitrite, total phosphorus, ammonia, various chlorophyll pigments, and primary production. In addition, the NODC maintains a database of originator's data files and documentation as part of a Data Accession Tracking Data Base (ATDB). Users of the WOD05 can retrieve the original data and metadata files if they were sent to NODC. It is worth noting that in some cases, data received at NODC may include measured variables which were not digitally stored in the database (*e.g.*, trace metals, organic compounds, different ions and isotopes of each element in the periodic table, *etc*.). Information about these variables is maintained in the ATDB.

2.6. PROSPECTS FOR THE FUTURE

It is expected that relatively large amounts of historical chemical and biological data still exist in non-digital and digital form at data centers, research institutions, universities, and libraries worldwide. Biochemical data is also expected to become available from ongoing and future international oceanographic field programs such as the Global Ocean Observing System (GOOS), Climate Variability (CLIVAR) repeat hydrography field program and underway pCO2 measurements, and Argo floats equipped with physical and chemical sensors such as O_2 (Emerson *et al.,* 2002; Körtzinger *et al.,* 2004). There are several types of chemical sensors available for autonomous and lagrangian platforms that can contribute to the *World Ocean Database*. Future releases of the *World Ocean Database* will be enhanced by the addition of more data and metadata. The *World Ocean Database* is a worldwide source of unrestricted access to historical oceanographic data information. It is hoped that users of the WOD05 inform us of sources of historical data not present in the database as well as any data or metadata errors that might be present in the database to the NODC Ocean Climate Laboratory (http://www.nodc.noaa.gov/OCL/). Clearly, the OSD dataset does not include data from all of the historical measured chemical variables present in such a complex electrolyte solution such as seawater. Identification of new sources of chemical data is beneficial for improving mechanisms for data and metadata permanent archival, data management, and distribution into national and international data archives. Addition of new data will help improve the release of high-quality global, integrated, scientifically quality-controlled ocean profile-plankton database, scientific products, and diagnostic studies. Addition of new data will also help to provide observational constraints on the nature of oceanic variability in the instrumental record for present and future generations of observationalists, modelers, and public policy officials.

Table 2.2. The number of Ocean Station data (OSD) casts as a function of year in WOD05
The total number of casts = 2,258,437.

YEAR	CASTS	YEAR	CASTS	YEAR	CASTS	YEAR	CASTS
1772	2	1816	5	1860	0	1904	1,922
1773	1	1817	27	1861	0	1905	2,446

1774	0	1818	3	1862	299	1906	1,605
1775	0	1819	0	1863	0	1907	2,094
1776	0	1820	2	1864	1,798	1908	1,351
1777	0	1821	0	1865	352	1909	2,285
1778	0	1822	0	1866	1,494	1910	2,305
1779	0	1823	0	1867	78	1911	3,671
1780	0	1824	2	1868	791	1912	2,533
1781	0	1825	10	1869	557	1913	2,695
1782	0	1826	18	1870	727	1914	2,351
1783	0	1827	30	1871	0	1915	887
1784	0	1828	13	1872	0	1916	472
1785	0	1829	0	1873	29	1917	636
1786	0	1830	0	1874	132	1918	715
1787	0	1831	0	1875	90	1919	942
1788	0	1832	0	1876	500	1920	1,785
1789	0	1833	0	1877	383	1921	2,282
1790	0	1834	0	1878	25	1922	2,454
1791	0	1835	0	1879	17	1923	3,370
1792	0	1836	8	1880	49	1924	4,323
1793	0	1837	17	1881	2	1925	4,125
1794	0	1838	11	1882	8	1926	4,851
1795	0	1839	15	1883	79	1927	4,490
1796	0	1840	9	1884	1	1928	5,186
1797	0	1841	21	1885	0	1929	5,583
1798	0	1842	8	1886	17	1930	5,487
1799	0	1843	0	1887	28	1931	5,812
1800	0	1844	0	1888	128	1932	8,931
1801	0	1845	0	1889	221	1933	9,071
1802	0	1846	3	1890	62	1934	10,397
1803	0	1847	28	1891	197	1935	11,447
1804	10	1848	0	1892	156	1936	11,765
1805	1	1849	1	1893	178	1937	12,177
1806	0	1850	3	1894	184	1938	14,414
1807	0	1851	1	1895	41	1939	15,691
1808	0	1852	0	1896	46	1940	9,850
1809	0	1853	0	1897	18	1941	8,412
1810	0	1854	0	1898	441	1942	6,312
1811	0	1855	4	1899	842	1943	5,789
1812	0	1856	0	1900	1,018	1944	5,071
1813	0	1857	6	1901	1,204	1945	3,484
1814	0	1858	23	1902	1,181	1946	6,166
1815	0	1859	5	1903	1,828	1947	7,954

Table 2.2 (Continue)

YEAR	CASTS	YEAR	CASTS	YEAR	CASTS	YEAR	CASTS
1948	11,806	1963	42,743	1978	56,103	1993	30,158
1949	13,413	1964	50,106	1979	62,304	1994	16,369
1950	16,462	1965	49,445	1980	55,326	1995	19,495
1951	20,514	1966	47,396	1981	57,831	1996	14,333
1952	20,053	1967	50,912	1982	55,074	1997	13,823
1953	19,749	1968	49,048	1983	50,811	1998	10,916
1954	20,335	1969	55,208	1984	55,787	1999	9,527
1955	20,165	1970	49,436	1985	61,056	2000	4,748
1956	20,122	1971	55,968	1986	57,642	2001	2,372
1957	24,477	1972	62,811	1987	53,661	2002	1,082
1958	27,513	1973	57,826	1988	49,698	2003	965
1959	27,242	1974	50,801	1989	51,622	2004	747
1960	29,496	1975	48,101	1990	53,104		
1961	31,654	1976	50,635	1991	35,694		
1962	31,689	1977	49,994	1992	31,992		

Table 2.3. National contribution of OSD casts in WOD05.

NODC Country Codes	Country Name	OSD Casts	% of Total
49,60	Japan	528,077	23.38
90, RU	Union of Soviet Socialist Republics/Russia	432,224	19.14
31,32,33	United States	323,550	14.33
74	United Kingdom	132,324	5.86
18	Canada	111,556	4.94
99	Unknown	100,903	4.47
58	Norway	93,472	4.14
06,07	Germany	79,697	3.53
77	Sweden	51,876	2.30
34	Finland	46,379	2.05
24	Korea, Republic of	39,707	1.76
35	France	37,952	1.68
09	Australia	35,222	1.56
26	Denmark	32,136	1.42
91	South Africa	28,051	1.24
64	Netherlands	26,227	1.16
46	Iceland	18,780	0.83
67	Poland	16,459	0.73
65	Peru	10,827	0.48
48	Italy	10,159	0.45
14	Brazil	9,556	0.42
11	Belgium	9,327	0.41
68	Portugal	6,471	0.29
76	China, The Peoples Republic of	5,590	0.25
95	Yugoslavia	5,404	0.24

NODC Country Codes	Country Name	OSD Casts	% of Total
20	Chile	4,914	0.22
41	India	4,478	0.20
42	Indonesia	4,283	0.19
93	Venezuela	3,590	0.16
08	Argentina	3,502	0.16
28	Ecuador	3,469	0.15
IC	Ivory Coast	3,068	0.14
47	Israel	3,051	0.14
21	Taiwan	3,027	0.13
29	Spain	2,990	0.13
45	Ireland	2,980	0.13
86	Thailand	2,801	0.12
GH	Ghana	2,670	0.12
55	Malagasy Republic	2,524	0.11
MO	Monaco	2,087	0.09
SE	Senegal	1,975	0.09
61	New Zealand	1,917	0.08
RC	Congo	1,836	0.08
57	Mexico	1,457	0.06
22	Colombia	1,331	0.06
59	New Caledonia	1,283	0.06
MU	Mauritania	1,217	0.05
CU	Cuba	969	0.04
LT	Lithuania	869	0.04
NI	Nigeria	759	0.03
AN	Angola	621	0.03
10	Austria	488	0.02
SI	Singapore	412	0.02
36	Greece	324	0.01
89	Turkey	301	0.01
88	Tunisia	280	0.01
27	Arab Republic of Egypt	258	0.01
66	Philippines	235	0.01
62	Pakistan	167	0.01
MS	Malaysia	154	0.01
PA	Panama	139	0.01
YM	Yemen	85	<0.01
	Total	*2,258,437*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

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CHAPTER 3: CONDUCTIVITY-TEMPERATURE-DEPTH (PRESSURE) DATA (CTD)

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3.1. INTRODUCTION

The Conductivity-Temperature-Depth (CTD) profiling instrument measures temperature and salinity among other variables with high vertical resolution up to depths of 10,000 m. In practice, most CTD casts sample to considerably shallower depths.

Fundamental physical relationships between temperature (salinity, *etc.*) and electromagnetic properties of sea water are used to develop CTD sensors and appropriate conversion algorithms (Wallace 1974, Prien, 2001). The response time of CTD sensors is an important factor that determines the ability of the CTD to make "continuous" measurements. For instance, lowering the CTD at speed of 1 m/s and typical range of response time of temperature sensors can provide the vertical profiling at resolution 0.05 m to 0.3 m. CTD data that were submitted to NODC/WDC-A at "sub-meter" vertical resolution have been archived at this resolution whereas in the past, electronic storage limitations resulted in only selected levels being stored. CTDs measure pressure which is then converted to depth.

An earlier version of the CTD instrument was the STD (salinity-temperature-depth) which computed salinity from a conductivity sensor as the instrument was moving through the water column. Because of instrument problems that led to erroneous data values (spikes), this method was replaced by the CTD method for which conductivity measurements are recorded from the instrument and then salinity computed from the conductivity measurement with appropriate calibration information. New sensors are being developed to make "continuous" measurements of other variables (i.e. dissolved oxygen content, beam attenuation coefficient (BAC), chlorophyll concentration, etc.). This release of WOD, for the first time, includes BAC measurement from transmissometers (see Section 3.4).

CTD instrument deployed from a vessel can make measurements during both the downward and upward progression of the instrument through the water column. However, each CTD cast is submitted to NODC/WDC-A as an average of these two vertical casts or just one of them (usually the downward cast). When available this information is present in the WOD metadata of each cast.

Table 3.1 presents the list of all variables stored in CTD dataset.

3.2. CTD ACCURACY

The cited accuracy of CTD measurements represents the results of calibration of CTD sensors by comparison with established standards. This initial accuracy varies with instrument design typically from 0.005°C to 0.001°C (for temperature), 0.002 $S \cdot m^{-1}$ to 0.0003 $S \cdot m^{-1}$ (for conductivity, approximately 0.02 PSS to 0.003 PSS equivalent salinity), 0.08% to 0.015% (for pressure). These accuracies are subject to change by a factor of two or more after prolonged use of the CTD instrument in the sea (known as a calibration drift).

The overall quality of CTD measurements does not depend solely on the accuracy of CTD sensors. Other factors such as the difference in response time of temperature and conductivity sensors, varying speed of the CTD, along with rapid changes in ocean environment can be important sources of erroneous CTD data (see Lawson and Larson, 2001 for a detailed overview).

Table 3.1. List of all variables and profile counts in the WOD05 CTD dataset.

Variables	Profiles
Temperature	443,139
Salinity	436,009
Oxygen	71,687
Chlorophyll	30,681
Transmissivity	6,655
Pressure	295,130

3.3. CTD CAST DISTRIBUTIONS

Table 3.2 gives the yearly counts of High-resolution CTD casts for the World Ocean. Figure 3.1 shows the time series of the yearly totals of CTD casts for the World Ocean. There are a total of 444,464 CTD casts for the entire World Ocean. Table 3.3 gives the national contribution of CTD casts. The geographic distribution of CTD casts for World Ocean is shown on Figure 3.2. Distribution of the CTD observations as function of standard depth levels is shown on Figure 3.3. The CTD dataset contains data from 2,478 high-resolution XCTD casts (see chapter 5)

Table 3.2. The number of CTD casts in WOD05 as a function of year.
The total number of casts = 444,464

YEAR	CASTS	YEAR	CASTS	YEAR	CASTS	YEAR	CASTS
1961	97	1972	3,279	1983	11,459	1994	22,761
1962	42	1973	5,113	1984	12,197	1995	20,882
1963	71	1974	7,509	1985	12,102	1996	15,371
1964	1	1975	6,964	1986	14,262	1997	19,627
1965	0	1976	8,215	1987	19,420	1998	18,536
1966	12	1977	8,383	1988	15,349	1999	16,624
1967	1,531	1978	10,363	1989	16,820	2000	13,954
1968	727	1979	9,680	1990	17,937	2001	13,448
1969	2,748	1980	9,544	1991	18,975	2002	10,364
1970	985	1981	12,004	1992	23,848	2003	5,703
1971	1,285	1982	9,947	1993	25,082	2004	1,243

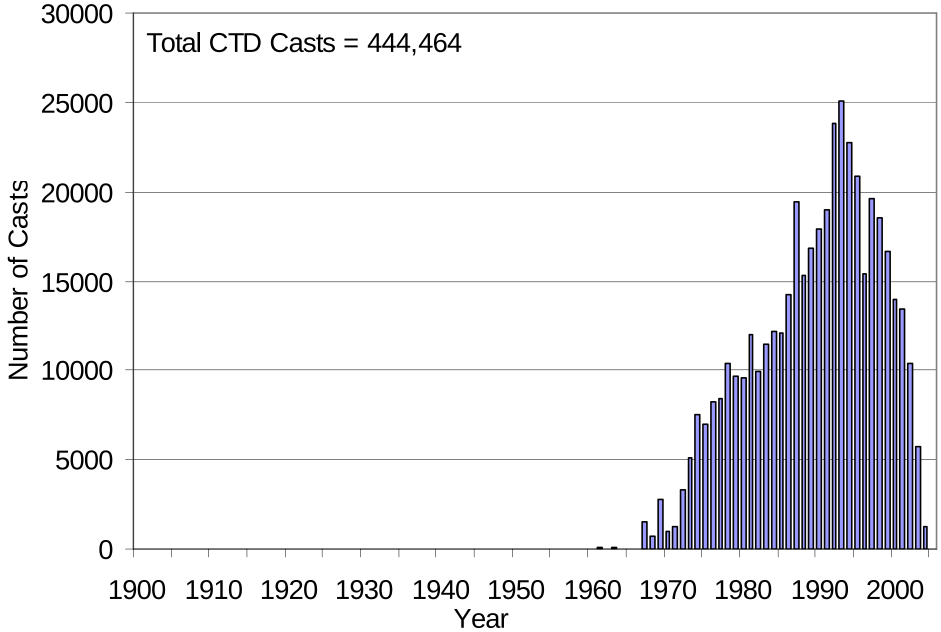

Figure 3.1. Temporal distribution of high-resolution CTD casts in WOD05.

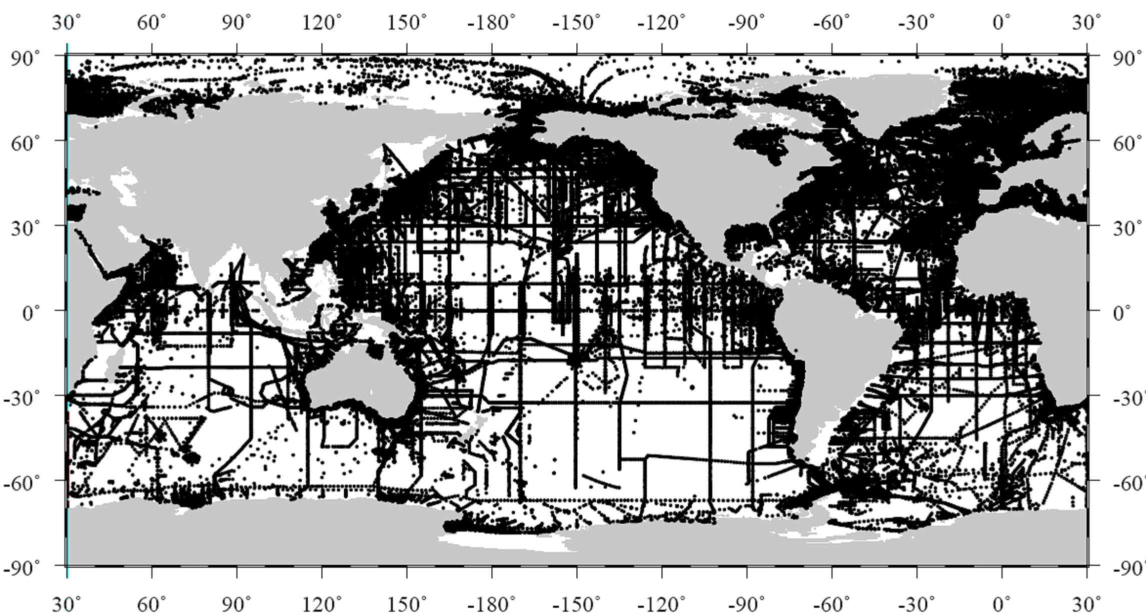

Figure 3.2. Geographic distribution of high-resolution CTD casts in WOD05.

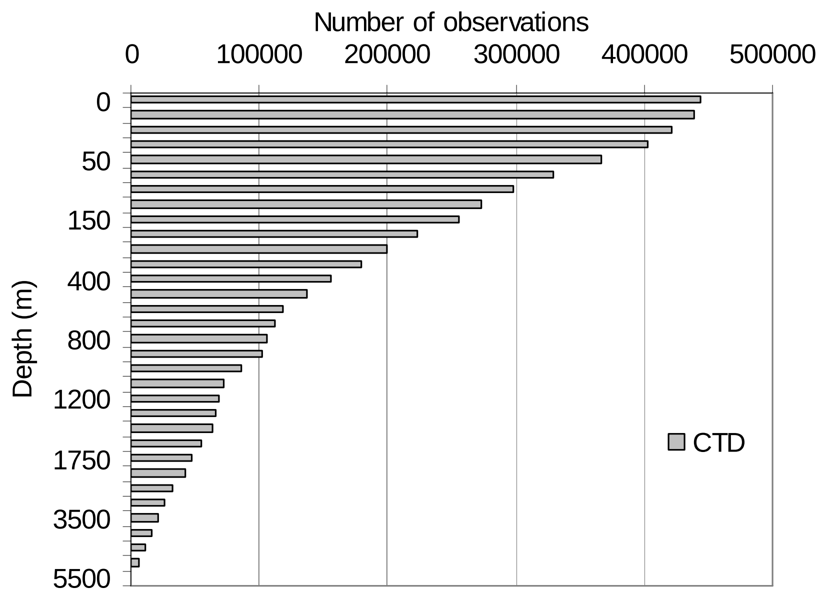

Figure 3.3. Distribution of high-resolution CTD data at standard depth levels in WOD05.

Table 3.3. National contributions of high-resolution Conductivity / Temperature / Depth (CTD) casts.

NODC Country Codes	Country Name	CTD Count	% of Total
31, 32, 33	United States	136,724	30.76
18	Canada	120,954	27.21
06, 07	Germany	31,241	7.03
35	France	25,891	5.83
21	Taiwan	23,744	5.34
58	Norway	16,096	3.62
90, RU	Union of Soviet Socialist Republics/Russia	14,214	3.20
09	Australia	12,387	2.79
74	United Kingdom	11,464	2.58
49	Japan	11,016	2.48
48	Italy	8,109	1.82
91	South Africa	6,357	1.43
20	Chile	6,067	1.37
29	Spain	5,207	1.17
76	China, The Peoples Republic of	2,772	0.62
26	Denmark	2,251	0.51
64	Netherlands	1,966	0.44
46	Iceland	1,816	0.41
67	Poland	1,546	0.35
68	Portugal	1,289	0.29
ZZ	Miscellaneous Organizational Units	564	0.13
24	Korea, Republic of	363	0.08
08	Argentina	354	0.08
36	Greece	336	0.08
34	Finland	251	0.06
28	Ecuador	217	0.05
11	Belgium	212	0.05
89	Turkey	199	0.04
47	Israel	195	0.04
42	Indonesia	159	0.04
41	India	143	0.03
61	New Zealand	102	0.02
65	Peru	74	0.02
99	Unknown	60	0.01
57	Mexico	59	0.01
77	Sweden	55	0.01
45	Ireland	10	<0.01
	Total	*444,464*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

3.4. TRANSMISSOMETER OBSERVATIONS

3.4.1. Introduction

Transmissometers measure the attenuation of well-collimated light of a given wavelength over a known distance in water. Light attenuation is due to both absorption and scattering. When referenced to pure water, the beam attenuation coefficient (BAC, referred to as c in following equations) defines light losses due to absorption by dissolved and particulate matter and from scattering by particles. Changes in the attenuation of light through water are related primarily to changes in the abundance of particles and secondarily to the type of particles present. The amount of light absorbed or scattered by different types of particles and colored dissolved organic matter (CDOM) also varies by wavelength and is affected by the composition of the particles, their size, shape, and internal index of refraction distribution (http://www.wetlabs.com/iopdescript/attenintro.htm).

The majority of transmissometer data presented in WOD05 were collected using instruments operated at 660 nm (red) wavelength. Attenuation is virtually independent of salinity (Richardson and Gardner, 1997). Most of the attenuation signal comes from particles less than 20 microns in diameter. Large particles and aggregates greater than 500 microns in diameter are not abundant in the ocean (*i.e.* DuRand and Olson, 1996; Stramski and Kiefer, 1991; Chung *et al.,* 1996; 1998). Typically only a few large particles exist in 1000 milliliters of water, so they rarely appear in the small sensing volume of the transmissometer (~45 milliliters). When they are present, they usually create a spike in attenuation.

The standard unit for storing beam attenuation coefficient values in WOD05 is determined as $c = ln\ (T_r)\ /\ r\ (m^{-1})$, where T_r is percentage of light transmitted through the instrument's path-length and calculated from a calibrated raw voltage signal measured by the instrument; r is the instrument's path-length (in m). It should be noted, however, that a significant amount (2579 profiles) of early submitted data are still in T_r and in raw voltage (301 profiles). Therefore, those data are not included into the WOD05 distribution but they are mentioned in following statistics and eventually will be converted to the standard units and added to the future releases of the database.

The BAC can be described as a sum of three components:

$c = c_w + c_{CDOM} + c_p$, where:

c_w – due to pure seawater → constant at 660 nm

c_{CDOM} – due to colored dissolved organic matter ≈ 0 at 660nm

c_p – due to particles.

Since attenuation is due to both absorption and scattering,

$a_p + b_p = c_p$

where: a = absorption, b = scattering

a_p - absorption by particles negligible at this spectral range (Bricaud *et al.,* 1998)

$b_p = b_{pf} + b_{pb}$ → forward & backward scattering

In the red part of the spectrum, attenuation due to dissolved materials is negligible, so that attenuation in the red is due primarily to particles. The beam attenuation coefficient in the red is an excellent proxy for the total volume of particles (Bartz *et al.,* 1978; Bishop, 1999; http://www.wetlabs.com/; http://www.hobilabs.com; http://www.chelsea.co.uk).

3.4.2. Spatial and Temporal Distribution of Transmissometer Profiles

Transmissometer profiles presented in WOD05 were collected during several international and U.S. national programs for the period of 1979-2001. The majority of data comes from the World Ocean Circulation Experiment (WOCE), Joint Global Ocean Flux Study (JGOFS), Bermuda Atlantic Time Series (BATS), Hawaiian Oceanographic Time Series (HOT), South Atlantic Ventilation Experiment (SAVE) and Northeast Gulf of Mexico (NEGOM) programs. Greater part of data was post-processed at Texas A&M University under grants from the U.S. National Science Foundation (NSF) (Chung *et al.,* 1996, 1998; Mishonov *et al.,* 2003; Mishonov and Gardner, 2003; Richardson *et al.,* 2003; Zawada *et al.,* 2005; Gardner *et al.,* 2006).

Figure 3.4.1 represents the geographical distribution of the transmissometer profiles in WOD05 for the World Ocean.

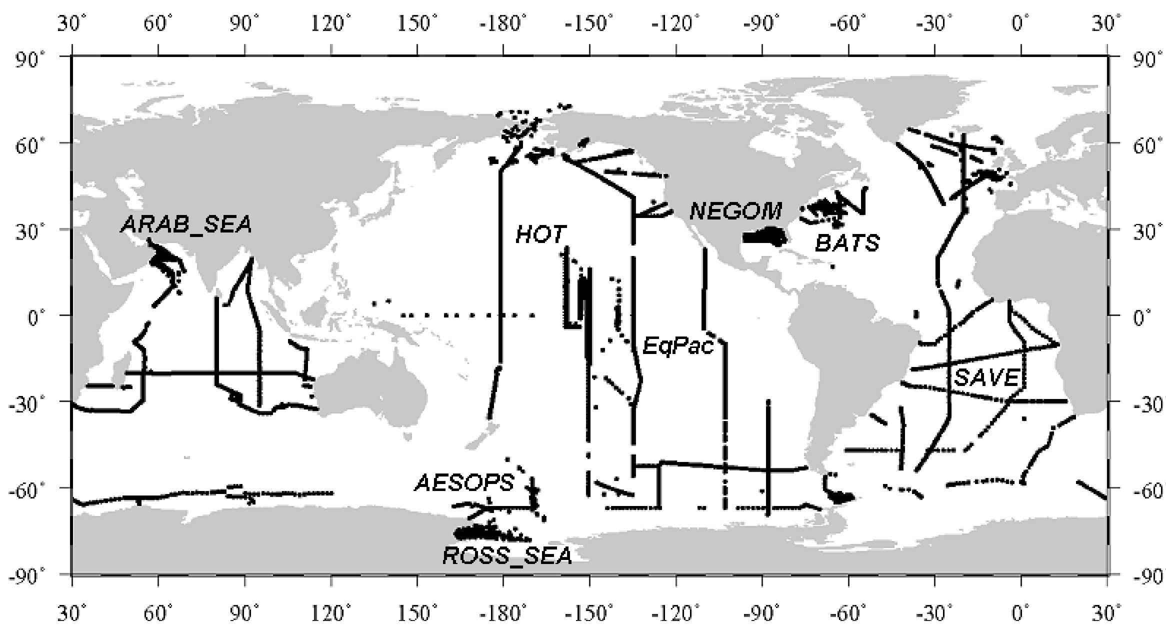

Figure 3.4.1. Geographic distribution of the BAC profiles in WOD05 with major contributing projects marked (unmarked basin-wide lines belong to the WOCE program).

Table 3.4.1 and Figure 3.4.2 present the temporal distribution of transmissometer profiles in WOD05 as a function of year.

Table 3.4.1. The number of BAC profiles in WOD05 as a function of year. The total number of profiles = 6,655

YEAR	PROFILES	YEAR	PROFILES	YEAR	PROFILES	YEAR	PROFILES
1979	284	1985	0	1991	388	1997	564
1980	2	1986	45	1992	621	1998	402
1981	0	1987	54	1993	711	1999	328
1982	1	1988	264	1994	432	2000	198
1983	75	1989	283	1995	1,576	2001	5
1984	0	1990	120	1996	282		

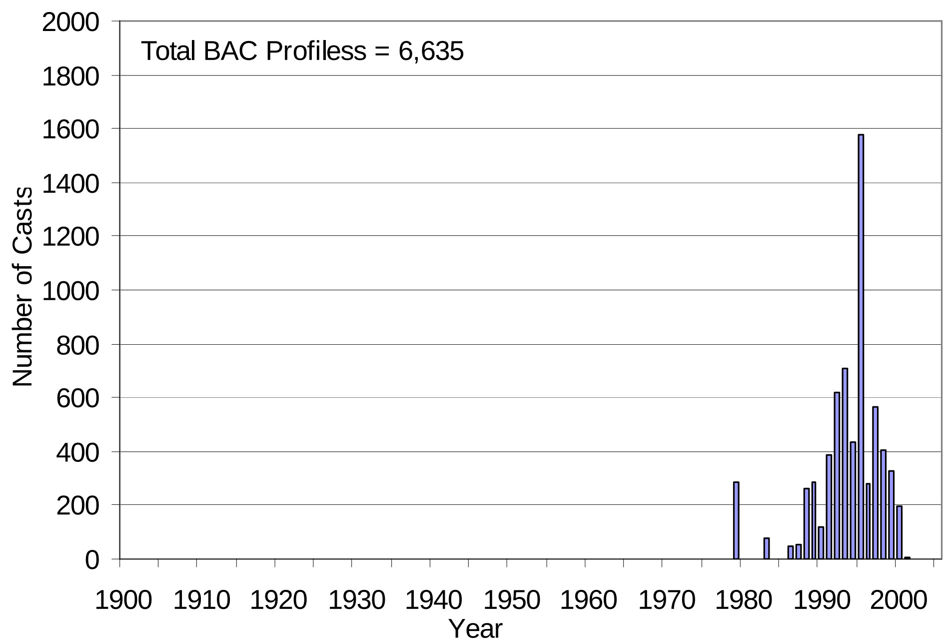

Figure 3.4.2. Temporal distribution of BAC profiles in WOD05.

3.4.3. Relevant Web Sites

World Ocean Circulation Experiment (WOCE): http://whpo.ucsd.edu/,

Joint Global Ocean Flux Study (JGOFS): http://usjgofs.whoi.edu/.

Bermuda Atlantic Time Series (BATS): http://w3.bbsr.edu/cintoo/bats/bats.html.

Hawaiian Oceanographic Time Series (HOT): http://hahana.soest.hawaii.edu/hot/hot_jgofs.html.

Northeast Gulf of Mexico Program (NEGOM): http://seawater.tamu.edu/negom/.

Global Transmissometer data base at Texas A&M University: http://oceanography.tamu.edu/~pdgroup/DataDir/SMP-data.html.

WetLabs, Inc.: http://www.wetlabs.com/.

HOBILabs, Inc.: http://www.hobilabs.com.

Chelsea Technologies Group: http://www.chelsea.co.uk.

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CHAPTER 4: EXPENDABLE BATHYTHERMOGRAPH DATA (XBT)

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4.1. INTRODUCTION

The Expendable Bathythermograph (XBT) was deployed beginning in 1966 and has replaced the Mechanical Bathythermograph (MBT) in most measurement programs. The XBT allows the measurement of the upper ocean's temperature profile when launched from underway surface ships, submarines, and aircraft. The system consists of three main components: an expendable measuring probe, a launcher, and an electronic data acquisition unit. The expendable probe includes a thermistor and a copper wire spool which unwinds as the probe falls through the water column. The temperature information from the thermistor is transmitted through the copper wire to the launcher on the platform. The launcher holds a second copper wire spool that unwinds as the platform continues its underway trajectory. Finally the temperature signal is sent from the launcher through a cable to the data acquisition system, where the data are monitored and recorded.

The system has different details when the expendable probes are launched from a submarine or from an aircraft. From a submarine, a float carries the expendable probe to the sea surface. Upon reaching the sea surface, the probe detaches from the float and start to falls through the water column. From an aircraft, the expendable probe and a floating surface unit are deployed with a parachute. After reaching the sea surface, the probe detaches from the floating unit and falls through the water column. The temperature information from the thermistor is transmitted through the copper wire to the floating surface unit which transmits the data to the acquisition system in the aircraft via a radio signal.

Of all the XBT profiles in WOD05, 43.4% were obtained with probes manufactured by Lockheed Martin Sippican (formerly known as Sippican), 1.4% were obtained with probes manufactured by Tsurumi Seiki Co. LTD (TSK), and 0.2% were obtained with probes manufactured by Sparton. There is no manufacturer information for the probe used for most of the XBT profiles, or 55.1%. Each manufacturer has several models of XBT probes which have different maximum sampling depths with the associated launching platform moving at or below the allowed maximum speed. As an example, Table 4.1 below shows the characteristics for some expendable probes produced by Lockheed Martin Sippican. The most popular model is the T-4, with about 25% of the XBT profiles in WOD05 known to be obtained with such a probe.

Table 4.1. Characteristics of expendable probes produced by Lockheed Martin Sippican.

Model	Maximum Depth	Rated Ship Speed
T-4	460 m	30 kts
T-5	1830 m	6 kts
Fast Deep™	1000 m	20 kts
T-6	460 m	15 kts
T-7	760 m	15 kts
Deep Blue	760 m	20 kts
T-10	200 m	10 kts
T-11	460 m	6 kts

The XBT system does not directly measure depth. The depth of a temperature measurement measured by the expendable probe is estimated using a depth-time equation. This equation converts the time elapsed from the moment the probe enters the water, in seconds, to depth, in meters.

4.2. XBT ACCURACY

Lockheed Martin Sippican reports temperature accuracy of ±0.1°C for their surface ship expendable probes and ±0.15°C for their submarine expendable probes, with a depth accuracy of ±2% for all probes. Tsurumi Seiki Co. LTD reports temperature accuracy of ±0.1°C and depth accuracy of ±2% or 5 m, whichever is larger.

4.3. XBT DEPTH-TIME EQUATION ERROR

Since the XBT system does not measure depth directly, the accuracy of the depth associated with each temperature measurement is dependent on the equation which converts the time elapsed since the probe entered the water to depth. Unfortunately, problems have been found in various depth-time equations used since the introduction of the XBT system.

The original depth-time equation developed by Sippican for their T-4, T-6, T-7, and Deep Blue models underestimates the probes fall rate. At a given elapsed time, the falling probe is actually deeper than indicated by the original equation. Thus, the water temperatures are associated by the original equation with depths that are shallower than the actual depths at which they are measured. The error, first documented by Flierl and Robinson (1977), increases with increasing elapsed time reaching 21 meters, or about a 2.5% error, for depths around 800 meters. Sippican's original equation was used by TSK for their T-4, T-6, T-7, and Deep Blue models, and by Sparton for their XBT-4, XBT-6, XBT-7, XBT-7DB, XBT-20, and XBT-20DB models.

In 1994, Hanawa *et al.* published an International Oceanographic Commission (IOC, 1994) report detailing a study of XBT fall rates using different probes manufactured by Sippican and TSK and dropped in different geographic locations. A new depth-time equation, the Hanawa *et al.* (1995) equation, was given, as well as an algorithm for correcting depths for existing data collected using the original equation. The report emphasized the need to continue to archive existing data with the original depth equation only, applying the correction when necessary for scientific research.

Sparton XBT-7 probes were studied by Rual *et al.* (1995) and Rual e*t al.* (1996). It was determined that the Hanawa *et al.* (1995) equation was suitable for use with these probes.

Thadathil *et al.* (2002), however, suggest that the Hanawa *et al.* (1995) equation is not valid for measurements in high-latitude low temperature waters.

Following the report of Hanawa *et al.* (1995) and IOC (1994), TSK altered their software between January and March 1996 to make the Hanawa *et al.* (1995) equation the default equation (Greg Ferguson, personal commmunication). Sippican did the same around August 1996, (James Hannon, personal communication). However an universal switch to the new software has not been made. As of mid-2005, data from XBT drops are recorded using both the original and Hanawa *et al.* (1995) depth-time equations.

Kizu *et al.* (2005) published a new depth-time equation for the TSK T-5 probes, but no manufacturer software has been released with their equation.

Corrections to the depth-time equations for air-dropped XBT probes (AXBT) manufactured by Sippican and Sparton were calculated by Boyd (1987) and Boyd and Linzell (1993b) respectively.

4.4. CORRECTIONS TO XBT DEPTH-TIME EQUATION ERRORS

Before the various depth-time equations errors were widely known, a significant amount of data were recorded and archived without notation of what type of expendable probe was used. About 55%, or 1.06 million, of the total 1.93 million XBT temperature profiles in WOD05 have "unknown" type of XBT instrument, Of these, 0.81 million are positively identified as coming from shipboard drops. The other 0.24 million were dropped from unknown platforms. These missing ancillary metadata make it very hard to know whether the reported depths for a particular XBT profile were obtained with an incorrect depth-time equation.

Presently, many XBT data are still recorded and archived with no indication of the depth-time equation used. This is particularly critical now, since there is more than one depth-time equation in use for many XBT types.

The XBT data in the WOD05 on observed levels use the original depth-time equations, unless otherwise indicated. Secondary header 33 indicates reported information on the depth equation used – see Johnson *et al.* (2006) for more information on WOD05 format and code descriptions. Secondary header 33 is set to 0 if the original depth-time equation was used for data collected after a corrected depth-time equation was introduced; it is set to 1 if the Hanawa et al. or another amended depth-time equation was used.

The XBT data in the WOD05 interpolated to standard levels uses the appropriate corrected depth when possible. Since more than half of all XBT profiles are of type unknown, a test was applied to these data to see if a depth correction was necessary. If the greatest reported depth is less than 840 meters, the largest realistic depth for the probes with underestimated fall rates, the depths were corrected using the Hanawa *et al.* (1995) equation. It was assumed that, following the IOC recommendation, data available in the WOD05 was received at NODC with depths calculated using the original equations unless otherwise noted.

The above assumption is not always valid for data collected since new depth-time equations became available on recording software released by each XBT manufacturer. For data collected since January 1996, if the depth-time equation used was not noted, the data were not corrected when interpolating to standard levels and were marked so as not to be used for depth sensitive calculations. Of a total of 300,434 XBT drops during the relevant time periods, there are 78,494 drops without depth-time equation information.

An attempt to ascertain the depth-time equation information was made by contacting the data originators. Most of the data originators are large data centers and the information could not be recovered. The actual values of the reported depths can be used to recognize the depth-time equation used, when the full depth trace is reported (Donald Scott, personal communication). Although most data received at NODC comes with only selected depth levels, when possible, this technique was used.

Secondary header 54 contains information on our decision on whether the depths need correction for each XBT given the criteria listed above. This secondary header also carries information on exactly which corrected depth-time equation should be used to recalculate the reported depth values.

IMPORTANT: THE OBSERVED LEVEL XBT DATA IN WOD05 ARE THE SAME DATA AS SUBMITTED BY THE ORIGINATORS. IF YOU ARE USING OBSERVED LEVEL XBT DATA FROM WOD05, PLEASE USE SECONDARY HEADER 54 TO SEE WHETHER A DEPTH CORRECTION IS NECESSARY.

THE STANDARD LEVEL XBT DATA IN WOD05 WERE PREPARED, WHEN NEEDED AND POSSIBLE, USING A CORRECTED DEPTH-TIME EQUATION. IF YOU ARE USING STANDARD LEVEL XBT DATA FROM WOD05, PLEASE USE SECONDARY HEADER 54 TO SEE WHETHER A CORRECTED DEPTH-TIME EQUATION WAS USED, A CORRECTION WAS NOT NEEDED, OR A CORRECTION COULD BE NEEDED BUT THERE WAS NOT ENOUGH INFORMATION.

4.5. SURFACE DATA ACQUIRED CONCURRENTLY WITH XBT CASTS

On a surface ship sometimes a sea-surface water sample is obtained at the time of the XBT launch. Temperature and salinity of the water sample are usually measured and recorded as ancillary information of the XBT launch. Meteorological conditions at the time of the XBT launch could also be recorded, *e.g.* air temperature, wind speed and direction, cloud type and cover, barometric atmospheric pressure, as well as sea conditions: wave height and direction, sea state.

4.6. XBT PROFILE DISTRIBUTIONS

Table 4.2 gives the yearly counts of XBT profiles for the World Ocean. Fig. 4.1 shows the time series of the yearly totals of Expendable Bathythermograph profiles for the World Ocean, southern hemisphere oceans, and northern hemisphere oceans respectively. There are a total of 1,930,399 XBT profiles for the entire World Ocean with 347,097 profiles (18.0%) measured in the southern hemisphere and 1,583,302 profiles (82.0%) measured in the northern hemisphere. Table 4.2 gives national contributions of XBT sorted by contribution from each country.

Table 4.2. The number of all XBT profiles as a function of year in WOD05.
Total Number of Profiles = 1,930,399

YEAR	PROFILES	YEAR	PROFILES	YEAR	PROFILES	YEAR	PROFILES
1966	1,747	1976	48,461	1986	75,069	1996	55,614
1967	9,390	1977	54,459	1987	71,648	1997	48,077
1968	26,671	1978	53,375	1988	62,179	1998	42,041
1969	34,319	1979	56,291	1989	44,198	1999	47,121
1970	44,411	1980	55,136	1990	80,021	2000	30,730
1971	57,616	1981	54,916	1991	69,458	2001	16,637
1972	53,215	1982	55,978	1992	64,101	2002	13,169
1973	54,940	1983	58,979	1993	68,036	2003	18,545
1974	54,966	1984	55,812	1994	66,385	2004	26,485
1975	54,539	1985	68,690	1995	74,968	2005	2,006

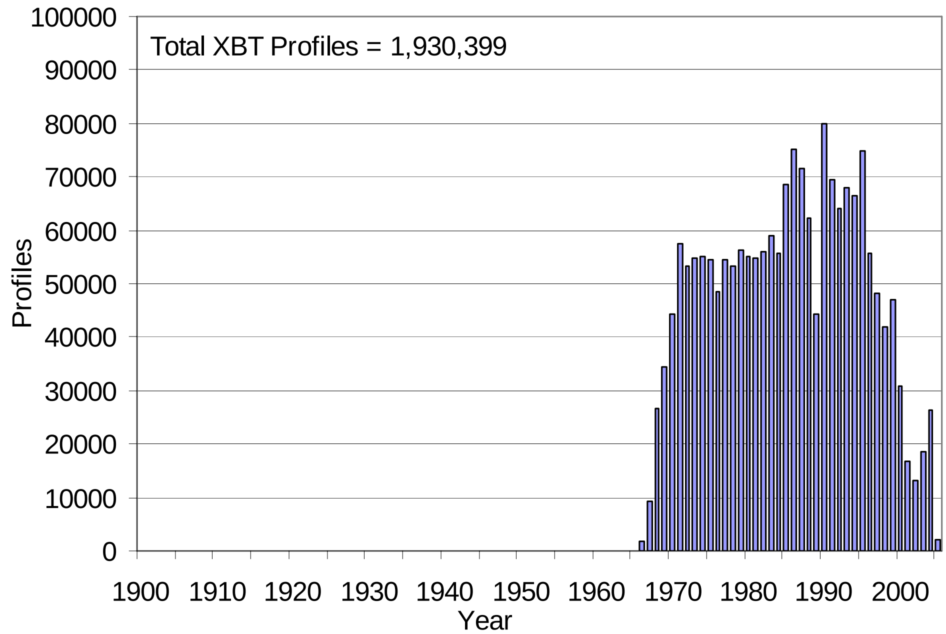

Figure 4.2. Temporal distribution of Expendable Bathythermograph (XBT) profiles in WOD05.

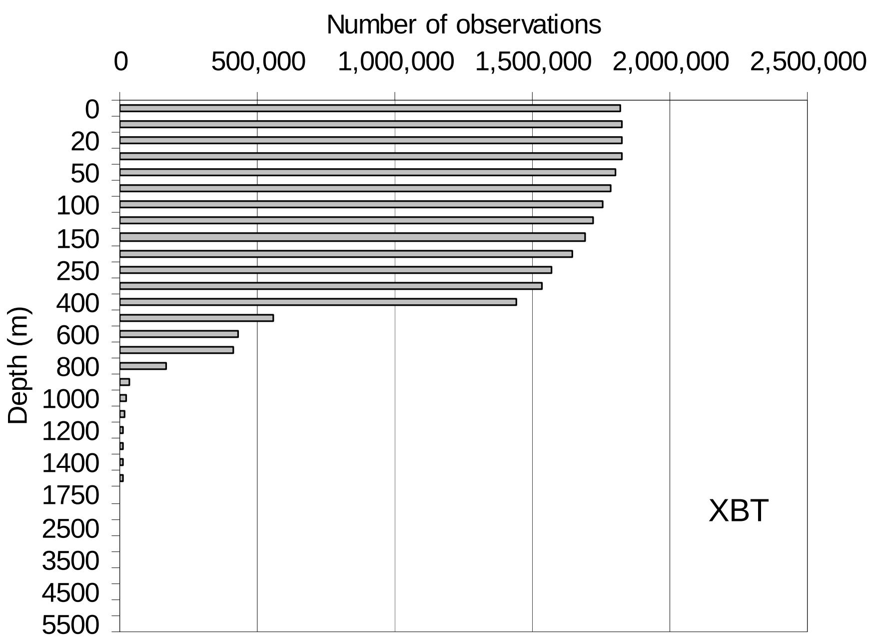

Figure 4.3. Distribution of Expendable Bathythermograph (XBT) data at standard depth levels in WOD05.

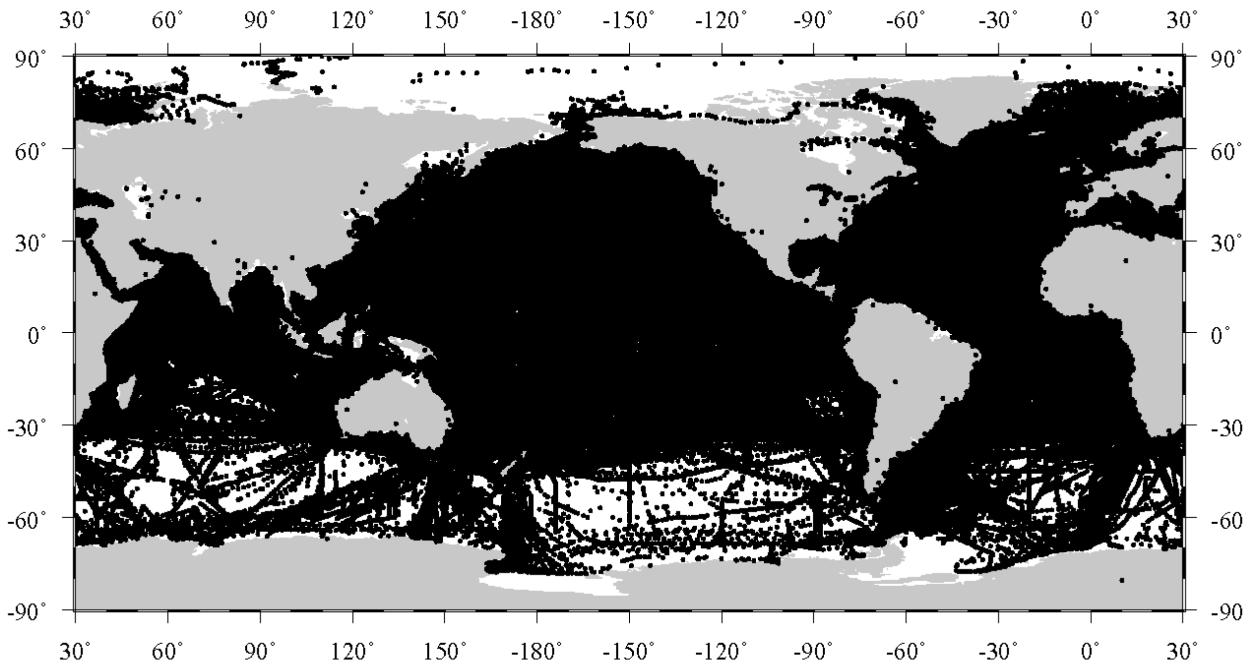

Figure 4.4. Geographic distribution of XBT profiles in WOD05.

Table 4.3. National contribution of XBT profiles in WOD05.

NODC Country Code	Country Name	XBT Count	% of Total
31, 32, 33	United States	819,805	42.46
49	Japan	285,786	14.80
74	United Kingdom	194,086	10.05
99	Unknown	150,236	7.78
09	Australia	88,500	4.58
06	Germany, Federal Republic of	62,611	3.24
18	Canada	50,384	2.61
35	France	49,465	2.56
54	Liberia	41,994	2.18
PA	Panama	37,823	1.96
SI	Singapore	16,083	0.83
90, RU	Union of Soviet Socialist Republics/Russia	14,495	0.75
64	Netherlands	14,251	0.74
BH	Bahamas	9,882	0.51
AG	Antigua	8,501	0.44
91	South Africa	8,297	0.43
26	Denmark	7,870	0.41
58	Norway	7,256	0.38
SV	Saint Vincent	5,598	0.29

NODC Country Code	Country Name	XBT Count	% of Total
61	New Zealand	5,593	0.29
76	China, The Peoples Republic of	4,810	0.25
46	Iceland	4,574	0.24
77	Sweden	4,552	0.24
BA	Barbados	3,236	0.17
HK	Hong Kong	3,210	0.17
CY	Cyprus	3,115	0.16
29	Spain	2,995	0.16
20	Chile	2,438	0.13
TN	Tonga	2,328	0.12
66	Philippines	2,298	0.12
57	Mexico	2,234	0.12
08	Argentina	2,213	0.11
KU	Kuwait	1,812	0.09
67	Poland	1,320	0.07
48	Italy	1,219	0.06
42	Indonesia	1,214	0.06
36	Greece	1,174	0.06
FJ	Fiji Islands	866	0.04
21	Taiwan	743	0.04
68	Portugal	732	0.04
65	Peru	714	0.04
ML	Malta	713	0.04
28	Ecuador	492	0.03
MH	Marshall Islands	463	0.02
41	India	362	0.02
14	Brazil	345	0.02
95	Yugoslavia	306	0.02
89	Turkey	220	0.01
SA	Saudi Arabia	197	0.01
ZZ	Miscellaneous Organizational Units	195	0.01
92	Uruguay	146	0.01
WS	Western Samoa	94	<0.01
MS	Malaysia	83	<0.01
MA	Mauritius	77	<0.01
07	Germany, Democratic Republic of	67	<0.01
55	Malagasy Republic	62	<0.01
24	Korea, Republic of	53	<0.01
IC	Ivory Coast	43	<0.01
UR	Ukraine	33	<0.01

NODC Country Code	Country Name	XBT Count	% of Total
22	Colombia	32	<0.01
86	Thailand	29	<0.01
CR	Costa Rica	29	<0.01
HR	Croatia	16	<0.01
HO	Honduras	12	<0.01
SC	Seychelles	11	<0.01
TT	Trinidad/Tobago	6	<0.01
	Total:	*1,930,399*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

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CHAPTER 5: EXPENDABLE CONDUCTIVITY-TEMPERATURE-DEPTH DATA (XCTD)

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5.1. INTRODUCTION

An Expendable Conductivity, Temperature and Depth (XCTD) is an ocean profiling instrument, which usually consist of a data acquisition system onboard the ship, a launcher, and an expendable probe with electronics, a temperature sensor, and a conductivity sensor (http://www.ifremer.fr/ird/soopip/xctd_probes.html). Probes can be launched from ships, submarines, and airborne platforms. The earliest XCTD data in WOD05 were collected in 1993, and comprise 15 casts launched from the U.S. nuclear submarine *Pargo* on her first civilian oceanographic cruise in the Arctic Ocean (Morison *et al.,* 1998) in the framework of the Scientific Ice Expeditions Program (SCICEX). In total 784 casts collected during SCICEX are included in WOD05.

The XCTD itself consist of a falling probe, which is linked to the acquisition system through a thin insulated conductive wire which is used to transmit the temperature and conductivity data back to the acquisition system in real time. Depth is estimated from the elapsed time between when the probe enters the water and the time each temperature measurement is made using a fall rate equation. As a rule, a vendor supplied drop-rate equation is utilized. Processed profile data can be transmitted in real-time through satellite (*e.g.* INMARSAT). Profiles as deep as 1500m and comprising data points every meter can be made: with 4Hz sample rate and roughly 3.2 $m \cdot s^{-1}$ fall velocity, XCTD data will be recorded every 0.8m (Johnson, 1995). Most recent probes, however, are able to sample every 40ms, which approximately equal to 14 cm interval in depth (Mizuno and Watanabe, 1998).

Over the years of collection, XCTD data were submitted in WOD05 in both higher and lower vertical resolution formats, therefore these data are stored in two WOD05 databases: higher resolution data resides in the CTD dataset (2,478 XCTD casts), and lower resolution data resides in the OSD dataset (864 casts).

5.2. XCTD PRECISION AND ACCURACY

The accuracy of XCTD data depends on the probe used and usually is: for temperature ±0.02°C, for conductivity ±0.03 mS·cm^{-1} and for depth 2%. System response time is 40 mSec for conductivity and 100 mSec for temperature (TSK XCTD probe specification; Sippican Inc. web-site). If these errors are correlated the salinity error could be as high as ±0.08, otherwise a salinity accuracy of ±0.05 is expected (Johnson, 1995). Similar numbers were also reported by Mizuno and Watanabe (1998).

Since the XCTD instrument is still in a relatively early stage of development, some problems with data accuracy may exist. Early comparison of the XCTD data with CTD performed by Sy (1993) revealed that "test results conclusively show that XCTD probes do not meet the manufacturer's specification". A test of modified probes indicated: a) "that the XCTD sensor accuracies are better than ±0.02°C and ±0.04 mS·cm^{-1} without any correction for the conductivity offset" (Alberola *et al.,* 1996); b) that "the system is close to the point of meeting the claimed specification" (Sy, 1996); and c) that "the system is close to providing the performance required by the oceanographic community for upper ocean thermal and salinity investigation" (Sy, 1998). A good example of utilizing XCTD data is demonstrated by Sprintall and Roemmich, (1999).

5.3. XCTD DROP-RATE ERROR

The XCTD instrument does not measure pressure or depth directly. The depth of the instrument is computed from the elapsed time from when the probe enters the water through use of a fall-rate equation. Research conducted by Jonhson (1995) reveal that the manufacturer-supplied fall-rate coefficients give too slow a descent for some probes. Similar data were shown by Alberola *et al.,* (1996). Therefore, revised fall-rate equations were introduced (Johnson, 1995; Mizuno and Watanabe, 1998).

Depth-correction algorithm was applied to XCTD data while computing temperature and salinity values at standard depth levels. For that purpose depth values were first recalculated back to elapsed time and then two different manufacturer-dependant depth equations were used for adjusted depth calculation.

For data collected by Sippican instruments equation of Jonhson (1995) was used. To indicate that data were subject of such treatment, secondary header code #54 was set to 103. Following procedure and parameters were employed:

$$t = (s_1 \cdot d_x + s_2) - s_3$$

$$d_z = s_a \cdot t + s_b \cdot t^2$$

where: s_1 = 0.30731408, s_2 = 6.707·e^{-9}, s_3 = -8.1899·e^{-5}; s_a = 3.227, s_b = -2.17e^{-4}; t – time since drop (seconds); d_x – originally calculated depth (meters); d_z – new calculated depth (meters).

For data collected by TSK instruments equation of Mizuno and Watanabe (1998) was used. To indicate that data were subject of such treatment, secondary header code #54 was set to 104. Following procedure and parameters were employed:

$$t = (t_1 \cdot d_x + t_2) - t_3$$

$$d_z = t_a \cdot t + t_b \cdot t^2$$

where: $t_1 = 0.29585798$, $t_2 = 1.002 \cdot e^{-9}$, $t_3 = -3.1658 \cdot e^{-5}$; $t_a = 3.426$, $t_b = -4.70 \cdot e^{-4}$; t – time since drop (seconds); d_x – originally calculated depth (meters); d_z – new calculated depth (meters).

5.4. XCTD CAST DISTRIBUTIONS

Table 5.1 gives the yearly counts of XCTD profiles for the World Ocean. Figure 5.1 shows this graphically. There are a total of 3,322 XCTD profiles for the entire World Ocean (2,458 in CTD and 864 in OSD) in WOD05. Table 5.2 gives national contributions of XCTD data to WOD05. The geographic distribution of XCTD casts is shown on Figure 5.2.

Table 5.1. The number of XCTD casts in WOD05 as a function of year CTD/OSD[1]. Total Number of casts = 3,322.

YEAR	CAST	YEAR	CASTS	YEAR	CASTS	YEAR	CASTS
1993	15	1996	104	1999	310	2002	421
1994	0	1997	131	2000	439/440	2003	466
1995	114	1998	166/1	2001	277/423	2004	215

[1] CTD – high-resolution casts; OSD – low-resolution casts

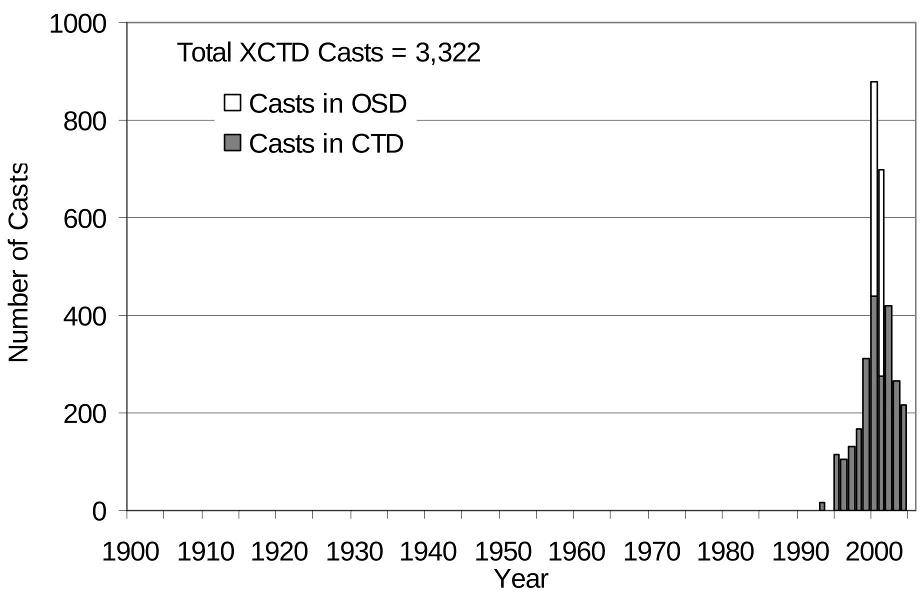

Figure 5.1. Temporal distribution of XCTD casts in WOD05.

Table 5.2. National contributions of XCTD casts in WOD05.

NODC Country Code	Country Name	XCTD Casts	% of Total
49	Japan	1,604	48.28
31, 33	United States	1,106	33.29
99	Unknown	541	16.29
76	China	71	2.14
	Total	*3,322*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

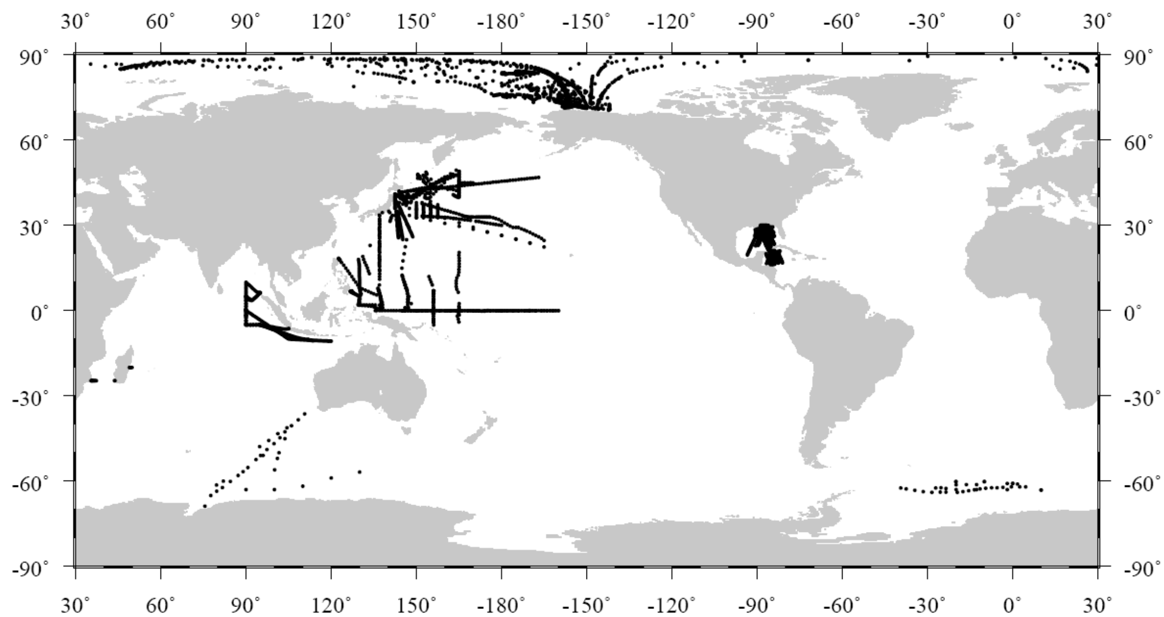

Figure 5.2. Geographic distribution of XCTD casts in WOD05.

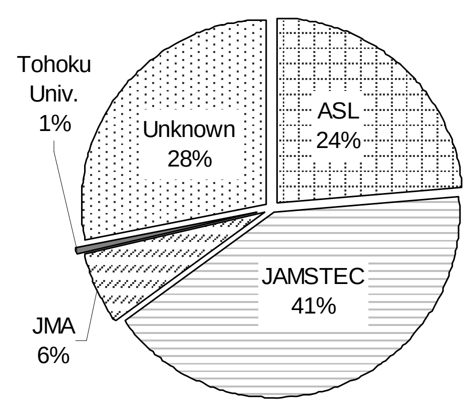

Figure 5.3. Contribution of XCTD casts from different institutions.

The majority of XCTD data were collected and submitted by several institutions: Arctic Submarine Laboratory (ASL US, 784 Casts), Ocean Research Department of Japan Marine Science and Technology Center (JAMSTEC, 1,377 casts), Japan Meteorological Agency (JMA, 207 casts), and Tohoku University (Japan, 19 casts). A significant amount of casts (955) have no information about submitting institution. Figure 5.3 illustrates distribution of the XCTD data among the contribution institutions. Figure 5.4 illustrates the distribution of the XCTD data as a function of depth at standard depth levels.

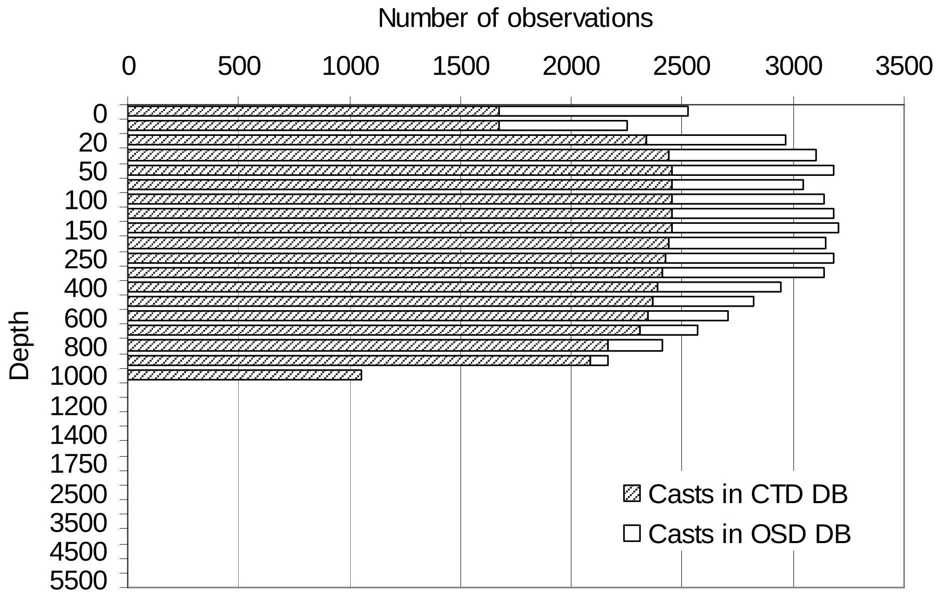

Figure 5.4. Distribution of XCTD data in WOD05 at standard depth levels.

5.5. RELEVANT WEB SITES

Arctic Submarine Laboratory (ASL): http://www.csp.navy.mil/asl/.

Japan Marine Science & Technology Center (JAMSTEC): http://www.jamstec.go.jp/jamstec-e/index-e.html.

INMARSAT: http://www.inmarsat.com/

Japan Meteorological Agency (JMA): http://www.jma.go.jp/jma/indexe.html.

Tohoku University: http://www.tohoku.ac.jp/english/index.html.

Ship Of Opportunity Programme (SOOP): http://www.ifremer.fr/ird/soopip/xctd_probes.html.

The Tsurumi Seiki Co., Ltd: http://www.tsk-jp.com/

TSK XCTD probe specification. Available at: http://tsk-jp.com/tska/PDF_Files/Expendable%20Systems.pdf.

Lockheed Martin Sippican, Inc.: www.sippican.com

Scientific Ice Expeditions Program (SCICEX): http://www.ldeo.columbia.edu/res/pi/SCICEX/.

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CHAPTER 6: PROFILING FLOATS DATA (PFL)

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6.1. INTRODUCTION

Profiling floats are autonomous vehicles equipped with oceanographic sensors which measure vertical profiles of oceanographic variables. These vehicles float passively at a preprogrammed pressure level and then rise to the ocean surface at a predetermined time interval to broadcast collected information to a satellite. Satellite technology is used to record the float position as well as date and time of receipt of the data. The float's collected information consists of measurements taken by sensors on the trip to the surface, and in some cases on the preceding dive. Several different sensors may be attached to the profiling float. However, compromises must be made between the weight and power usage of the sensors and the intended lifetime of the profiling float's battery. Most profiling floats are equipped with pressure, temperature, and conductivity sensors (for calculating salinity). Oxygen sensors have also been deployed, as well as transmissometers, optical irradiance sensors, velocity meters, even rainfall and wind speed sensing instrumentation. Only measurements of pressure, temperature, salinity, and oxygen are included in the PFL dataset of the *World Ocean Database 2005* (WOD05). Oxygen sensors are relatively new for profiling floats, so there are very few oxygen profiles from PFL instruments in WOD05.

The float's active movement is achieved by changes its buoyancy using external bladders. Oil is pumped from an internal chamber to an external bladder, increasing volume and decreasing density, to force the float to rise to the surface. Oil is then pumped from the external bladder back into the float casing to decrease the volume, increasing the density to the point where the float will sink until it achieves a neutral density commensurate with the pressure level at which it will passively move.

Floats are relatively low cost. Davis *et al*. (2001) calculate that they are equivalent in cost per profile (temperature only) to an XBT. But their value is much greater since they also measure salinity and are able to measure during any sea or weather condition (with the partial exception of ice cover). Profiling floats are adding measurements in geographic regions and seasons for which little, if any data were previously available.

6.2. PREDECESSORS OF PROFILING FLOATS

The precursors of the present profiling floats were neutrally buoyant floats used to track currents at a predetermined level in the ocean. These floats did not measure temperature or conductivity. The first neutrally buoyant floats were designed and deployed by Swallow (1955). These floats sunk to their neutrally buoyant level in the water column and were then tracked by a nearby surface ship. The Swallow floats were used to verify the deep western boundary current predicted by Stommel (1957) (Swallow and Worthington, 1961). In the late 1960s, the SOFAR (Sound Fixing And Ranging) float was developed (Webb and Tucker, 1970; Rossby and Webb, 1970). This was similar to a Swallow float. They differed in that the float was tracked by underwater listening devices which picked up sound emitted by the floats at intervals which allowed geolocation. The listening devices did not have to be in close proximity to the float, eliminating a major limitation of the Swallow float. Further advances led to the RAFOS floats which reversed the geolocation procedure of the SOFAR floats by having the float listen for signals emitted by stationary underwater devices (Rossby *et al*., 1986). The RAFOS float was smaller than the SOFAR float since it did not need to emit sound, and therefore it was less expensive to deploy. However, it still required a network of sound sources.

6.3. FIRST PROFILING FLOATS

One of the objectives of the World Ocean Circulation Experiment (WOCE, active fieldwork period 1990-1998) was to estimate the mean flow of the World Ocean. To set up a worldwide system of sound sources to achieve this objective using RAFOS floats would have been prohibitively expensive. The Autonomous LAgrangian Circulation Explorer (ALACE) floats (Davis *et al*., 1992) were the implemented solution. First operationally deployed in the Drake Passage in 1990, these floats eliminated the need for sound sources by surfacing periodically to be geolocated by ARGOS satellites. The tradeoff for manageable costs were small uncertainties introduced in the velocity at depth due to drift while ascending and descending the water column and while broadcasting their signal at the surface. From here it was a logical step to introduce oceanographic sensors onto the ALACE float to record temperature and salinity during the floats ascent to the surface. In 1991, the first temperature sensors were deployed on ALACE floats, making them Profiling ALACE floats (P-ALACE floats), and in 1994 both temperature and salinity sensors were deployed together (Davis *et al*., 2001).

6.4. PRESENT FLOAT TECHNOLOGY

Further improvements to the P-ALACE float design were made. Float R1, by Webb Research was introduced at the request of Dr. Steve Riser in 1996 (personal communication Dan Webb). It was replaced by its successor, the Autonomous Profiling EXplorer (APEX) by Webb Research, which is still in use today. Since 1997, APEX floats have been deployed from merchant vessels moving at speeds up to 25 knots, removing the need to employ research vessels in some areas. Since 1999, deployment has taken place from C130 Aircraft by the U.S.

Naval Oceanographic Office (NAVOCEANO). Other second generation floats include the Sounding Oceanographic Lagrangian Observer (SOLO), developed at Scripps Institute of Oceanography. This float replaced the P-ALACE floats reciprocating high pressure pump with a single stroke hydraulic pump (Davis *et al.*, 2000) (The APEX uses a similar pump). This advance allowed the SOLO to more easily reach a desired isobar or isotherm and to cycle between subsurface depths before ascending to the surface. The MARVOR float was created by the Institut Francais de REcherche de la MER (IFREMER) and Teklec (now Martec), a French engineering firm, within the framework of the WOCE program. MARVOR floats use the same geo-location principle as RAFOS floats, but they also cycle to the surface to send data to ARGOS satellites. As the P-ALACE was the profiling version of the ALACE float, the PROVOR is the profiling version of the MARVOR float (Loaec *et al*., 1998). MARVOR floats have been deployed since 1994, PROVOR floats since 1997. Both Martec and Metocean (Canada) now produce PROVOR floats on the same design. MARVOR/PROVOR floats operate on the same bladder/buoyancy principles as the ALACE floats. PROVOR floats have the added ability to record and store oceanographic profile data on their descent as well as their ascent. The Japanese Agency for Marine-Earth Science and Technology (JAMSTEC) and Tsurumi Seiki Co. (TSK) have developed and deployed the New profilINg floats of JApan (NINJA) (Ando *et al.*, 2003) beginning in 2002. Navigating European Marine Observer (NEMO) floats have been deployed in the Southern Ocean starting in early 2004 by the Alfred Wegner Institute (AWI, Germany). These floats are based on the SOLO design and are equipped with algorithms based on temperature measurements which help them avoid surfacing in ice covered areas. NEMO floats combine this ability with RAFOS positioning, extending the reach of profiling floats to ice-covered regions. Figure 6.1 shows the relative distribution of each type of profiling float in WOD05.

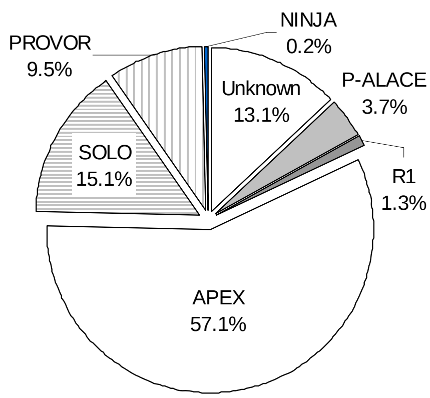

Figure 6.1. Casts from different types of profiling floats.

6.4.1. The Argo Project

The Argo project is an umbrella project which coordinates the deployment, quality control, and public access for profiling float data. Argo is not an acronym, it refers to the relationship between the JASON altimeter measuring sea surface heights and the Argo floats revealing the subsurface structure, evoking Jason and his ship the Argo from Greek mythology (Gould, 2005). Since the year 2000, nearly all data from deployed floats are available through this project. Floats are deployed by individual countries, projects, and institutions, usually with some level of coordination with Argo. Most float data is captured from the ARGOS satellites by the Argo Data Assembly Centers (DACs) and placed on the World Meteorological Organization (WMO) Global Telecommunications System (GTS) within 24 hours. These data are also relayed in near-real-time to the two Argo Global Data Assembly Centers (GDACs), the French Coriolis Center at IFREMER, and the U.S. Global Ocean Data Assimilation Experiment

(GODAE) server in Monterrey, California hosted by the U.S. Navy. Within 24 hours the data are made available to the public through these sites as well. Preliminary quality checks are performed at the DACs on the incoming data. These data are the real time data. Further quality control is performed at the DACS, the GDACs, at regional centers, and by the primary investigators responsible for the floats. A delayed mode version of the data is then released. **WOD05 only contains real-time data**, for reasons explained below under data problems. Each float is assigned a WMO identification number for easy identification. Meetings and workshops on data quality control, data access, and scientific research with floats have been held to keep the scientific community informed and coordinate responses and solutions to quality control and access problems. The goal of Argo is to deploy and maintain a global array of profiling floats to monitor the large scale circulation of the world ocean, as well as its heat and fresh water content. With this stated goal, pressure, temperature and salinity sensors are the only necessary oceanographic sensors, although floats may be equipped with other sensors. Argo is well on its way to the target of 3000 floats deployed, with 2461 as of the end of March, 2006. The preference is for the floats to deliver profiles from 2000 decibars to the surface every 10 days. Since the floats are deployed for other specific research goals, the parking depth (depth of passive motion) may not be at 2000 decibars. In fact, the recommended parking depth for Argo is 1000 decibars. However, the float should descend to 2000 decibars before beginning to record temperature and salinity. Some floats cycle to the surface at intervals other than 10 days.

The profiling float data in WOD05 consists of data from the WOCE project, data from the Global Temperature and Salinity Profile Project (GTSPP), which is an archive for data from the GTS, and the U.S. GODAE server. Since the Coriolis and GODAE data are synchronized, there should be no differences between the two data sets. Figure 6.2 shows the relative distribution from each data set (Total 168,988 casts as of Feb. 8, 2005). Float data in *World Ocean Database* 2001 (WOD01) were all from GTSPP. These were replaced, when possible, by WOCE and Argo data, as these data have additional quality control.

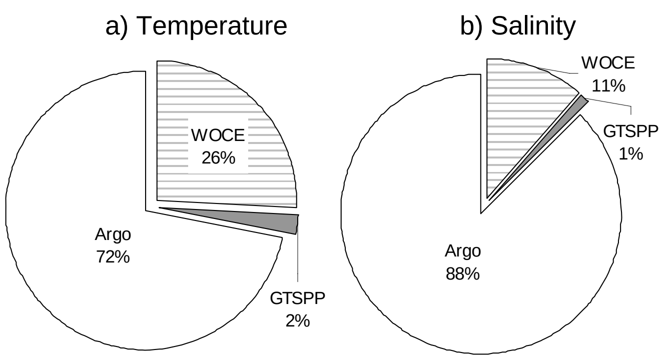

Figure 6.2. PFL data contributions from different sources.

6.5. SENSOR ACCURACY

The temperature and salinity data from the profiling floats come from various CTD sensors. The P-ALACE floats used an YSI 46016 thermistor, with estimated precision of 0.005°C, and a Falmouth Scientific Inc. (FSI) conductivity sensor with an estimated accuracy of 0.01 $mS \cdot cm^{-1}$ (milliSiemens·centimeter^{-1}). The pressure sensor used was a Paine strain gauge sensor. The sensor had hysteresis errors of order 5 meters initially, which were later reduced by thermally isolating the sensor (Davis *et al*., 2001). To reduce pressure reading errors, Seabird replaced the Paine strain gauge pressure sensor in their CTDs with a Druck pressure sensor (see Data Problems section, below). Later floats used FSI CTD sensors or CTD sensors from Seabird. The Seabird sensors have 0.002°C temperature accuracy, 0.005 salinity accuracy, and 2.4 db pressure accuracy. The NINJA uses a TSK CTD with 0.001 $S \cdot m^{-1}$ and 0.01°C accuracy for conductivity and temperature respectively. All accuracy data are from the product specifications (except the P-ALACE thermistor information from Davis *et al*. 2001). Seabird specifications are for Seabird-41 CTD for ALACE floats.

For oxygen measurements, the Aanderaa 3835 oxygen sensor has accuracy of 8 μM or 5%, whichever is greater. Accuracy of the Seabird-43 oxygen sensor is 2% of saturation. These values are from the product specifications. Kortzinger and Schimanski (2005) discuss oxygen measurements from profiling floats.

6.6. DATA PROBLEMS

Data problems are of two types: 1) Sensor problems, 2) Data stream errors. Each will be examined separately.

6.6.1. Sensor problems

The biggest persisting challenge for profiling float sensors is salinity drift. Conductivity cells are calibrated against samples of standard seawater before deployment of the float. However, even over the course of a short oceanographic cruise, the conductivity sensor on a standard winch-deployed CTD can experience slowly increasing unidirectional errors (drift) due to biofouling and small changes in cell geometry. Profiling floats are designed to be almost constantly immersed in the harsh ocean environment for four years. Therefore, it is to be expected that the conductivity sensor on a float will experience drift. Oka (2005) estimated a salinity drift of -0.016 ± 0.006 per year from recalibration of three floats recovered after 2-2.5 years of deployment. From examining the extant float data, some floats can experience much larger drifts, or even abrupt deviations from calibration. A number of algorithms for correcting for drift have been proposed (Wong *et al*., 2003 [WJO]; Bőhme and Send, 2005 [BS]; Durand and Reverdin 2005). The Argo delayed-mode data are corrected for drift using either the WJO or BS algorithms, depending on the DAC which is making the correction. Both algorithms correct the drift based on a reference dataset of historical oceanographic data. Only 20% of data are available in delayed mode as of March, 2006, and the values of the delayed mode data are not yet final (Minutes of 6th Argo Data Management Meeting, 2005). For this reason, **only the real-time Argo data are available in WOD05.** This means that there is no correction for salinity drift in WOD05. Many data which have large drifts have been flagged in automatic quality control checks. Many more were flagged subjectively by inspection to find the point at which salinity drift became unacceptably large.

A partial solution to the salinity drift problem is the application of biocide to the sensor. This has worked well to reduce salinity drift, but also has introduced another problem. Some floats have errors in the salinity due to ablation of the biocide. These errors usually disappear after the first 10 profiles (personal communication, S. Riser).

In 2003, it was found that problems with the Druck Pressure Sensor were causing some floats to stay at the surface for prolonged periods and eventually to become surface drifters. The Druck Pressure Sensor is the successor to the Paine pressure sensor in Seabird CTDs. Even when not severe, the problem may have caused errors in the salinity measurement due to increased biofouling due to prolonged surface exposure. When the problem was found, the CTDs were recalled and the source of the problem was fixed, but this was not possible for floats already deployed.

During a normal transmission to satellite, a float needs to stay at the surface up to 12 hours. This is where much of the biofouling occurs. Some floats have been equipped to communicate with two-way communicating satellites from Iridium. Two-way communication cuts down on the need for repeated rebroadcasts of the same message, since the broadcasting float can be notified of receipt of the message. This cuts down on surface time. The problem is that Iridium is an expensive alternative.

Another identified problem is a thermal lag caused because the thermistor and the conductivity cell are located a small distance from each other. If there is a large vertical gradient in temperature, this can cause erroneous spikes in the salinity field. Work has been done to correct this lag problem by G. Johnson and corrections are available in the delayed-mode data. However, the error is quite different between different Seabird sensors found on floats, and not all the necessary metadata is available in all Argo data (G. Johnson, personal communication). **The profiling float data on WOD05 are not corrected for thermal lag.** Some anomalous spikes in salinity near large temperature gradients, probably caused by the thermal lag error, have been marked by automatic or subjective checks in WOD05.

Table 6.1. Corrections to float pressure profiles with hysteresis problem (after Schmid, 2005).
Correction factor was subtracted from original pressure values for each pressure in the profile.

WMO Float ID#	# of Profiles	Average correction (m)	Maximum Correction (m)
13857	140	9.4	14.5
13858	48	12.7	12.7
13859	155	6.0	8.4
15819	121	17.9	27.7
15820	174	12.7	13.9
15821	97	13.5	82.8
15852	116	5.8	6.4
15853	120	6.9	8.4
15854	66	11.8	12.9
15855	61	9.7	9.7
31810	124	18.7	19.5
31855	73	13.2	50.3
31856	47	15.4	17.7
31857	109	15.7	52.0
31858	23	15.6	21.1
31859	163	19.9	24.7

Another identified problem is pressure hysteresis. As mentioned above, some pressure gauges have some pressure hysteresis error. Some early profiling floats which used a Micron Instruments pressure gauge had fairly large pressure hysteresis problem (Schmid, 2005). Schmid (2005) outlines an algorithm for correcting this hysteresis problem. **This correction was applied to 1,633 float profiles in the tropical Atlantic in WOD05**. A list of the floats and the average pressure correction are shown in Table 6.1.

There are no significant identified problems with the temperature sensors. Oka and Ando (2004) found no drift in temperature from 3 recovered floats after 6-9 months. They did find significant error in one of the three recovered conductivity cells (~ -0.02), from a PROVOR float, showing again the relatively larger problems with the salinity measurements from profiling floats compared to temperature measurements.

Oxygen sensors have been deployed on floats operationally since 2002. Kortzinger *et al*. (2005) found no instrument problems using the Aanderaa 3830 sensor after 6-9 months deployment. Both Aanderaa and Seabird sensors compare well with Winkler titrated oxygen values and appear to have stable calibration according to recently presented results (Gilbert *et al*., 2006).

6.6.2. Data-Stream Errors

Problems caused by transmission of data from one site to another are always possible. The more data transfers are made, the more possibilities for error. The profiling float data are no exception. The most prevalent error, and one which is not usually recoverable, is errors in transmission of data packages from the float to the ARGOS satellites. Many of these transmission errors result in portions of profiles, or entire profiles containing erroneous information. Most of these errors are of such a nature that they are found and flagged in automatic quality control checks in WOD05 if they have not been removed beforehand. But there may be data with errors of this nature which escaped all quality control steps.

A data-stream error encountered while replacing the GTSPP version of the profiling floats with the U.S. GODAE (Argo) version was a mislabeling of the depth measurements as pressure measurements in the Argo version of the data. These errors came in that portion of the data which were gathered from the GTS, but for which no DAC in Argo is responsible. These data are included with Argo data even though they do not go through the same processing as other Argo data. The convention for data broadcast on the GTS is to use units of depth rather than pressure. Increasing the confusion, some DACs put pressure values out on the GTS instead of depth values. These problems have been solved. All DACs now put out data on the GTS with depth. All pressures for data not from DACs in Argo were recalculated from the depths both in WOD05, and as of March 28, 2006 in the Argo data at the GDACs (T. Carval, personal communication). This involved about 25,000 profiles. There are still approximately 9,000 profiles for which the GTSPP depths match the Argo pressures. Since these data are from Argo DACS, it is assumed that pressure is the correct unit in these cases, so this is the unit used in WOD05.

6.7. ORIGINATORS FLAGS

The originators flags from the Argo program are kept intact in the WOD05 data. The flags are as follows:

0 – no quality control (QC) performed
1 – good data
2 – probably good data
3 – bad data that are potentially correctible
4 – bad data
(from Argo quality control manual Version 2.0b, 2004).

Note that not all data marked with originators 3 or 4 are marked with WOD05 quality control flags. Visual inspection of examples of these data found no reason not to use these data for scientific research. This just means that a quality control test that failed by Argo standards did not fail by WOD05 standards, or that the failing test was not performed for WOD05. The user of WOD05 can choose to use the Argo flags, the WOD05 flags, both, or neither.

Argo also supplies a grey list. This is a list of floats and sensors which have been deemed to have failed at some point. The date of failure is also listed. **The information on the grey list is used to set a quality control flag for PFL data in WOD05.**

6.8. PFL DATA DISTRIBUTIONS

Figure 6.3 shows the geographic distribution of profiling floats for the period 1994-2005. This distribution shows that Argo has met one of its goals of full geographic coverage of non-ice covered ocean. The depth distribution, Figure 6.4 shows that many of the surface (0-5 meters) values do not exist or are missing. From 10 m depth the vertical distribution is steady until 400 meters where it begins to decrease down to 2000 meters. Table 6.2 shows that nearly 60% of the floats are of U.S. origin, followed by Canada at 12%. It also shows that many countries around the world are contributing profiling float data. The year distribution in Table 6.3 and Figure 6.5 shows the rapid increase of float distribution year by year up to 2005. The low number for 2005 is simply because WOD05 only includes data up to Feb. 8, 2005.

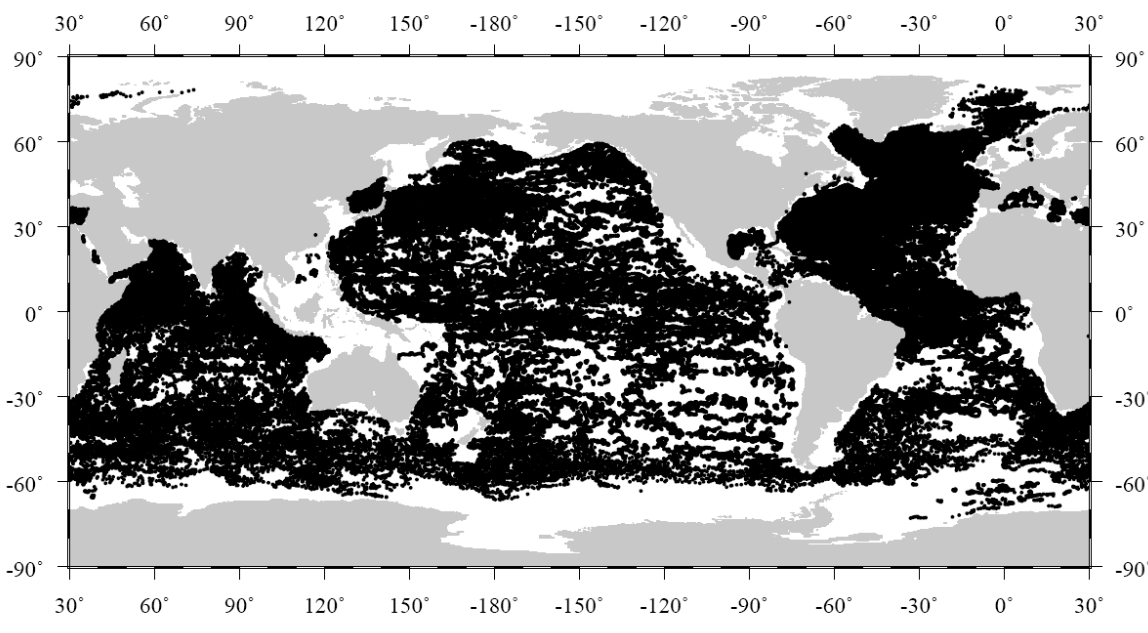

Figure 6.3. Geographic distribution of profiling floats (PFL) for the period 1994-2005 in WOD05.

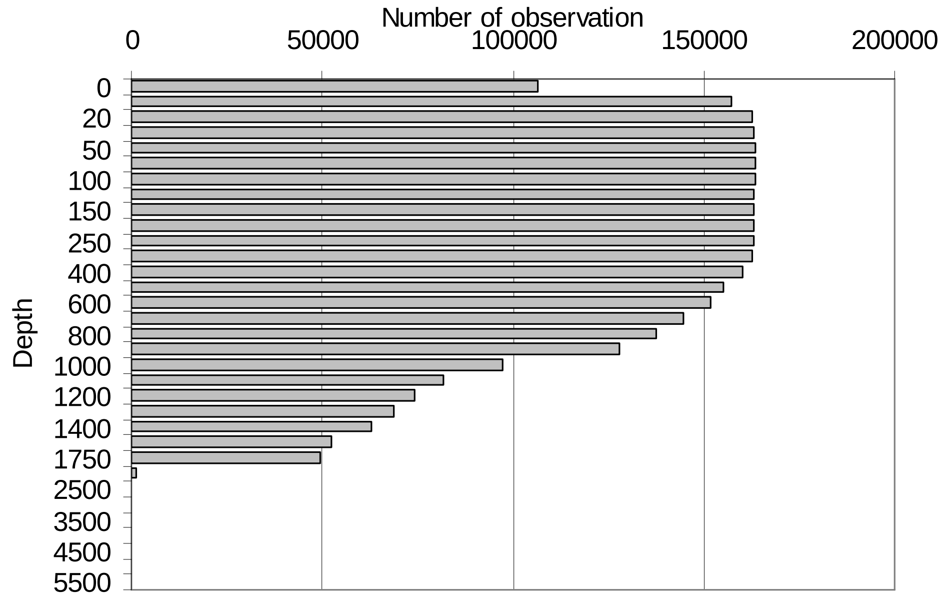

Figure 6.4. Distribution of Profiling Float Data (PFL) data at standard depth levels in WOD05.

Table 6.2. National contribution of PFL casts in WOD05.

NODC Country Codes	Country Name	PFL Casts	% of Total
31,32	United States	99,560	58.92
49,51	Japan	19,977	11.82
18	Canada	8,586	5.08
35	France	7,557	4.47
74	United Kingdom	6,942	4.11
06	Germany	6,400	3.79
EU	European Union	5,941	3.52
41	India	3,687	2.18
24	Korea, Republic of	3,062	1.81
09	Australia	2,522	1.49
99	Unknown	1,516	0.90
76	China, The Peoples Republic of	786	0.47
58	Norway	582	0.34
26	Denmark	419	0.25
48	Italy	408	0.24
29	Spain	353	0.21
61	New Zealand	328	0.19
90 ,RU	Union of Soviet Socialist Republics/Russia	153	0.09
45	Ireland	81	0.05
39	Unknown	80	0.05
64	Netherlands	48	0.03
	Total	*168,988*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

Table 6.3. The number of Profiling Float Data (PFL) casts as a function of year
The total number of casts = 168,988.

YEAR	CASTS	YEAR	CASTS	YEAR	CASTS	YEAR	CASTS
1994	53	1997	6,093	2000	13,795	2003	31,475
1995	1,038	1998	11,569	2001	14,717	2004	46,745
1996	2,617	1999	14,239	2002	20,420	2005	6,227

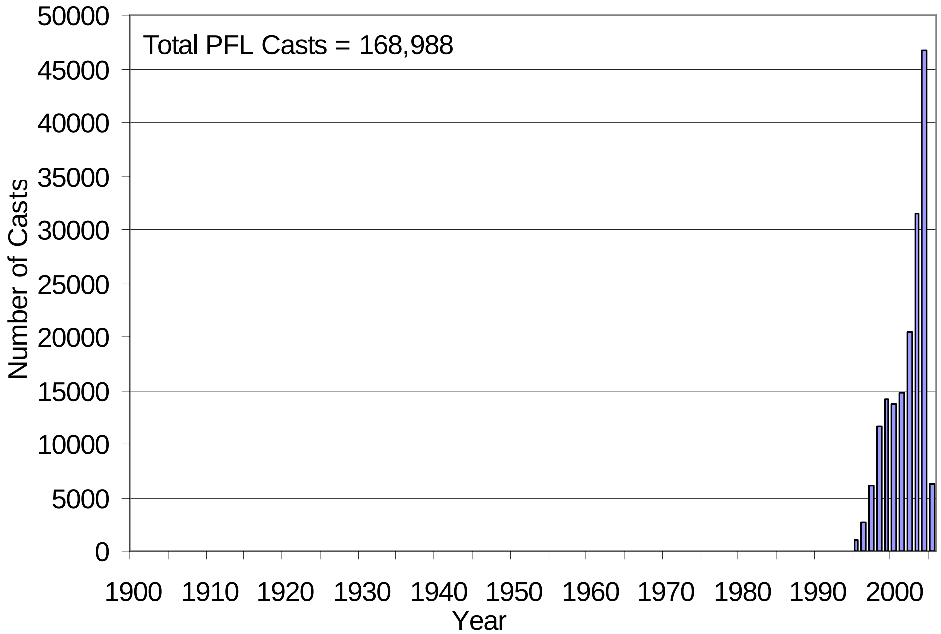

Figure 6.5. Temporal distributions of Profiling Float Data (PFL) casts in WOD05.

6.9. RELEVANT WEB SITES

Aanderaa Oxygen Sensor:
http://www.aanderaa.com/docs/B140_Oxygen_Optode_Temp_Sensor_3835.pdf.

Argo homepage: http://www.argo.ucsd.edu.

Argo Information Center homepage: http://argo.jcommops.org/.

FSI Excell CTD: http://www.falmouth.com/DataSheets/CTSensorDigital.pdf.

Seabird 41 CTD for ALACE floats: http://www.seabird.com/alace.htm.

Seabird 43 oxygen sensor: http://www.seabird.com/products/spec_sheets/43data.htm.

Seabird 9+ CTD:
http://www.seabird.com/pdf_documents/datasheets/911plusbrochureFeb05.pdf.

TSK CTD: http://tsk-jp.com/tska/PDF_Files/Seamate.pdf.

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[1]English version of Argo Information Center Newletter available on their website (see above).
[2] Document available on Argo Information Center website (see above).

CHAPTER 7: MECHANICAL BATHYTHERMOGRAPH DATA (MBT)

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7.1. INTRODUCTION

The Mechanical Bathythermograph (MBT) is an instrument developed during the late-1930's (Spilhaus, 1938) that can be dropped from either a stationary or moving surface ship to produce an upper ocean temperature profile. This instrument was a substantial improvement of an instrument known as the “oceanograph” which was designed by Dr. Carl Rossby and Dr. Karl Lange (Rossby and Montgomery, 1934) for the purpose of studying the upper ocean thermal structure. The introduction of the MBT allowed ships to make synoptic surveys of oceanographic regions and for discovery of fine structure of the ocean's thermal structure. Spilhaus (1941) used the instrument to identify “fine” structure (in the horizontal) from temperature profiles near the edge of the Gulf Stream. Pressure is determined from a pressure sensitive tube known as a Bourdon tube. A temperature sensitive element in the nose of the MBT enables the instrument to trace temperature as a function of depth.

Different versions of the MBT have different maximum depth ranges with 295 m being the deepest depth measured from any U.S. version. Earlier versions of the instrument were limited to making measurements in the upper 140 m of the water column. A review of the development of the MBT is given by Spilhaus (1987). Another more comprehensive review is provided by Couper and LaFond (1970).

In most countries and institutions the use of the MBT has been replaced by the XBT. Only 1.5% of all the MBT profiles in our archives were collected between 1991 and 2000 (Table 7.1). While the U.S.A. is responsible for more than half of all the MBT profiles, only Japan and Russia continue to significantly make MBT measurements and to transfer them to oceanographic data centers. Indeed, these countries account for more than 99% of the MBT profiles reported in the period mentioned above.

7.2. MBT ACCURACY

The accuracy of the MBT has been the subject of several studies. Leipper and Burt

(1948) report the results of comparisons between MBT temperature measurements and near simultaneous reversing thermometer measurements which were made by D. Pritchard of the U.S. Navy Electronics Laboratory in Lake Meade. By comparing the temperature traces on the up and down casts of the MBT it was inferred that there was "an almost complete absence of internal waves of large amplitude and short period, hysteresis of the instruments, or rapid temperature changes due to advection". These results are reproduced in Table 7.2 given below. Clearly there is good agreement between the reversing thermometer measurements (which typically had an accuracy of 0.02°C at this period of time) and the MBT measurements. However, there is a problem with interpreting the results from Table 7.2 because it is not clearly stated in the table, or the text of the technical report of Leipper and Burt, what temperature units were used. Throughout their report, Leipper and Burt use the Fahrenheit scale. If this scale applies to the results in Table 7.2, then the agreement is impressive. If the results are in degrees Celsius, the agreement is less impressive but the data are still useful for many scientific purposes. Other studies attribute an accuracy of about 0.5°F to the MBT instrument. This figure is comparable to the accuracy of expendable bathythermograph (XBT) probes for which the thermistor sensing element is not calibrated (Tabata, 1978). Although both MBT and XBT probes are an order of magnitude less precise than reversing thermometers, the *standard error of the mean* of any estimate based on these temperature measurements decreases with the increase in number of data used. This applies to random errors. Hence, historical bathythermograph measurements provide valuable information when estimating mean features by averaging over many measurements in space and/or time.

7.3. SURFACE DATA ACQUIRED CONCURRENTLY WITH MBT CASTS

On occasions a sea-surface water sample is taken at the time of the MBT cast. Temperature and salinity of the water sample are usually measured and recorded as ancillary information of the MBT cast. Meteorological conditions at the time of the MBT cast could also be archived, *e.g.* air temperature, wind speed and direction, cloud type and cover, barometric atmospheric pressure, as well as sea conditions: wave height and direction, sea state.

A significant amount of ancillary meteorological information was recovered by the NODC/OCL through the digitization of historical MBT cards from the Scripps Institution of Oceanography and the Woods Hole Oceanographic Institution.

7.4. MBT PROFILE DISTRIBUTIONS

Table 7.1 gives the yearly counts of MBT profiles for the World Ocean. Figure 7.1 shows the time series of the yearly totals of Mechanical Bathythermograph profiles for the World Ocean, southern hemisphere oceans, and northern hemisphere oceans respectively. There are a total of 2,336,064 MBT profiles for the entire World Ocean with 260,130 profiles (11.1%) measured in the southern hemisphere and 2,075,934 profiles (88.9%) measured in the northern hemisphere. Table 7.3 gives national contributions of MBT profiles.

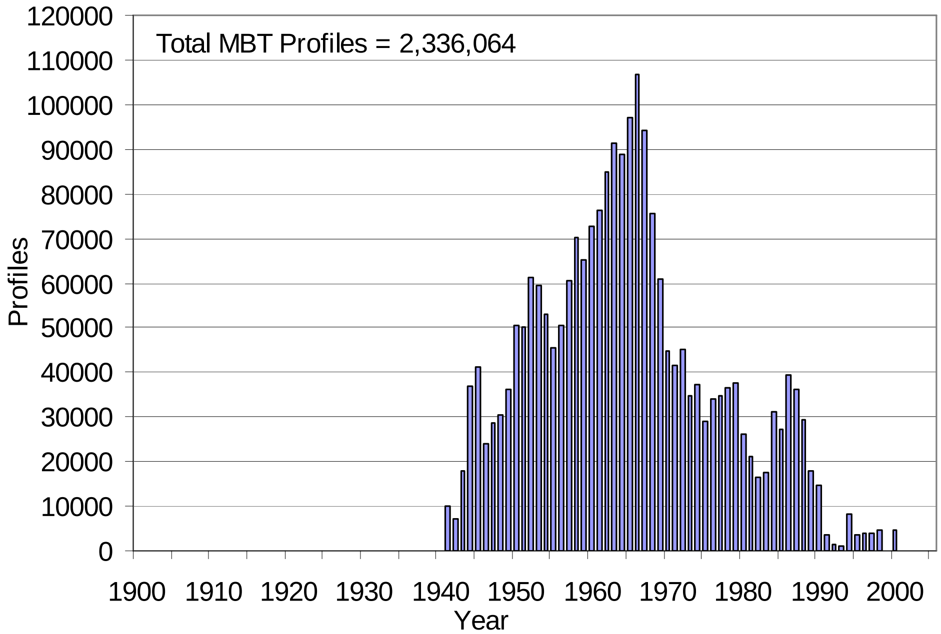

Figure 7.1. Temporal distribution of Mechanical Bathythermograph (MBT) profiles in WOD05.

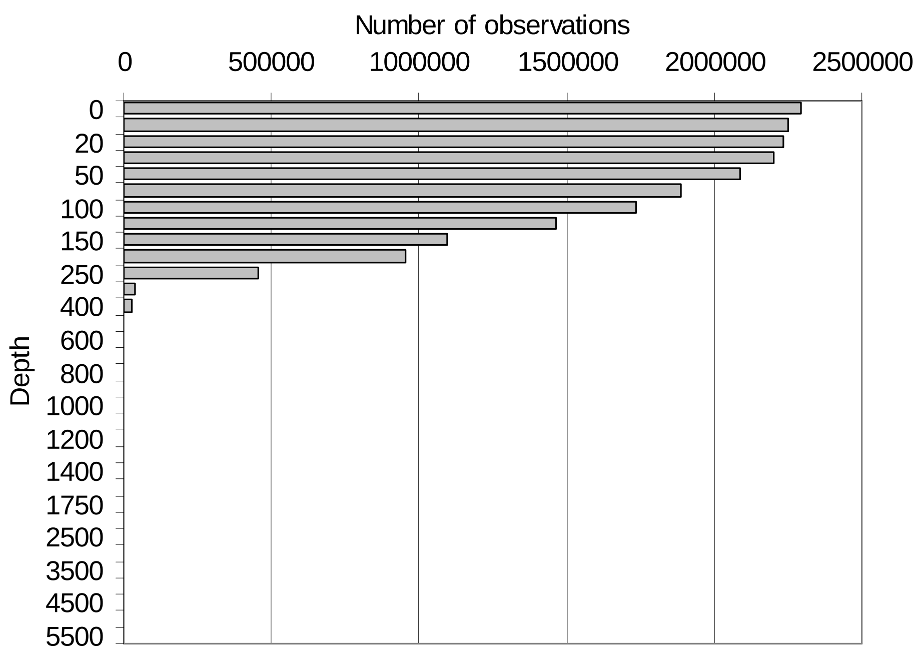

Figure 7.2. Distribution of Mechanical Bathythermograph (MBT) data at standard depth levels in WOD05.

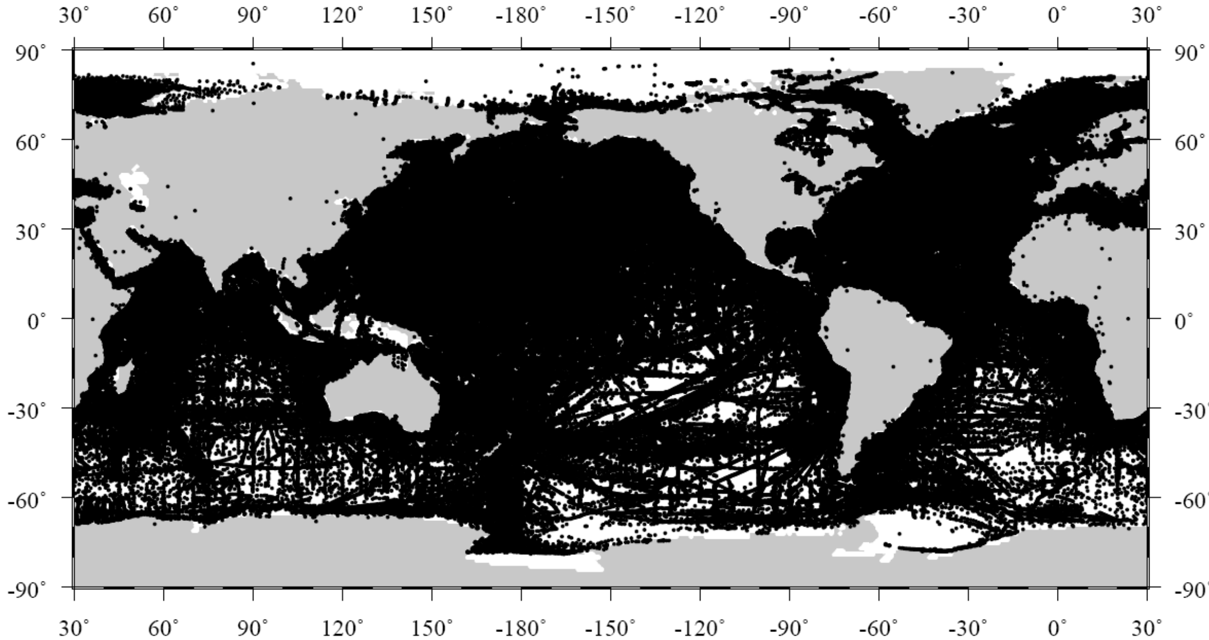

Figure 7.3. Geographic distribution of Mechanical Bathythermograph (MBT) profiles in WOD05.

Table 7.1. Number of all MBT profiles as a function of year in WOD05.
Total Number of Profiles = 2,336,064

YEAR	PROFILE	YEAR	PROFILE	YEAR	PROFILE	YEAR	PROFILE
1941	10,154	1956	50,530	1971	41,428	1986	39,369
1942	7,014	1957	60,491	1972	45,187	1987	36,207
1943	17,767	1958	70,119	1973	34,858	1988	29,457
1944	36,871	1959	65,296	1974	37,408	1989	17,823
1945	41,104	1960	72,684	1975	29,130	1990	14,559
1946	23,823	1961	76,393	1976	34,165	1991	3,690
1947	28,808	1962	84,909	1977	34,715	1992	1,549
1948	30,312	1963	91,328	1978	36,576	1993	1,169
1949	36,040	1964	89,007	1979	37,777	1994	8,417
1950	50,335	1965	97,198	1980	26,300	1995	3,453
1951	50,292	1966	106,874	1981	21,092	1996	3,905
1952	61,343	1967	94,257	1982	16,645	1997	3,859
1953	59,342	1968	75,460	1983	17,480	1998	4,552
1954	52,929	1969	60,909	1984	31,202	1999	0
1955	45,481	1970	44,918	1985	27,285	2000	4,819

Table 7.2. Comparison of observations taken with Mechanical Bathythermographs and reversing thermometers.
Reproduced from Leipper and Burt (1948).

TABLE 2.3. OBSERVATIONS TAKEN WITH BATHYTHERMOGRAPHS AND REVERSING THERMOMETERS			
BT	**No. of stations**	**No. of thermometer observations**	**Standard Deviation of Temperature Differences***
# 1784A (Shallow)	9	20	0.15
# 1258A (Deep)	10	41	0.19
# 514A (Deep)	12	36	0.10

*We reproduce this table as it appeared in the work by Leipper and Burt (1948). Unfortunately, they did not specify whether the units of temperature were reported in degrees Celsius or Fahrenheit. However, all other citations of temperature in their report were given in units of degrees Fahrenheit. Even if these results are in units of degrees Celsius, the agreement is still good. For example, individual XBT probes are accurate to a few tenths of a degree Celsius.

Table 7.3. National contributions of Mechanical Bathythermograph (MBT) profiles in WOD05

NODC Country Codes	Country Name	MBT Casts	% of Total
31,32,33	United States	1,169,867	50.09
90, RU	Union of Soviet Socialist Republics/Russia	444,142	19.02
49	Japan	296,230	12.69
18	Canada	184,844	7.91
74	United Kingdom	118,643	5.08
06	Germany, Federal Republic of	25,005	1.07
09	Australia	18,474	0.79
99	Unknown	16,393	0.70
35	France	13,538	0.58
08	Argentina	12,090	0.52
64	Netherlands	8,088	0.35
48	Italy	6,268	0.27
65	Peru	5,212	0.22
20	Chile	4,161	0.18
68	Portugal	2,628	0.11
61	New Zealand	2,435	0.10
RC	Congo	1,234	0.05
11	Belgium	1,218	0.05
58	Norway	913	0.04
28	Ecuador	885	0.04
22	Colombia	747	0.03
93	Venezuela	673	0.03
41	India	540	0.02
55	Malagasy Republic	405	0.02
36	Greece	327	0.01
SE	Senegal	245	0.01
29	Spain	195	0.01
SL	Sierra Leone	187	0.01
IC	Ivory Coast	100	<0.01
MO	Monaco	97	<0.01
NI	Nigeria	89	<0.01
14	Brazil	82	<0.01
86	Thailand	77	<0.01
91	South Africa	20	<0.01
GH	Ghana	12	<0.01
	Total	*2,336,064*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC

7.5. REFERENCES AND BIBLIOGRAPHY

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CHAPTER 8: DIGITAL BATHYTHERMOGRAPH (DBT) PROFILES

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8.1. INTRODUCTION

The Digital Bathythermograph (DBT) is an instrument developed to record and report temperature profile data electronically. The self-contained underwater instrument includes a thermistor and a strain gauge. Temperature and depth/pressure measurements are automatically archived in the underwater unit as it is lowered in the water column. Upon retrieval, the underwater unit is connected to a computer and data are retrieved and archived. All DBT profiles are stored in the MBT dataset of WOD05.

8.2. DBT ACCURACY

The DBT has a temperature accuracy of ±0.05°C. However, Pankajakshan et al. (2003) report temperature errors of -0.3°C to +1.0°C in Indian DBT data from the Indian Ocean. No errors were observed in DBT data collected in the Pacific Ocean by Japanese and USA institutions.

8.3. DBT PROFILE DISTRIBUTIONS

Table 8.1 gives the yearly counts of DBT profiles for the World Ocean. Figure 8.1 shows the time series of the yearly totals of Digital Bathythermograph profiles for the World Ocean, southern hemisphere oceans, and northern hemisphere oceans respectively. There are a total of 80,212 DBT profiles for the entire World Ocean with 4,845 profiles (6.0%) measured in the southern hemisphere and 75,367 profiles (94.0%) measured in the northern hemisphere. Table 8.2 gives national contribution of DBT data.

Table 8.1. The number of Digital Bathythermograph (DBT) profiles as a function of year in WOD05. The total number of casts = 80,212.

YEAR	CASTS	YEAR	CASTS	YEAR	CASTS	YEAR	CASTS
1977	27	1983	8,370	1988	5,469	1993	2,507
1978	234	1984	9,462	1989	3,443	1994	108
1979	1,920	1985	8,700	1990	4,148	1995	2
1980	5,244	1986	5,531	1991	4,662	1996	27
1981	5,910	1987	4,551	1992	2,285	1997	88
1982	7,524						

Table 8.2. National contributions of Digital Bathythermograph (DBT) profiles in WOD05.

NODC Country Codes	Country Name	DRB Casts	% of Total
49	Japan	68,263	85.10
18	Canada	11,102	13.84
24	Korea, Republic of	847	1.06
	Total	*80,212*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

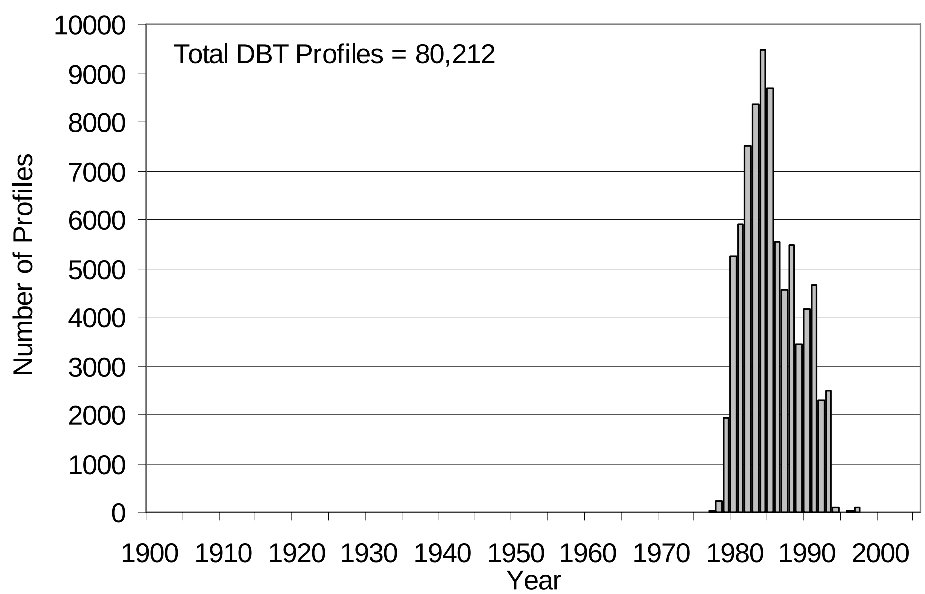

Figure 8.1. Temporal distribution of Digital Bathythermograph (DBT) profiles in WOD05.

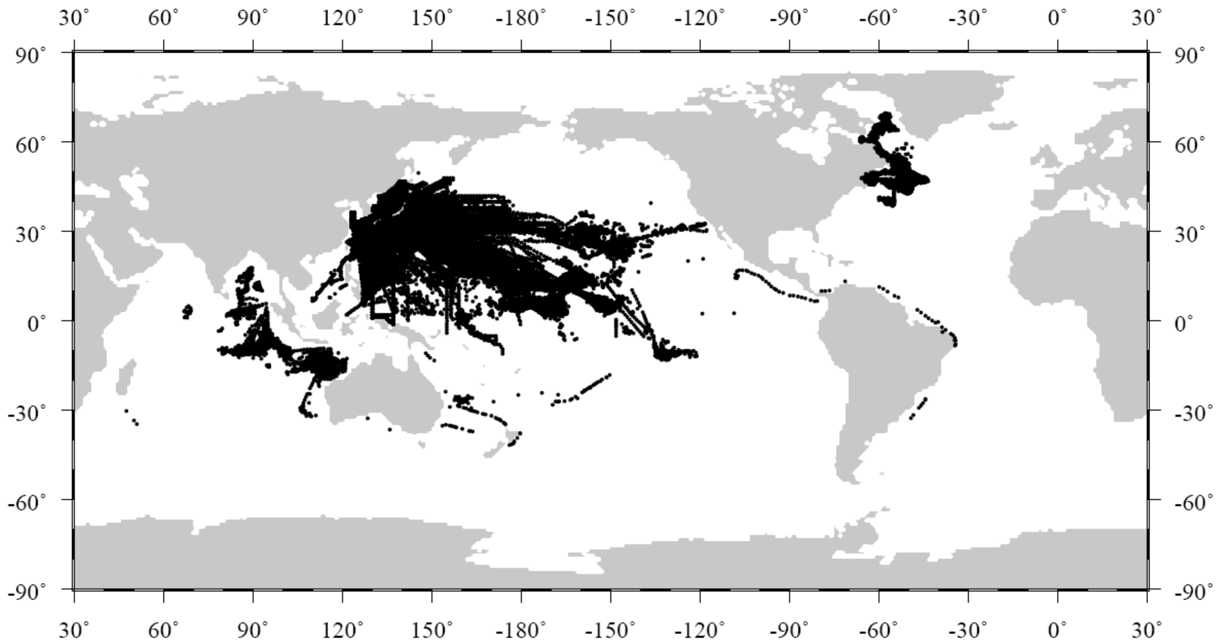

Figure 8.2. Geographic distribution of Digital Bathythermograph (DBT) profiles in WOD05.

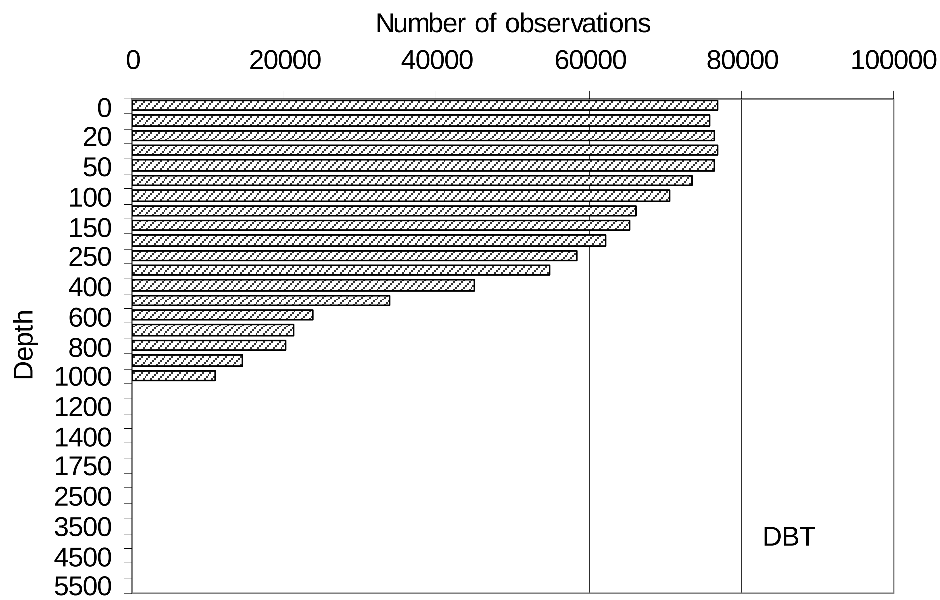

Figure 8.3. Distribution of Digital Bathythermograph (DTB) data at standard depth levels in WOD05.

8.4. REFERENCES AND BIBLIOGRAPHY

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CHAPTER 9: MOORED BUOY DATA (MRB)

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9.1. INTRODUCTION

The National Data Buoy Center web-site (http://seaboard.ndbc.noaa.gov/) notes that "In March 1966, the Panel on Ocean Engineering of the Interagency Committee on Oceanography convened a group of Federal agency representatives to address the problems and possibilities associated with automated data buoy networks. This group recommended a national system of ocean data buoys and the Committee asked the United States Coast Guard to conduct a feasibility study of a consolidated national data buoy system". After ten months of work, the study report made the following conclusions:

- extensive requirements exist for oceanographic and meteorological information to satisfy both operational and research needs in the oceanic and Great Lakes environments;
- automatic, moored buoys were capable of meeting a significant portion of those needs; and that
- a network of such buoys, would be an essential element of an overall environmental information and prediction system (Shea, 1987).

As further explained in the U.S. Department of Commerce's publication NDBCM WO547 – "The National Data Buoy Project (NDBP) was established in December 1967 for the purpose of developing a national capability to deploy and operate networks of automatic buoys to retrieve useful information describing the marine environment on a reliable, real time basis". As noted by Shea (1987) in "A History of NOAA" – "By the 1960's, scientists had recognized the need for more detailed information on environmental conditions over vast marine areas which remained largely uncovered except for occasional observations from ships or aircraft of opportunity, oceanographic research expeditions, or the few existing ocean station vessels. As a result, a number of Federal Agencies and universities began programs to develop and implement networks of buoys which could routinely and automatically report environmental conditions like temperature, wind speed and direction, etc."

Data Buoy Cooperation Panel web site describes moored buoys as "normally relatively large and expensive platforms. Data are usually collected through geostationary meteorological satellites such as GOES or METEOSAT. If a moored buoy goes adrift it represents a potential loss of costly equipment and a possible hazard to navigation. For these reasons the ARGOS system has been used for location determination for moored buoys. In addition, some World Meteorological Organization (WMO) Member countries use the ARGOS system for normal transmission of meteorological observations from moored buoys" (see http://www.dbcp.noaa.gov/dbcp/1hb.html#MB).

As part of the Tropical Ocean-Global Atmosphere (TOGA) program, efforts were made to enhance the real-time ocean observing system in the tropical Pacific Ocean. The Tropical Atmosphere Ocean (TAO) array of moored buoys spans the tropical Pacific from 137°E to 95°W and from 8°S to 8°N. The TAO system began in 1985 as a regional-scale set of meridional arrays on both sides of the Equator at 110°W and 165°E and has steadily expanded to its present size of approximately 70 moorings. Moorings are typically separated by 2-3 degrees of latitude and 10-15 degrees of longitude. The TAO array of moored buoys provides surface wind, sea surface temperature (SST), upper ocean temperature, as well as subsurface temperatures and salinity down to a depth of 500 meters, and current measurements (Mangum, 1994; Mangum *et al.,* 1994; McPhaden, 1995; McPhaden *et al.*, 1998). The majority of TAO moorings are ATLAS moorings developed at NOAA's Pacific Marine Environmental Laboratory (PMEL) Seattle, WA, in the 1980's (http://www.pmel.noaa.gov/tao/index.shtml). The ATLAS mooring is a taut wire surface mooring with a toroidal float. It is deployed in depths of up to 6000 meters (Milburn *et al.,* 1996). The expansion of this array is the result of international collaboration between scientists from France, Japan, Korea and the USA. The first ATLAS mooring was deployed in December 1984. Collected data are transmitted to shore in real time using ARGOS System (http://www.cls.fr/html/argos/welcome_en.html), processed by Collecte Localisation Satellites (CLS, http://www.cls.fr/) or Service ARGOS Inc. (http://www.argosinc.com/), and placed on the Global Telecommunication System (GTS, http://www.wmo.ch/index-en.html). Post recovery processing and analysis of the data is performed at PMEL. The TAO array now supports programs like the Global Climate Observing System (GCOS, http://www.wmo.ch/web/gcos/gcoshome.html), World Climate Research Programme (WCRP, http://www.wmo.ch/web/wcrp/wcrp-home.html), Climate Variability and Predictability Programme (CLIVAR, http://www.clivar.org/), and the World Weather Watch Programme (WWW, http://www.wmo.ch/web/www/www.html) (Data Buoy Cooperation Panel web-site).

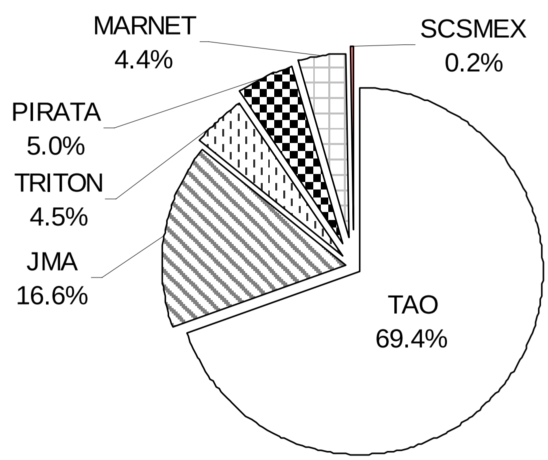

Figure 9.1. Distribution of the moored buoys data among the major research programs.

PIRATA (Pilot Research Moored Array in the Tropical Atlantic) is a project designed by a group of scientists involved in CLIVAR, and is implemented by the group through multi-national cooperation. Contributions are provided by France (with the participation of IRD in collaboration with Meteo-France, CNRS, Universities and IFREMER), by Brazil (INPE and DHN) and by the USA (NOAA/PMEL, NASA and Universities). The purpose of PIRATA is to study ocean-atmosphere interactions in the tropical Atlantic that are relevant to regional climate variability on seasonal, inter-annual and longer time scales (http://www.pmel.noaa.gov/pirata/).

The MARNET (Marine Environmental Monitoring Network in the North Sea and Baltic Sea) project has four of its buoys located in the North Sea and five buoys in the Baltic Sea. The program is oriented to use existing platforms as a base for instrument installation. In the North Sea two unmanned lightships and two North Sea Buoys (NSB II and NSB III) are used. In the Baltic Sea two large discus buoys, stabilized mast, semi-submersible buoy and pier/platform near the Kiel lighthouse are used. The main components of the measuring equipment are sensors, data acquisition unit, data storage system, and data collection platform (DCP). Sensors with analog and digital outputs are connected to the data acquisition unit. The raw data are transmitted via DCP and satellite (METEOSAT) to the land-based station at the Bundesamt für Seeschifffahrt und Hydrographie (BSH, http://www.bsh.de/). The data storage is a security back-up in case the satellite communications system breaks down. Oceanographic sensors measuring the following variables are installed: temperatures at 5 to 8 depth levels (depending on water depth); conductivity at 2 to 4 depth levels; oxygen concentration at 2 depth levels; radioactivity at 1 or 2 depth levels; currents; water levels; nutrient analyzers and samplers for micro-contaminants are accommodated in deck containers; sea water pumping units (http://www.bsh.de/en/Marine%20data/Observations/MARNET%20monitoring%20network/index.jsp).

The WOD05 contains data on daily averaged temperature and salinity values of water salinity and temperature collected by moored buoys (MRB) during the period from 1980 to February 2005. The majority of data came from ongoing programs: 309,013 casts collected from the TAO buoy array. 73,693 casts came from three buoys located around Japan and operated by Japan Meteorological Agency (JMA). 22,075 casts were acquired during PIRATA program. 20,138 casts came from TRITON program. 19,445 casts were collected during the MARNET program, 905 casts were collected during the South China Sea Monsoon Experiment (SCSMEX), and 102 casts came from other sources (See Figure 9.1 for percentage and related web-links below for additional information). There are six countries that have contributed the majority of the moored buoys data in WOD05: USA, Japan, Germany, Brazil, France, and Taiwan. Table 9.1 and Figure 9.2 provides detailed information on each country contribution.

Table 9.1. National contributions of MRB casts in WOD05.

NODC Country Code	Country Name	MRB Casts	% of Total
31	United States	285,663	64.14
49	Japan	117,265	26.33
6	Germany	19,445	4.37
14	Brazil	14,107	3.17
35	France	7,985	1.79
21	Taiwan	905	0.20
	Total	*445,371*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

9.2. MRB DATA PRECISION AND ACCURACY

The accuracy of MRB temperature and salinity data depends on the temperature and conductivity sensors used. For TRITON buoys, for example, sensor range and accuracy are: conductivity 0-70/0.003 ms cm^{-1}; temperature -3 – 33/0.002°C; depth 0-1000 pounds per square inch absolute (psia) / 0.15% full scale (Kuroda, 2001; Ando *et al.*, 2005). Data acquired during TAO and PIRATA programs were collected from PROTEUS and ATLAS buoys using SeaBirds Electronics' SEACAT sensors which have SST accuracy of 0.01°C for the PROTEUS mooring and 0.03°C for ATLAS moorings; subsurface temperature accuracy is 0.01°C for the PROTEUS mooring and 0.09°C for ATLAS moorings (Freitag *et al.,* 1994; Cronin and McPhaden, 1997). MARNET data collected using oceanographic sensors calibrated at the BSH's calibration laboratory by means of triple point, gallium cells, reference resistors and resistance bridges of the highest available precision, as well as salinometers calibrated with *Copenhagen standard sea water* (http://www.olympus.net/IAPSO/standardserv91_95.html). The three sea water baths used for temperature and conductivity calibration reach a temperature stability of $\pm 1 \cdot 10^{-3}$°C. After deployment, the sensors are checked and cleaned at monthly intervals. During each monthly check, an *in situ* comparative measurement is carried out using a reference CTD system.

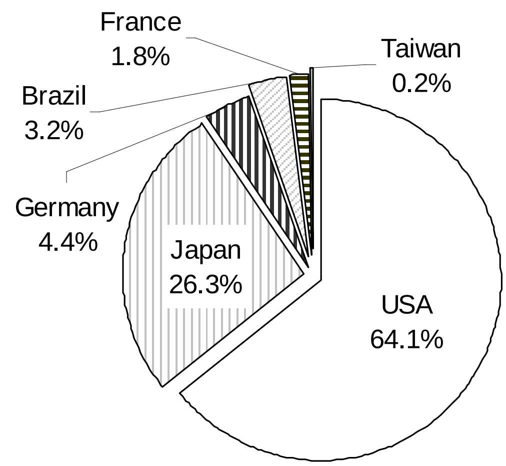

Figure 9.2. Distribution of the moored buoys data among the contributing countries.

9.3. MRB CAST DISTRIBUTIONS

Table 9.2 gives the yearly counts of MRB casts for the World Ocean and this is graphically illustrated on Figure 9.3. Data flow steadily increased after the TOA buoys were deployed and reached its maxima in 1995-2000.

The geographic distribution of the MRB casts for 1980-2005 is shown in Figure 9.4. There are a total of 445,371 MRB casts for the entire World Ocean with ~351,500 casts (79%) measured in the tropics (15°N – 15°S). These data were contributed by TRITON, TAO, JMA, and PIRATA programs. MARNET and JMA programs have contributed ~93,800 casts (21%) measured in the area north of 30°N.

Figure 9.5 shows the distribution of the MRB data as function of depth. Since the majority of the moored buoys are designed to sample only the upper layer of the ocean, most of the data were collected within upper 250 meters of the water column.

Table 9.2. The number of MRB casts in WOD05 as a function of year in WOD05. Total number of casts = 445,371

YEAR	CASTS	YEAR	CASTS	YEAR	CASTS	YEAR	CASTS
1980	299	1987	3,695	1994	29,836	2001	28,580
1981	543	1988	4,939	1995	29,381	2002	26,818
1982	535	1989	6,057	1996	31,361	2003	27,326
1983	1,008	1990	7,015	1997	33,024	2004	25,999
1984	1,098	1991	9,740	1998	37,341	2005	6,518
1985	1,586	1992	23,530	1999	40,194		
1986	2,963	1993	28,250	2000	37,735		

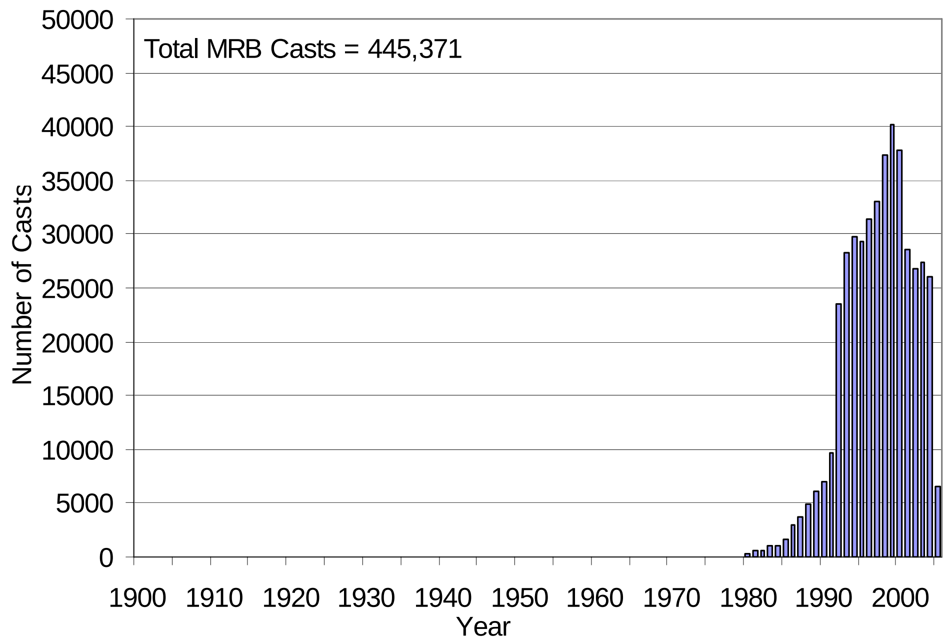

Figure 9.3. Temporal distribution of MRB casts in WOD05.

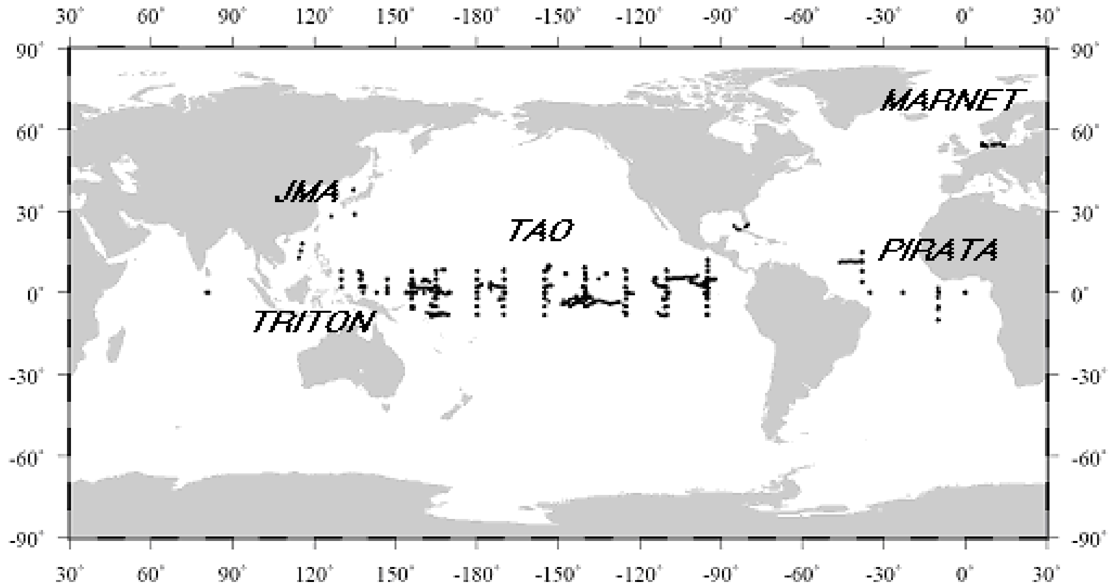

Figure 9.4. Geographic distribution of MRB casts collected by major research programs in WOD05.

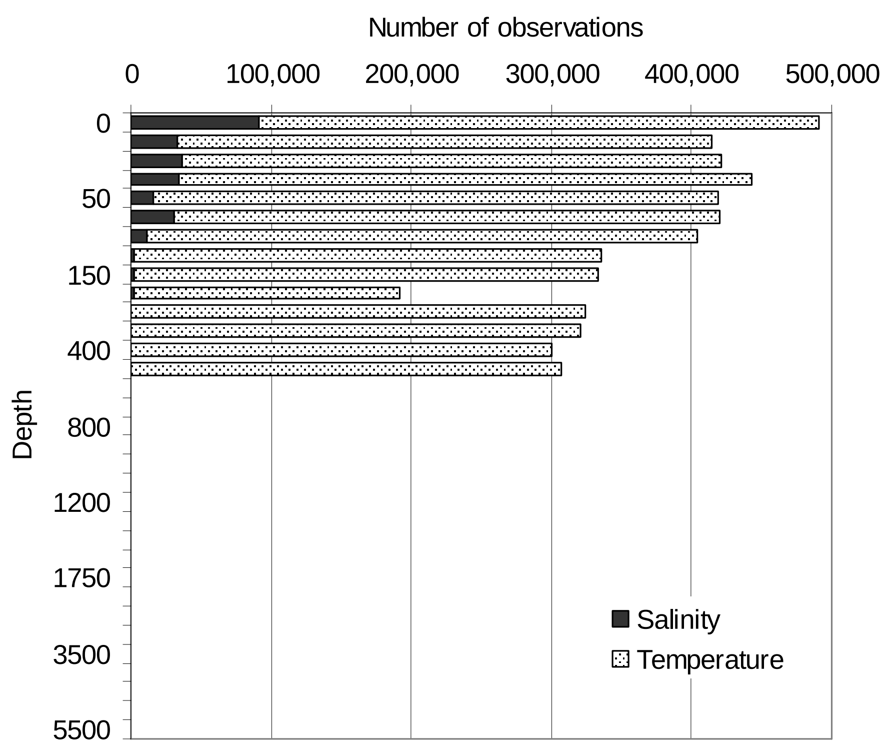

Figure 9.5. Distribution of MRB data at standard depth levels in WOD05.

9.4. RELEVANT WEB SITES

ARGOS Program: http://www.cls.fr/html/argos/ocean/moored_en.html.
GOES: http://goes.gsfc.nasa.gov/).
JAMSTEC TRITON Buoy project http://www.jamstec.go.jp/jamstec/OCEAN/TRITON/.

MARNET description available at
http://www.bsh.de/en/Marine%20data/Observations/MARNET%20monitoring%20network/Langtext.PDF.
METEOSAT: http://www.esa.int/SPECIALS/MSG/index.html.
National Data Buoy Center: http://seaboard.ndbc.noaa.gov/.
NOAA Magazine: http://www.magazine.noaa.gov/stories/mag22.htm.
PIRATA Program: http://www.pmel.noaa.gov/pirata/, mirror site:
http://www.brest.ird.fr/pirata/miroir/.
South China Sea Monsoon Experiment:
http://www.pmel.noaa.gov/tao/proj_over/scsmex/scsmex-display.html
TAO/TRITON collaboration: http://www.pmel.noaa.gov/tao/proj_over/triton.html.
Tropical Atmosphere Ocean Project: http://www.pmel.noaa.gov/tao/index.shtml;
http://gcmd.nasa.gov/records/GCMD_ds256.1.html.
WMO-IOC Data Buoy Cooperation Panel: http://www.dbcp.noaa.gov/dbcp/index.html.

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CHAPTER 10: DRIFTING BUOY DATA (DRB)

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10.1. INTRODUCTION

Drifting buoys are a cost effective means for obtaining meteorological and oceanographic data from remote ocean areas. They form an essential component of the marine observing systems that were established as part of many operational and research programs. Drifting buoys are used as a practical alternative to acquiring data from inaccessible regions as opposed to maintaining costly manned stations (DBCP, 2006; IABP, 2006).

The first drifting buoys, drift bottles, were used in the early 1800s in an effort to map surface currents. The bottles were weighted down so that they were almost entirely submerged and usually carried a note that recorded launch location and time. Bottles were used because previous attempts at mapping ocean currents using ship drift measurements proved unreliable due to the added effect of wind on the movement of the ships (Lumpkin and Pazos, 2006). With the advent of radio, the position of the drifters could be transmitted from small, low-drag antennae and triangulated from the shore. In the early-1970s, positions started to be gathered via satellites. As technology improved, drifters started to obtain meteorological measurements, sea surface temperatures, as well as oceanographic measurements (IADP, 2006; Lumpkin and Pazos, 2006).

10.1.1. Arctic Ocean Buoy Program

The first sea ice buoys used by the Arctic Data Buoy Program were deployed in the ice floes of the Arctic Basin in 1979; they recorded meteorological parameters such as surface atmospheric pressure, air temperature, wind speed, as well as geographic position. Data were transmitted and collected via the ARGOS system and then distributed on the Global Telecommunication System (GTS) (IABP, 2006; GTS, 2006).

Between the years 1985 and 1994, the Arctic Data Buoy Program of the Polar Science Center of the Applied Physics Laboratory at the University of Washington deployed 24 modified data buoys in ice floes on the Arctic Ocean. These were the first buoys, as well as first sea ice buoys, to be equipped with Seabird CTD sensors for collecting oceanographic data along with the meteorological data. These modified buoys, known as Polar Ocean Profile

(POP) buoys, measured subsurface ocean temperature, salinity and depth. They also measured air temperature, and barometric pressure. The direction and velocity of the sea ice floe was interpolated from changes in position from each buoy. Measurements were taken at twelve minute intervals. Subjected to the stresses and strains of the Arctic pack ice, these buoys varied greatly in their longevity, though the battery pack is supposed to last for approximately three years (Rigor, 2002; IABP, 2006; JAMSTEC, 2006).

The main components of a Polar Ocean Profile Buoy start with an ARGOS antenna with air temperature and barometric pressure sensors in a fiberglass shroud that protrudes from the ice floe. This sits on a flotation/ablation skirt that is directly on top of the ice. Within the ice itself are the buoy electronics assembly housing and an alkaline (D-cell) battery pack, all encased in an aluminum hull. Attached to the bottom of the hull, extending into the water column is a 24-conductor electromagnet cable upon which an SBE-16 SEACAT CTD sensor is attached. The SBE-16 SEACAT has a total of 6 sensors, placed at depths of 10, 40, 70, 120, 200, and 300 meters; a depth sensor is added to the sensors at 40, 120, and 300 meters. At the very end of the electromechanical cable is a 50 pound ballast weight (IABP, 2006).

10.1.2. Global Temperature-Salinity Profile Program (GTSPP)

The Marine Environmental Data Service (MEDS, Canada), collects all the data from all drifting buoys via the Global Telecommunication System (GTS) as well as performs quality control on and archives the data. MEDS has been a Responsible National Oceanographic Data Center – RNODC, since January 1986 under the auspices of the Intergovernmental Oceanographic Commission (IOC). They acquire, processes, quality control, and archive real-time drifting buoy data that is reported over the GTS as well as delayed-mode data that are acquired from other sources. Over 200,000 new records are captured monthly from the GTS by MEDS. Data transmitted as drifting buoy data by MEDS through the GTSPP program are only from buoys that transmit subsurface data. This drifting buoy data includes buoy position, date, time, surface and subsurface water temperature, salinity, air pressure and temperature and wind direction (MEDS, 2006). Currently, buoy data from GTSPP in the WOD05 database comes mostly from the United States and France. It consists of temperature readings and some have meteorological measurements such as wind speed, wind direction, dry bulb temperature, and barometric pressure.

10.1.3. JAMSTEC Buoys

In the early-1990s, the Japan Marine Science and Technology Center (JAMSTEC) developing polar ocean profiler buoys. The joint development of the Ice Ocean Eenvironmental Buoy (IOEB) with the Woods Hole Oceanographic Institution (WHOI) was the first attempt to develop a drifting ice buoy equipped with not only meteorological, sea ice and oceanographic sensors, but also with other sensors, such as optical sensors and time series collection devices, that would determine the activities of marine organisms. The first IOEB was deployed in the Beaufort Sea in April 1992; the second deployed April 1994 into the Arctic Transpolar Drift. These first buoys lacked mobility and had little consistency in measurements due to the large number of different sensors on it. Also, each buoy was expensive to assemble and required large scale camps and lots of equipment and materials to install on the ice. They also had to be recovered to analyze collected sediment samples (JAMSTEC, 2006).

JAMSTEC and MetOcean Data System Ltd. developed a new drifting buoy in 1999. The new buoy was named J-CAD (JAMSTEC Compact Arctic Drifter) and its mission was to conduct long-term observations in the Arctic Ocean multi-year ice zones, they are a participant of the IABP. Since 2000, the J-CAD has been used to measure the structure of upper ocean currents and water properties. Ten J-CADs have been installed into the sea ice in various regions of the Arctic Ocean and have been collecting oceanographic and meteorological data. The data J-CAD collects are: air temperature, barometric pressure, wind direction, wind speed, sea surface temperature, platform heading, platform tilt, latitude, longitude, date and time of reading, GPS drift speed, GPS drift direction, CTD sensors' depth, pressure, temperature, conductivity, salinity, potential temperature, density, and several ADCP parameters (the ADCP data are not available through the WOD series). The sensors measure their data in one-hour intervals and the J-CAD deployment location varies by different projects' requirements (JAMSTEC, 2006; Kikuchi *et al.,* 2002).

The total weight of the J-CAD system was designed to be 255 kg or less. This way it can be deployed using a small, light crane system. The maximum external diameter of the underwater sensors is 28 cm. This is so each sensor can be lowered through a 30 cm hole in the ice. A smaller hole means simpler equipment needed to drill it. It is equipped with three types of sensors: meteorological, oceanographic, and buoys status sensors. The J-CAD buoys consist of a floatation collar made of foam resin buoyancy material (Surlyn Ionomer resin manufactured by Du Pont Co.) enclosed by aluminum. The housing for instruments, also made from aluminum and foam resin, hold the data logger/controller engine (Tattletale model 8) with a 48Mb flash card memory, a GPS receiver, two satellite communication systems, the GPS interface MetOcean Digital Controller, and two 245 Ahr lithium battery packs to supply power. On the top of the aluminum enclosure is an ARGOS antenna mast that includes the air temperature sensor, the barometer port, and two GPS antennas. There is also a PC interface for the physical downloading of data from the flash card memory, to configure the data logger, and to set various sensor operating parameters (JAMSTEC, 2006).

Meteorological sensors equipped on the J-CAD consist of a YSI Inc. model_44032 high-precision thermistor for air temperature, a Paroscientific Inc. model 216B barometer, and a RM Young Co. model 5106-MA anemometer. The outside air or sea ice temperature is measured from the thermistor placed at the top of the ARGOS antenna mast. The barometer port is also at the top of the mast and is covered by a water trap and a Gore-Tex membrane to protect it from moisture. Finally, the wind sensor is vertically mounted on the top of the J-CAD tower; this tower is designed to withstand 120 knot winds (JAMSTEC, 2006).

The ocean temperature and conductivity data are obtained from Sea-Bird SBE37IM CT sensors, two of which are equipped with pressure sensors that are part of the CT instrument. On a J-CAD buoy, four CT and two CTD sensors can be mounted. The CT sensors are usually attached at 25m, 50m, 80m, and 180m. The two CTD sensors are usually placed at 120m and 250m. These depths can be easily adjusted to the sea area under observation. There are also two WorkHorse 300 kHz ADCPs from RD Instruments attached at 12m (facing downward) and at 260m (facing upward/downward) to measure the underwater currents. These ADCPs also measure the heading, pitch and roll of the buoy and have a thermistor to measure the water temperature at the ADCPs' depth (JAMSTEC, 2006; Kikuchi *et al.*, 2002).

The J-CAD is equipped with sensors that check the physical status of the buoy. A model TCM2, three-axis magnetometer (Precision Navigation Inc.) measures the platform's orientation. It is mounted inside the hull and provides estimates of platform direction and vertical tilt. There is also a compass that indicates the rotation of the ice base that the J-CAD platform is installed upon. Two GPS receivers are attached to the ARGOS mast. One receiver is a Jupiter model TU30-D140-231 (Conexant Systems Inc.) and is interfaced with the MetOcean Digital Controller. The data from this GPS is used as the J-CAD position reported for the data. The second GPS is an integral part of the Panasonic KX-G7101 ORBCOMM Subscriber Communicator but is only used as a complement to the ORBCOMM satellite system. Finally there is a sensor to measure the temperature of the water and/or ice that is surrounding the J-CAD hull. It is an YSI model_44032 high-precision thermistor that is in constant contact with the inside wall of the platform hull. The instrument is safely inside the J-CAD and, due to the high thermal conductivity of aluminum, the interior wall temperature matches the outside temperature, giving an accurate reading (JAMSTEC, 2006).

In the spring of 2000, an international research team supported by the U.S. National Science Foundation (NSF) was formed to conduct annual expeditions to the North Pole. These expeditions established a group of un-manned platforms, collectively referred to as an observatory, to record as much data as possible. Drifting buoys from the IABP and the JAMSTEC J-CAD are major components of this project, entitled the North Pole Environmental Observatory (NPEO) Project. The Pacific Marine Environmental Laboratory (PMEL) also maintains drifting weather buoys as part of this program (NPEO, 2006; Kikuchi *et al.,* 2002).

10.2. DRB ACCURACY

The SBE-16 SEACAT that is used in the AOBP's POP buoy is designed to accurately measure and record temperature and conductivity. It is powered by internal batteries that give it a year or more of recording time. The time-base is accurate to within 3 minutes per year. There is also an internal battery back-up to support the memory and the real time clock. Data from the AOBP's POP buoy's SBE-16 SEACAT consists of temperature and conductivity measurements from pre-determined depths along the cable. It is capable of temperature measurements ranging from -5 to +35°C with an accuracy of 0.01°C and has a resolution of 0.001°C. The conductivity measurement range is from 0 to 7 S m^{-1} with an accuracy of 0.001 S m^{-1} and resolution of 0.0001 S m^{-1} (Sea-Bird Electronics Inc., 2006).

The foremost concern of the POP buoy's accuracy was conductivity sensor drift due to fouling. Over a year, it seemed that the normal instrumental drift that occurs with age and use fell to less than one percent of the original accuracy. Because the buoys were not usually recovered or revisited, their approach to minimize fouling was to use light baffling shrouds coated with anti-fouling paint around the conductivity cell. More recently, Sea-Bird has provided anti-fouling tubes on the ends of the conductivity cells. The Arctic environment, being cold and dark for half of the year, is detrimental to the growth of fouling organisms. The few sensors that were recovered showed no evidence of fouling or fouling drift. Over time, fouling was generally found to not be a serious problem in the Arctic, though there were occasional problems with shallow sensors in the summer (Morrison, Pers. Com.; Rigor, 2002). Another problem with the POP buoys was inaccurate surface air temperatures that were caused by the small size of the buoy. The air temperature sensor was inside a fiberglass shroud that created a microcosm that would heat up in the summer and be drifted over and insulated by snow in the winter. This difference in internal and external environments rendered the air temperature readings "void" (Rigor *et al.,* 2000)

For data transmitted through GTSPP, the MEDS data quality control consists of two main parts: validation and verification. The data validation consists of reformatting the data to the MEDS processing format, this allows the data to be checked for its readability and correct interpretation. When the reformatting is complete, then the data values themselves are quality controlled or verified. This is to ensure that the number and codes represent reasonable physical quantities that exist in the given time and location. There are three parts to the verification process: checking the drift track, checking the variable values, and checking for duplicate profiles. The track is checked to make sure that the date is valid, not listed as a future date or one that is farther in the past then the buoy was deployed, and to make sure that the position is not over land. The inferred speed between each measurement location is also checked to make sure that it is reasonable. Values of variables are checked against the regional range as well as others for validity and any spikes in gradients or large inversions; any discrepancies are flagged with specific flags. Duplicate checking will identify any data that are versions of the same observation. Exact matches where each version of the same observation is identical usually results in one observation being deleted, unless the data were gathered by two different methods, then both observations are specifically flagged and kept in the database. The results of the quality control procedure are the setting of flags or making corrections where instrument failure or human error is evident on the data that needs it (MEDS, 2006).

J-CAD buoys use six Sea-Bird SBE-37 IM CT sensors, two of which are equipped with pressure sensors. The SBE-37 IM accurately measures conductivity and temperature with optional pressure. It has an internal battery, non-volatile memory and uses an Inductive modem to transmit data and receive commands. It is specifically designed for moorings and other long-duration, fixed-site deployments. Over 100,000 measurements can be taken before the battery runs low and its real-time clock is accurate to within 2.6 minutes per year. The range of temperature and conductivity measurements match the IABP's POP's SBE-16 SEACAT (-5 to +35°C and 0 to 7 S m^{-1} respectively), but the SBE-37 IM has an initial temperature accuracy of 0.002°C and initial conductivity accuracy of 0.0003 S m^{-1}. The pressure sensor used has a range of 0 to 7,000 meters and is accurate to within 1%. Resolution of the temperature, conductivity, and pressure data are 0.0001°C, 0.00001 S m^{-1}, and 0.002% respectively (Sea-Bird Electronics Inc., 2006).

10.3 DRB PROFILE DISTRIBUTIONS

There are data from 108,564 drifting buoy casts in WOD05, which were submitted by three major research programs. The majority of DRB data came from International Arctic Buoy Program, Polar Science Center (IAPB, 75,533 casts). JAMSTEC provided 26,791 casts from

J-CAD buoys and Arctic Ocean Buoy Program (AOPB) submitted 8,240 profiles (see Figure 10.1).

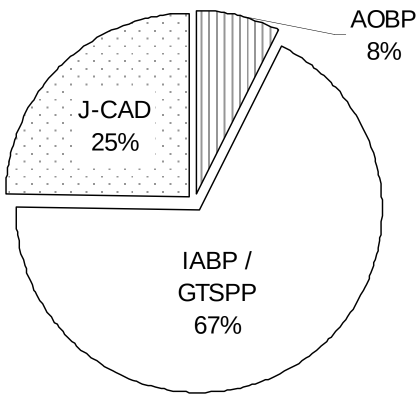

Figure 10.1. Distribution of the Drifter Buoys data in WOD05 among major research programs.

The geographic distribution of the DRB casts is illustrated on Figure 10.2. All DRB casts (except one Australian) are distributed in the northern hemisphere in Pacific, Atlantic and Arctic oceans. There are a few profiles from the Mediterranean Sea as well as the northern Indian Ocean, but they are only a minor part of the profile distribution.

The temporal distributions of the DRB data is shown in Table 10.3 as well as in Figure 10.3.

Table 10.4 gives national input to the DRB dataset by each contributing country.

Distribution of the DRB data as a function of depth at standard depth levels is illustrated in Figure 10.4.

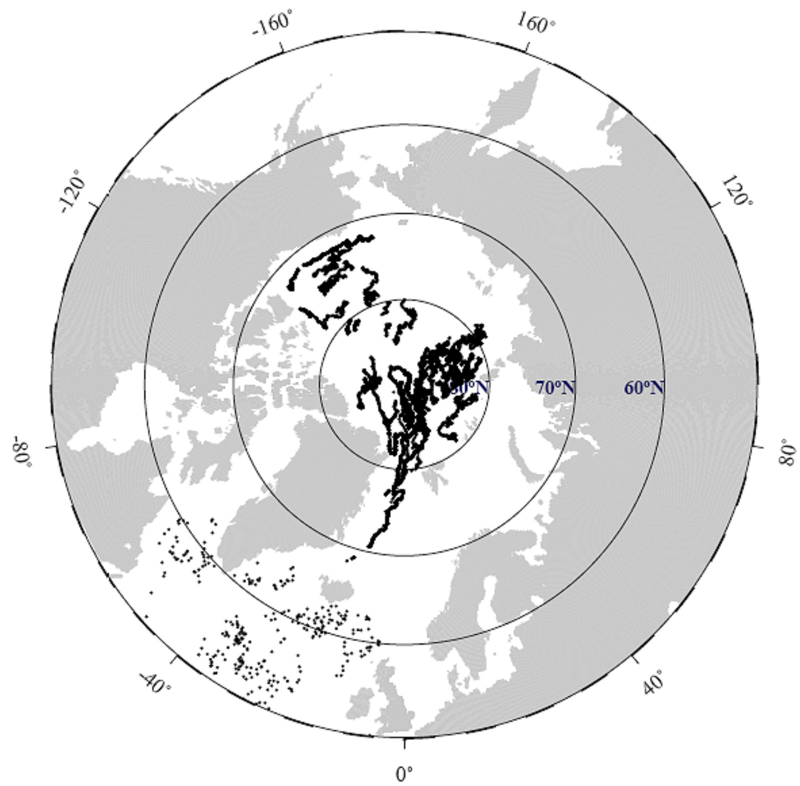

Figure 10.2. Geographic distribution of Drifting Buoy (DRB) Data in WOD05.

Table 10.3. The number of DRB profiles in as a function of year in WOD05.
The total number of profiles = 108,564.

YEAR	CASTS	YEAR	CASTS	YEAR	CASTS	YEAR	CASTS
1985	217	1990	1,175	1995	0	2000	12,611
1986	482	1991	1,422	1996	0	2001	62,952
1987	447	1992	606	1997	0	2002	9,249
1988	1,387	1993	462	1998	401	2003	7,905
1989	1,510	1994	532	1999	4,770	2004	2,436

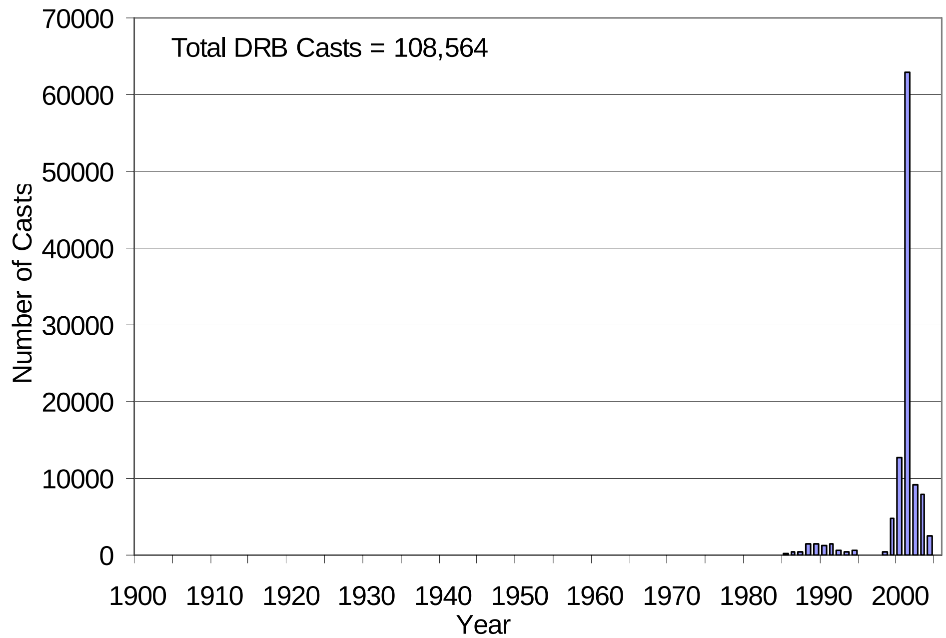

Figure 10.3. Time series of DRB casts as a function of year in WOD05.

Table 10.4. National contributions of DRB casts in WOD05.

NODC Country Code	Country Name	DRB Count	% of Total
35	France	58,100	53.52
49	Japan	26,791	24.68
31, 33	United States	23,133	21.31
99	Unknown	539	0.50
9	Australia	1	<0.01
	Total	*108,564*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

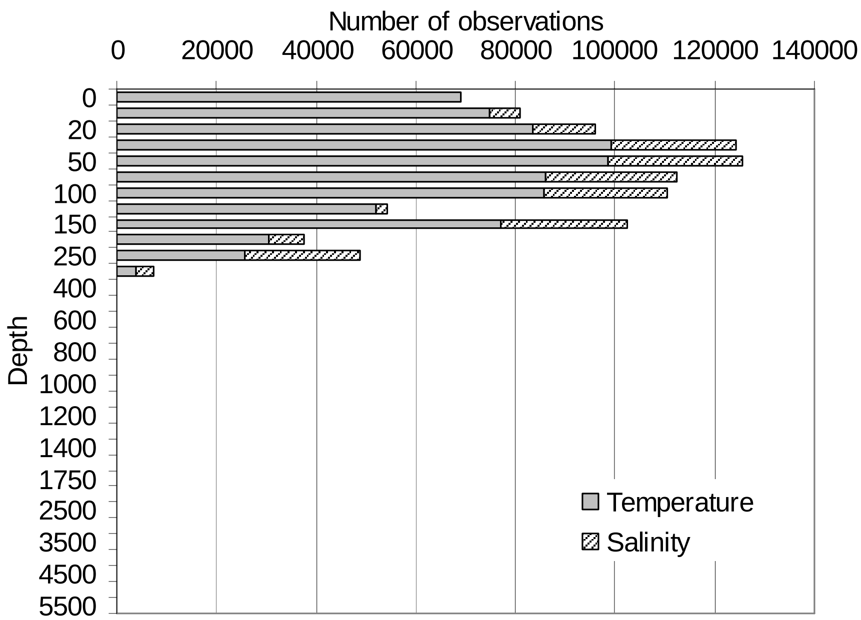

Figure 10.4. Distribution of DRB data at standard depth levels in WOD05.

10.4. RELEVANT WEB SITES

DBCP, 2006. Data Buoy Cooperation Panel, Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology, http://www.dbcp.noaa.gov/dbcp/index.html.

GTS, 2006. The Global Telecommunication System, World Meteorological Organization, http://www.wmo.ch/web/www/TEM/gts.html.

IABP, 2006. International Arctic Buoy Program, Polar Science Center, Applied Physics Laboratory, University of Washington, Washington, USA, http://iabp.apl.washington.edu.

JAMSTEC, 2006. JAMSTEC Compact Arctic Drifter (J-CAD), Arctic Ocean Climate System Group, Global Warming Observational Research Program, Institute of Observational Research for Global Change, Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan, http://www.jamstec.go.jp/arctic/J-CAD_e/jcadindex_e.htm.

MEDS, 2006. Marine Environmental Data Service (MEDS), Department of Fisheries and Oceans, Ontario, Canada, http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Home_e.htm.

NDBC, 2006. National Data Buoy Center (NDBC), National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Mississippi, USA, http://www.ndbc.noaa.gov.

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Rigor, I. 2002. I*ABP drifting buoy, pressure, temperature, position, and interpolated ice velocity.* Compiled by the Polar Science Center, Applied Physics Laboratory, Univ. of Washington, Seattle, in association with NSIDC. Boulder, CO: National Snow and Ice Data Center. Digital media.

CHAPTER 11: UNDULATING OCEAN RECORDERS DATA (UOR)

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11.1. INTRODUCTION

As stated on The Sir Alister Hardy Foundation's web-site (at http://192.171.163.165/history_cpr.htm): "The history of the Undulating Ocean Recorders (UOR) begins in 1925 when Sir Alister Hardy embarked on a two-year voyage to the Antarctic on the ship *Discovery* with the prototype of the Continuous Plankton Recorder (CPR Mark I). He designed this instrument specifically for the expedition. He recognized a need to sample over large space and time scales to evaluate changes in the abundance and distribution of plankton. In June 1932, the SS *Albatross* towed the first CPR and the continuous plankton survey was born. In 1959 the first transatlantic route was towed from Reykjavik to Newfoundland".

A need to develop a fast CPR, that would also be able to sample at more than one depth, was identified in the early 1970s and led to the development of the 'Undulating Oceanographic Recorder' by what is now Plymouth Marine Laboratory (http://www.pml.ac.uk/pml/). A machine called the Longhurst Hardy Plankton recorder to sample the plankton in vertical profiles was also developed (http://192.171.163.165/parables/a12.htm).

The modern UOR is a self-contained oceanographic sampler which can be towed from research vessels and merchant ships at speeds up to 25 knots. It can be launched and recovered by non-scientist crew-members while the vessel is under way. It can be used to carry instrumentation to sample plankton continuously and to measure chlorophyll, radiant energy, temperature, and salinity, all of which are recorded, with the measurement of depth (Aiken, 1981; Burt, 2000). This technique is often used for large marine ecosystem sampling or frontal zones because of its convenience and uninterrupted data coverage (Williams and Lindley, 1980; 1998; Pollard, 1986), ability to sample a large area in a reasonable period of time (Brown *et al.,* 1996), and it is expanding towards wider set of sensors used, such as by adding light absorption sensor and attenuation meters (Barth and Bogucki, 2000).

The WOD05 UOR dataset consist of temperature, salinity, chlorophyll concentration, and pressure profiles (see Table 11.1 for details) collected by CTD and fluorometer sensors mounted on a SeaSoar towing vehicle developed by Chelsea Technologies Group

Table11.1. List of all variables and profiles count in the WOD05 UOR dataset.

Measured Variables	Profiles
Temperature	46,163
Salinity	44,460
Oxygen	361
Chlorophyll	19,937
Pressure	46,705
Latitude	40,069
Longitude	40,069
Julian Day	40,069

(http://www.chelsea.co.uk) from an original design by the Institute of Oceanographic Sciences (now the Southampton Oceanography Centre, UK). SeaSoar is capable of undulating from the surface to 500 meters with faired cable or to 100m with unfaired at tow speed between 6.5-12 knots following a controlled and adjustable undulating path through the ocean. Sampled data, obtained from sensors mounted in SeaSoar, are transmitted to the towing vessel for processing, display and storage via a multi-core tow cable (http://www.chelsea.co.uk/Vehicles%20SeaSoar.htm).

WOD05 UOR data were collected in the framework of several major international programs in Atlantic, Pacific and Indian oceans from 1992 till 2000 (see Figure 11.1).

The majority of data (26,413 casts) came from the international research program "Tropical Ocean Global Atmospheres/Coupled Ocean Atmosphere Response Experiment" (TOGA/COARE). This program studied the interaction of the ocean and atmosphere in the western Pacific warm pool region. Field measurements were made along ~155°E line in 1992 - 1993 (for further details see TOGA/COARE web-site at http://www.soest.hawaii.edu/COARE/index.html).

A substantial amount of data was provided by National Marine Fishery Service (NMFS), which contributed 9,054 casts measured along the Oregon coast.

Another ample portion of the data was contributed by Joint Global Ocean Flux Study (JGOFS) – Antarctic Enviroments Southern Ocean Process Study (AESOPS) Program, which submitted 6,828 casts in the Antarctic Polar Front Zone area.

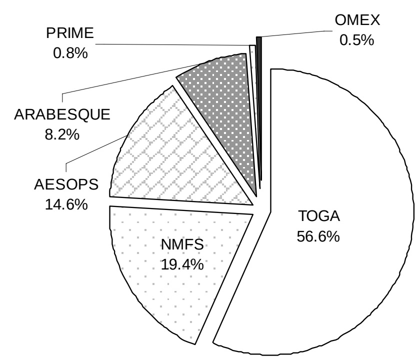

Figure 11.1. Distribution of the Undulating Ocean Recorder (UOR) data in WOD05 among the major research programs.

During the U.K. ARABESQUE project 3,829 profiles were collected in Indian Ocean. The ARABESQUE project was aimed to study the upper ocean microbial biogeochemistry in the Arabian Sea. Its focus was carbon and nitrogen cycling processes linked to climate change. The field programme was timed to coincide with the South West Monsoon and intermonsoon period through to the onset of the Northeast Monsoon (http://www.bodc.ac.uk/products/bodc_products/arabesque/).

The UOR dataset also includes 363 profiles that were collected during the Plankton Reactivity in the Marine Environment (PRIME) program, which was a National Environment Research Counsil of UK (NERC) funded thematic project to study the role of plankton in oceanic biogeochemical fluxes. The PRIME data stored in WOD05 were collected in the northeast Atlantic in 1996 (http://www.bodc.ac.uk/products/bodc_products/prime/).

The Ocean Margin Exchange (OMEX) project, the aim of which was to study, measure and model the physical, chemical and biological processes and fluxes occurring at the ocean margin, the interface between the open ocean and the continental shelf, contributed 218 casts. The first phase of the project, OMEX I, concentrated on studying the processes taking place along the northwest European shelf break. (http://www.bodc.ac.uk/products/bodc_products/omex_1/).

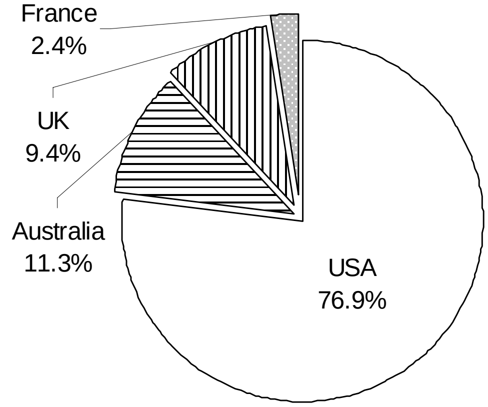

Figure 11.2. Distribution of the Undulating Ocean Recorders (OUR) data in WOD05 among the contributing countries.

11.2. UOR DATA PRECISION AND ACCURACY

The accuracy of UOR data depends on performance of the sensors used and post-processing of the data. A SeaSoar undulating vehicle is capable of carrying various instrumental packages. For the data stored in WOD05 database, the Sea-Bird Electronics SBE9/11+ CTD instrument was used most often. It is presumed that UOR data submitted into WOD05 were corrected for effects of: a) variable flow rate (Huyer *et al.,* 1993), b) thermal mass (Lueck, 1990; Morrison *et al.,* 1993), and c) offset between temperature and conductivity data (Larson, 1992; Morrison *et al.,* 1993).

11.3. UOR PROFILE DISTRIBUTIONS

Table 11.2 gives the yearly counts of UOR casts for the World Ocean and Figure 11.3 illustrate this graphically.

Table 11.2. The number of all UOR casts as a function of year in WOD05. Total number of casts = 46,705

YEAR	CASTS	YEAR	CASTS	YEAR	CASTS	YEAR	CASTS
1992	11,913	1994	3,974	1996	363	1998	0
1993	14,494	1995	59	1997	6,828	1999	0
						2000	9,054

Table 11.3 gives national input to UOR dataset by each contributing country. The geographic distribution of UOR casts and contributing projects is shown in Figure 11.4. Figure 11.5 illustrates distribution of the UOR data as a function of depth at standard depth levels.

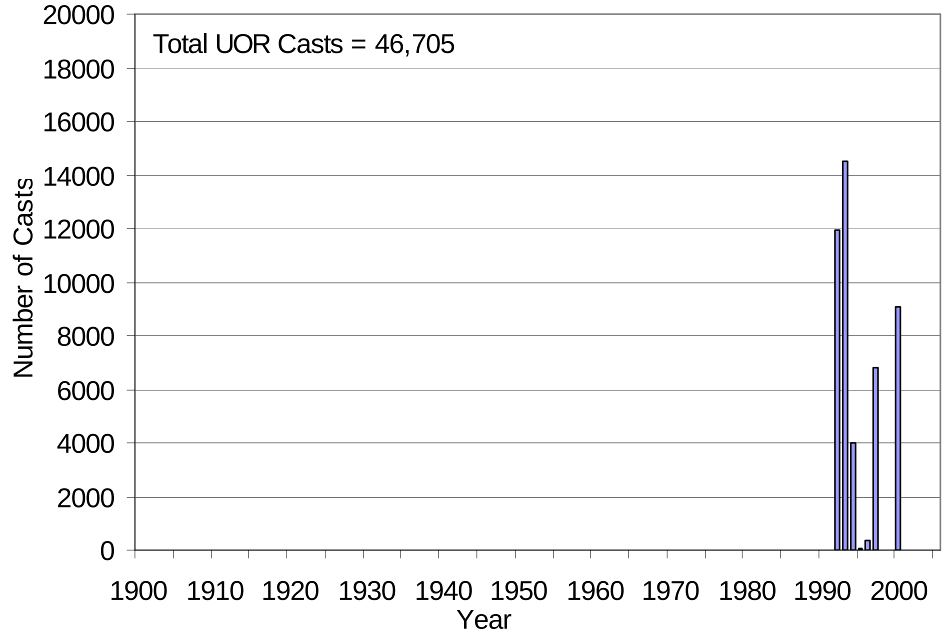

Figure 11.3. Temporal distribution of UOR casts in WOD05.

Table 11.3. National contributions of UOR casts in WOD05.

NODC Country Code	Country Name	UOR Casts	% of Total
31, 32	United States	35,908	76.88
09	Australia	5,269	11.28
74	United Kingdom	4,410	9.44
35	France	1,118	2.39
	Total	*46,705*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

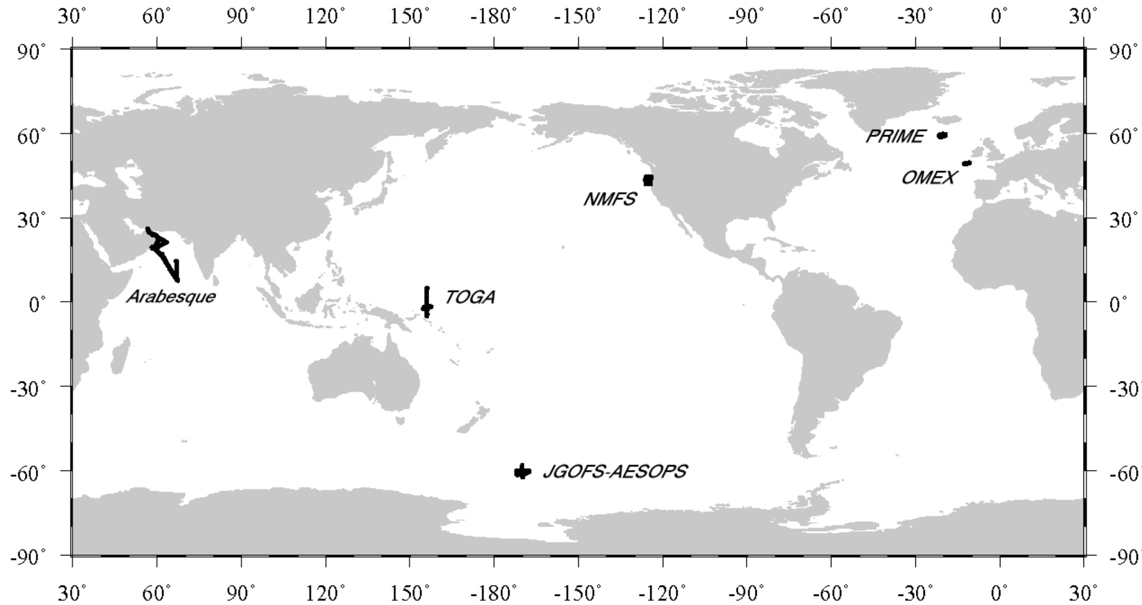

Figure 11.4. Geographic distribution of UOR casts and contributing projects in WOD05.

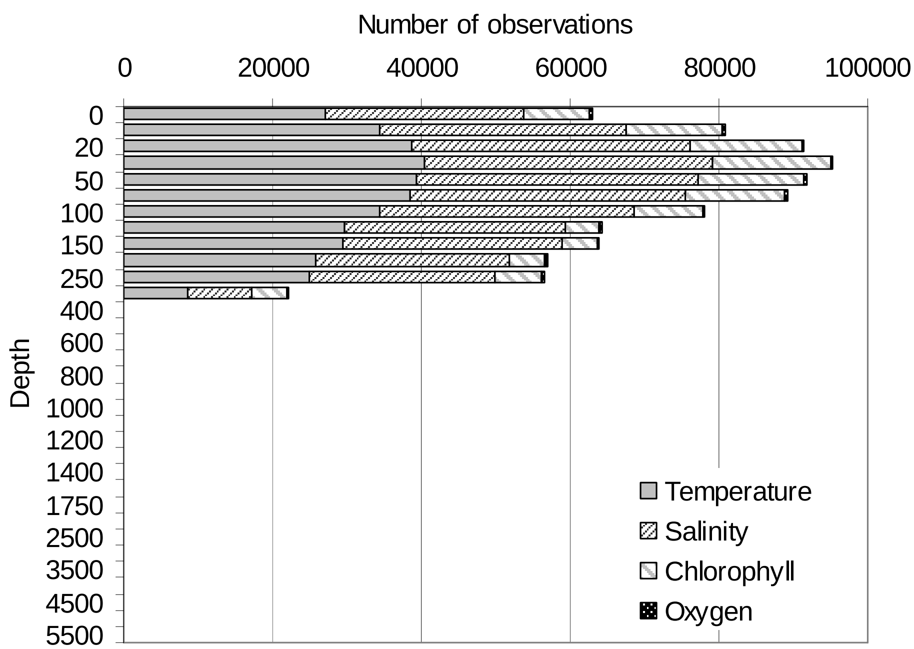

Figure 11.5. Distribution of UOR data at standard depth levels in WOD05.

11.4. RELEVANT WEB SITES

Chelsea Technologies Group: http://www.chelsea.co.uk/Vehicles.htm.
Ocean Margin Exchange (OMEX): http://www.bodc.ac.uk/omex/.
Plankton Reactivity in the Marine Environment (PRIME):
http://www.bodc.ac.uk/projects/uk/prime/;

ARABESQUE: http://www.bodc.ac.uk/products/bodc_products/arabesque/;
JGOFS-AESOPS: http://usjgofs.whoi.edu/jg/dir/jgofs/southern/rr-kiwi_6/.
Tropical Ocean Global Atmospheres/Coupled Ocean Atmosphere Response Experiment (TOGA-COARE): http://gcmd.nasa.gov/records/GCMD_COARE_ocmix_seasoar.html;
http://www.soest.hawaii.edu/COARE/;
http://www.soest.hawaii.edu/COARE/small_scale/data_report/2.1.html;
http://www.nodc.noaa.gov/archive/arc0001/9500002/01-version/data/0-data/nodc.documentation

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CHAPTER 12: AUTONOMOUS PINNIPED BATHYTHERMOGRAPH DATA (APB)

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12.1. INTRODUCTION

The Autonomous Pinniped Bathythermograph (APB) dataset contains *in situ* temperature data from time-temperature-depth recorders (TTDR) manually attached to pinnipeds (*e.g.*, elephant seals). Presently, the only data provided by instrumented pinnipeds and submitted to the NODC was collected by use of northern elephant seals (*Mirounga angustirostris*) in the northeast Pacific. This dataset was submitted by NOAA/National Marine Fisheries Service, Southwest Fisheries Center, Pacific Fisheries Environmental Laboratory, Pacific Grove, California as part of the Autonomous Pinniped Environmental Samplers Project.

Data from instruments attached to marine animals (instrumented animals) such as sea turtles, sea birds, sharks, tuna and pinnipeds, were initially collected for the principal purpose of studying animal ecology (Boehlert *et al.,* 2001; Block, 2005). In addition to animal ecology studies, scientists can use instrumented animals as autonomous ocean profilers to enhance sparse oceanographic observations in specific oceanic regions. The data supplied by instrumented animals could potentially fill data gaps due to harsh environmental conditions in areas such as the Bering Sea, Gulf of Alaska, and the Southern Ocean, especially in winter. These data can also help fill spatial gaps due to remoteness of some areas (McCafferty *et al.,* 1999) such as the southeast Pacific, and spatial gaps between routes of Ships-of-Opportunity (or Voluntary Observing Ships, VOS).

Temperature profiles from instrumented animals are less expensive than those obtained by traditional instruments such as Expendable Bathythermographs, XBT (Boehlert *et al.,* 2001). After recovering instruments from animals, the equipment can be re-used. The nominal vertical resolution of the available pinniped data (Boehlert *et al.,* 2001) is better than the vertical resolution of bottle station data and generally worse than the resolution of XBT and CTD data.

Northern elephant seals exhibit long duration dives (mean = 22 minutes, maximum = 120 minutes) with short surface intervals (1-3 minutes) (Le Bœuf *et al.,* 1988). They dive routinely down to 600 m, but can dive as deep as 1600 m (Delong and Steward, 1991). Figure 12.1 shows the vertical distribution of APB data.

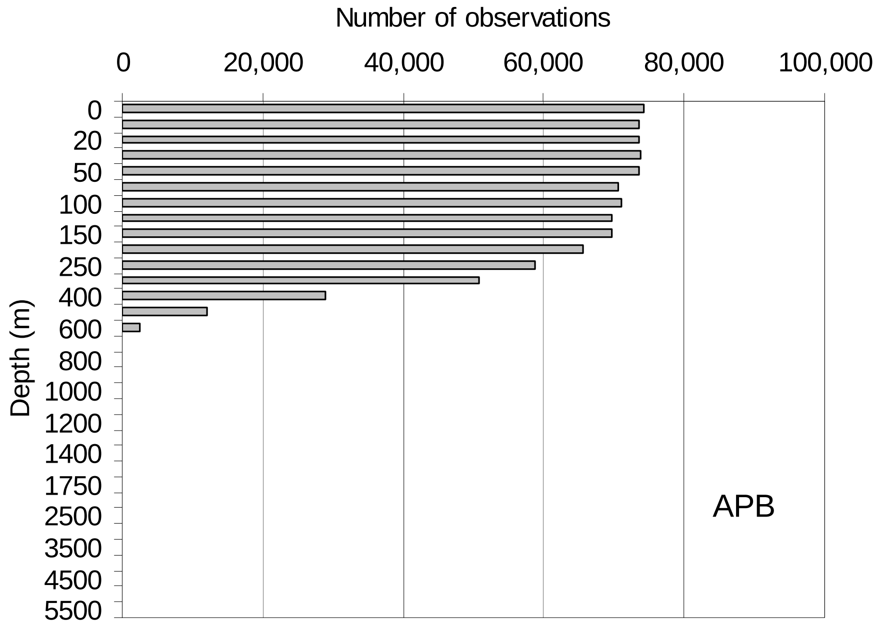

Figure 12.1. Distribution of Autonomous Pinniped Bathythermograph (APB) data at standard depth levels in WOD05.

12.2. INSTRUMENTATION AND DATA PRECISION

Geographic positions were determined using the ARGOS satellite transmitters. The half-watt satellite platform transmitter terminals (PTT; Model ST-6, Telonics, Mesa, Arizona) were affixed near the elephant seal's head using epoxy. The antenna was oriented to be out of the water when the seal surfaced. The PTT transmitted every 34 s while the seals were at the surface (Boehlert *et al.,* 2001).

Temperature and depth were recorded by the Mk 3 TTDR data recording tags manufactured by Wildlife Computers, Seattle, WA. The TTDRs were attached to the seal's pelage on the dorsal midline above the shoulders using epoxy. Observations of the animal's surface behavior showed only the head was out of the water and the back remained submerged, therefore the temperature sensor was always submerged (Boehlert *et al.,* 2001). The TTDR data were recorded every 30 s and were retrieved with the instruments when the seals returned to the rookery months later. The instrument has a temperature resolution of 0.1ºC and an accuracy of 0.5ºC. All of the TTDRs had a manufacturer's stated minimum recording temperature of 4.8ºC (Boehlert *et al.,* 2001).

The pressure transducers on the TTDRs were calibrated prior to deployment using a pressure station. The Mk 3 TTDRs used had two transducer channels. In order to increase the accuracy on shallower dives TTDRs were programmed to use channel 1 for depths <450 m (with accuracy <2 m) and channel 2 for depths >450 m (with accuracy <4 m) (Boehlert *et al.,* 2001).

After data retrieval in the field, data files were modified using the manufacturer's program (Wildlife Computer, Zoc.exe version 1.27). This modification was necessary to correct zero offset in depth. The software allowed visual inspection of all vertical profiles and it also allowed correction for surface drift. Since the seals surface after each dive, offset is adjusted for each dive. Some records required several offset corrections; some have a constant offset correction; and some records did not require any correction (Boehlert *et al.,* 2001).

12.4. APB PROFILE DISTRIBUTIONS

Depth and temperature were recorded by the Mk 3 TTDR as the elephant seals ascended and descended through the water column. When the seals surfaced, the ARGOS transmitter relayed their location and time stamp. During the seals multi-month migration, the seals dove continuously, night and day, capturing thousands of profiles along their migration route. The WOD05 has a total of 75,665 APB profiles. The dataset contains three years of data from March 1997 through May 1999: 19,875 profiles in 1997; 44,626 profiles in 1998; and 11,164 profiles in 1999. The geographic distribution of the APB data from 1997 to 1999 is shown in Figure 12.2.

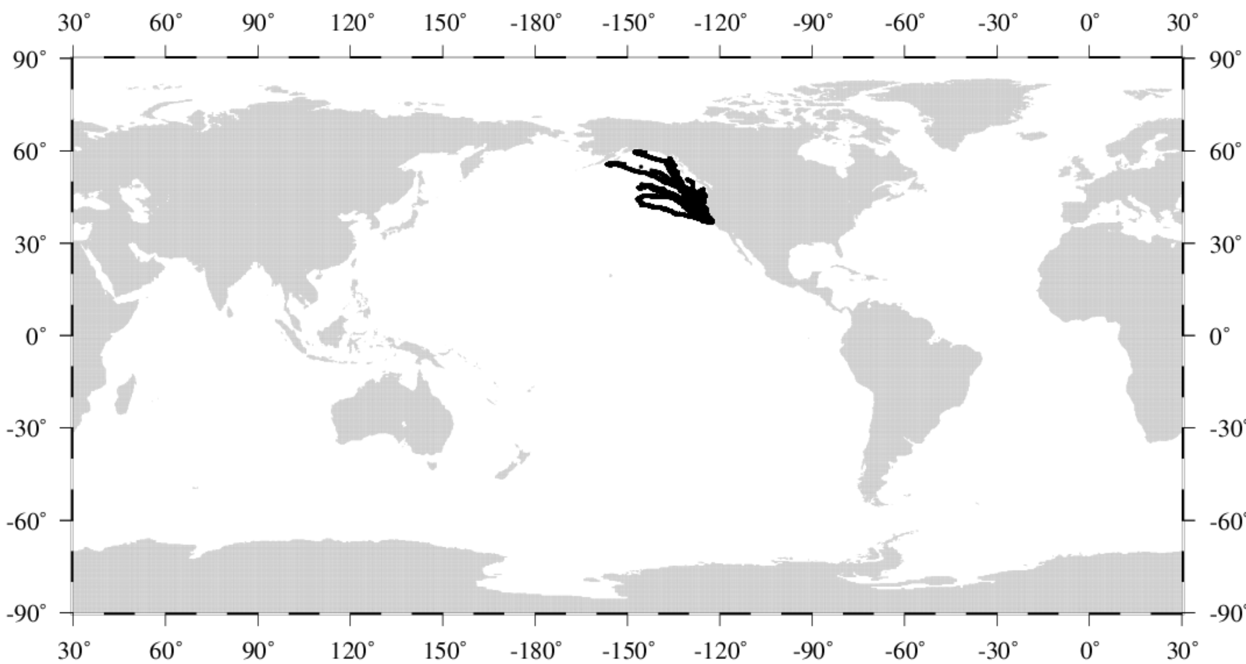

Figure 12.2. Geographic distribution of Autonomous Pinniped Bathythermograph data in WOD05 (submitted by Boehlert et al., 2001).

To fit the northern elephant seal data into the WOD format, the collected data were broken into distinct up and down profiles, with any long resting periods at the surface (depth = 0) removed. When an ARGOS position fix was made, the ARGOS-assigned quality flag for that fix (determined by the number of satellites receiving the signal) was stored along with the profile. Otherwise, the time intervals between the last and next ARGOS fixes were stored with the profile (second headers 84-86) (Jonhson *et al.,* 2006). WOD05 secondary header code 84 denotes ARGOS fix code; code 85 denotes ARGOS time (hours) from the last fix used to calculate position of the APB; and code 86 denotes ARGOS time (hours) to the next fix used to calculate position of the APB. In addition, each depth-temperature pair in a profile has latitude, longitude, and Julian-day attached to it. These values are interpolated between the two closest surface position fixes. Figure 12.3 is a sample output of an APB profile.

Longitude	Latitude	Year	Month	Day	Time	Cruise#	CC[1]	Prof_#
-122.761	37.440	1997	3	18	2.56	7	31	1

Num	Depth	Temp	Lat	Lon	Jday
1	0.00	10.700	37.440	-122.761	76.107
2	20.00	10.400	37.440	-122.762	76.107
3	68.00	9.700	37.440	-122.762	76.107
4	106.00	8.900	37.440	-122.762	76.108
5	132.00	8.600	37.440	-122.762	76.108
6	160.00	8.400	37.440	-122.763	76.108
7	184.00	8.300	37.440	-122.763	76.109
8	208.00	8.300	37.440	-122.763	76.109
9	230.00	8.200	37.440	-122.763	76.109
10	250.00	8.100	37.440	-122.764	76.110
11	264.00	8.000	37.440	-122.764	76.110
12	278.00	7.900	37.440	-122.764	76.110
13	286.00	7.900	37.440	-122.764	76.111
14	298.00	7.800	37.440	-122.765	76.111
15	312.00	7.700	37.440	-122.765	76.111
16	324.00	7.600	37.440	-122.765	76.112
17	336.00	7.600	37.440	-122.765	76.112
18	346.00	7.500	37.440	-122.766	76.113
19	356.00	7.500	37.440	-122.766	76.113
20	360.00	7.400	37.440	-122.766	76.113
21	366.00	7.300	37.440	-122.766	76.114
22	368.00	7.300	37.440	-122.767	76.114

Access#	573	
Project	371	
Station_Number	7968926	
Cast_Direction[2]	1	
T-S_Probe	13	
APBT_last_fix	0.235	
APBT_next_fix	9.101	
time_stamp	2006025	
Temperature	Instrument	801

Figure 12.3. Sample output of an APB profile.

[1] Column label "CC" denotes country code. In this example the code 31 is the United States.
[2] Cast_Direction value "1" denotes an upcast profile.

12.5. RELEVANT WEB SITES

NOAA/National Marine Fisheries Service, Southwest Fisheries Center, Pacific Fisheries Environmental Laboratory, Pacific Grove, California http://www.pfeg.noaa.gov/

Ship of Opportunity Programme (SOOP) http://www.ifremer.fr/ird/soopip/index.html

Voluntary Observing Ships (VOS) http://www.ndbc.noaa.gov/vosinfo.shtml

Wildlife Computers, Seattle, WA http://www.wildlifecomputers.com

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McCafferty, D.J., I.L. Boyd, T.R. Walker, and R.I. Taylor, 1999. Can marine mammals be used to monitor oceanographic conditions? *Marine Biology*, 134: 387-395.

CHAPTER 13: MICRO BATHYTHERMOGRAPH DATA (MICRO BT)

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13.1. INTRODUCTION

The Micro Bathythermograph (Micro BT) is a high-accuracy temperature and pressure instrument developed to record and report data electronically. WOD05 includes data collected with micro BT instruments manufactured by RBR Ltd. and Sea-Bird Electronics (SBE). The self-contained underwater instrument includes a rapid response thermistor and a strain gauge pressure sensor. Temperature and depth/pressure measurements are automatically archived in the underwater unit as it is lowered in the water column attached to a net, cable, or towed vehicle. The instrument can be programmed to measure and archive data at desired intervals. Upon retrieval, the underwater unit is connected to a computer and data are retrieved and archived. The micro BT instruments can also provide real time data using an underwater cable.

Micro BT instruments can measure temperatures over a varied range of depths, with RBR LTD. instruments being able to measure to a maximum depth of 1000 m, and SBE instruments to a maximum depth of 7000 m.

13.2. MICRO BT ACCURACY

RBR Ltd. reports a temperature resolution of 0.1°C, and SBE reports a temperature accuracy of ±0.002°C. Both manufacturers report a pressure accuracy of ±0.1% of full scale range.

13.3. MICRO BT PROFILE DISTRIBUTIONS

Table 13.1 gives the yearly counts of micro BT profiles for the World Ocean. Fig. 13.1 shows the temporal distribution of Micro Bathythermograph profiles for the World Ocean. Table 13.2 gives national contribution of Micro BT data. There are a total of 5,659 micro BT profiles for the entire World Ocean, all measured in the northern hemisphere (Figure 13.2).

Distribution of the micro BT data at standard depth is shown in Figure 13.3. Micro BT profiles are stored in the MBT dataset of WOD05.

Table 13.1. The number of all Micro BT profiles as a function of year in WOD05. Total Number of Profiles = 5,659

YEAR	PROFILES	YEAR	PROFILES	YEAR	PROFILES	YEAR	PROFILES
1992	182	1995	642	1998	478	2001	653
1993	354	1996	528	1999	556	2002	643
1994	314	1997	504	2000	662	2003	143

Table 13.2. National contributions of Micro Bathythermograph (Micro BT) profiles in WOD05.

NODC Country Code	Country Name	Micro BT Count	% of Total
31	USA	5,659	100.00

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

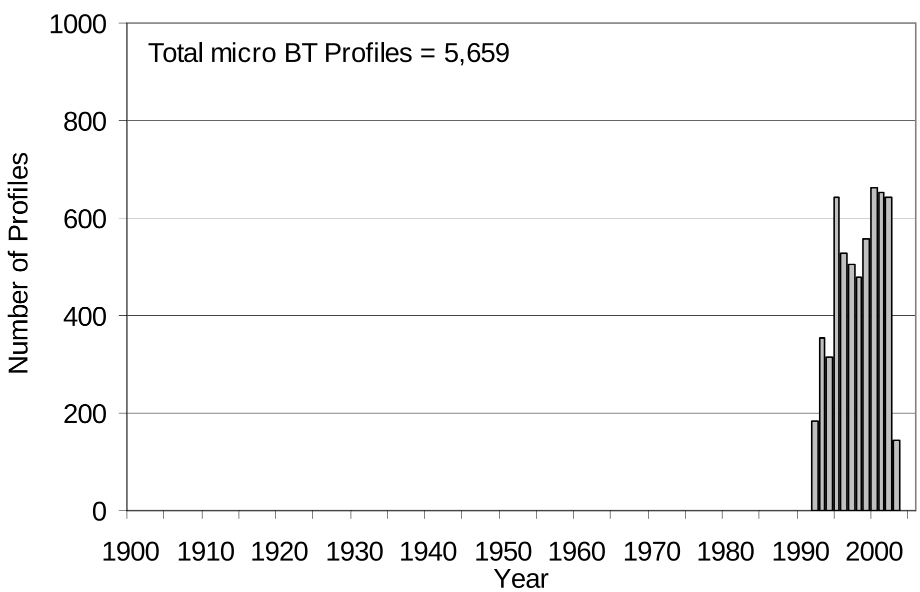

Figure 13.1. Temporal distribution of micro Bathythermograph data in WOD05.

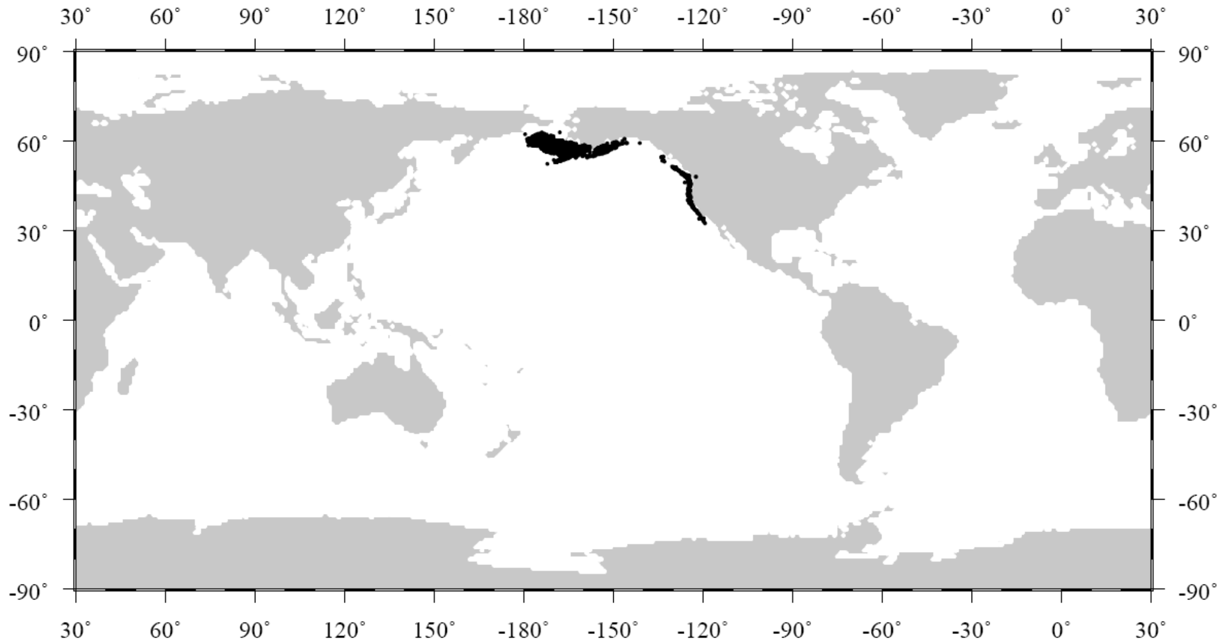

Figure 13.2. Geographic distribution of Micro Bathythermograph data in WOD05.

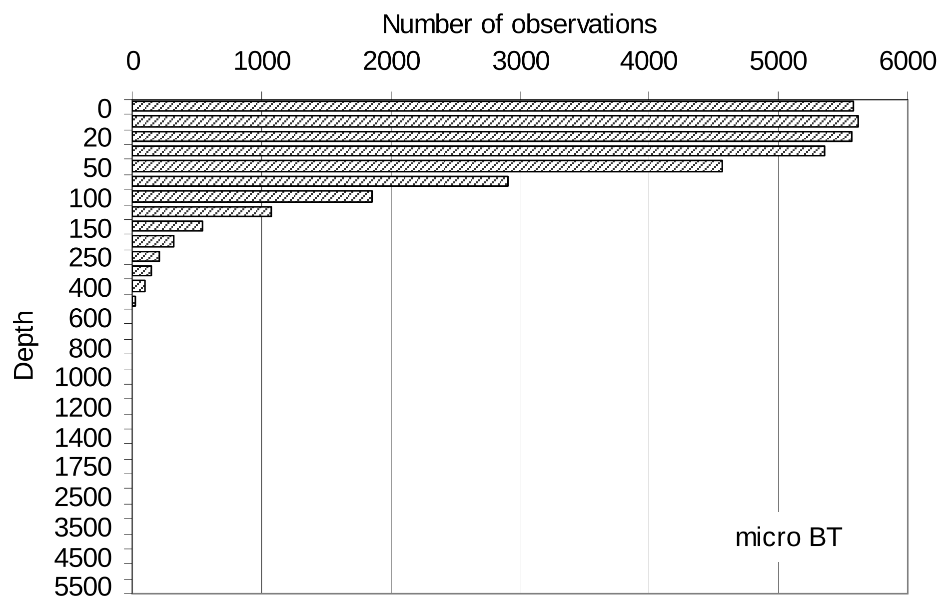

Figure 13.3. Distribution of micro Bathythermograph data at standard depth levels in WOD05.

CHAPTER 14: PLANKTON DATA

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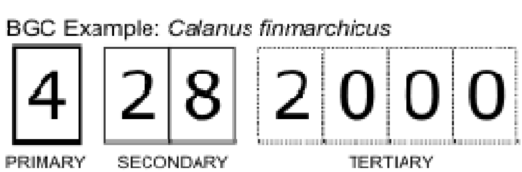
14.1. INTRODUCTION

The term 'plankton' comes from the Greek '*planktos*' (drifter). Plankton refers to floating or drifting organisms with limited locomotion powers (Kennish, 1990). While some forms of plankton passively drift by tides and currents, others are capable of independent swimming. The major plankton subdivisions include bacteria, phytoplankton, and zooplankton (Kennish, 1990). Planktonic organisms range in size from less than 2 microns to more than 2,000 microns (Levinton, 1995).

The plankton subset of the *World Ocean Database 2005* (WOD05) includes and extends the previously released *World Ocean Database 1998* (Conkright *et al., 1998*) and *World Ocean Database 2001* (O'Brien *et al.*, 2001). The WOD05 plankton data subset is a collection of measurements from serial bottle and plankton net-tow. The plankton measurements are represented in WOD05 as quantitative and qualitative abundance, and biomass data. The plankton measurements are stored in the OSD dataset.

Scientific taxonomic names in the WOD05 are stored as ITIS (Integrated Taxonomic Information System, http://www.itis.usda.gov) serial numbers. ITIS codes are not available for all plankton descriptions and biomass. WOD05 negative taxonomic codes (sequentially assigned numbers) were developed to preserve the original descriptions.

In addition to ITIS or negative taxonomic codes, each plankton description has a *Biological Grouping Code* (BGC) developed by O'Brien *et al.* (2001). The BGC is an ancillary code which places each taxon into broader groupings (*e.g., diatoms, copepods, phytoplankton*). The WOD05 user can access hundreds of individual taxons by using a single BGC code. The BGC groups are divided into *Primary* (e.g., Bacteria, Phytoplankton, Zooplankton), *Secondary* (e.g., cyanobacteria, diatoms, crustaceans), and *Tertiary Groups* (e.g., copepods). For example, the copepod *Calanus finmarchicus* has a BGC code of "4282000", specifying that it is in *Primary Group* "4" (zooplankton), *Secondary Group* "28" (crustaceans), and *Tertiary Group* "2000" (Copepods).



Broad, taxonomic group-based value range checks were used in WOD01 (O'Brien *et al.*, 2001) to flag extremely large or small values.

Table 14.1. WOD05 broad taxonomic group-based ranges.

Group	Min Value	Max Value	Units
Bacteria	0.001	5,000	$\# \cdot \mu l^{-1}$
Phytoplankton	0.001	50,000	$\# \cdot ml^{-1}$
Zooplankton	0.001	200,000	$\# \cdot m^{-3}$

Table 14.2. WOD05 biomass ranges.

Group	Min Value	Max Value	Units
Total Displacement Volume	0.005	10	$ml \cdot m^{-3}$
Total Settled Volume	0.025	50	$ml \cdot m^{-3}$
Total Wet Weight	0.5	10,000	$mg \cdot m^{-3}$
Total Dry Weight	0.01	500	$mg \cdot m^{-3}$
Total Ashfree Dry Weight	0.001	100	$mg \cdot m^{-3}$

Plankton counts and biomass measurements are stored with the data originator's units in WOD05 (*e.g*. counts in units of *"number per* m^3*", "count per* m^2*", "count per haul", "count per ml"*). To make comparison of different units easier, each count or biomass measurement has been recalculated into a common unit named *Common Biological Value* (CBV). The CBV value has a quality control flag associated with it.

WOD05 flags applied to Common Biological Values as follows:

0 - accepted value

1 - range outlier (outside of broad range check)

2 - questionable value

3 - group was not reviewed

4 - failed annual standard deviation check

The calculation method used to create the CBV is stored in the *CBV calculation method* field and described in detail in WOD05 documentation, Appendix 6.9, (Johnson *et al.*, 2006).

The typical plankton cast (for cast definition see Chapter 1), as represented in WOD05, stores taxon specific and/or biomass data in individual sets, called "Taxa-Record". Each "Taxa-Record" contains a taxonomic description, depth range (the upper and lower depth) of observation, the original measurements (*e.g.*, abundance, biomass or volume), and all provided qualifiers (*e.g.*, lifestage, sex, size, etc.) required to represent that plankton observation.

In addition to the observed data, a cast may include additional originator's metadata information such as the "institution" which collected and identified the species of plankton, the "voucher institution" (institution which stores samples), sampling gear (*e.g.*, Bongo Net, Continuous Plankton Recorder), net mesh size, sampling method (*e.g.*, vertical, horizontal, or oblique haul), meteorology, and other general header information which are described in detail in WOD05 documentation (Johnson *et al.*, 2006).

```
Longitude  Latitude  Year  Month  Day   Time Cruise#   CC   Prof_#
-4.883      79.017    1991     6       9    ----      10438    06   2087562

Mesh_size      200.000 Type_tow             2.000 Lge_removed      1.000
Gear_code      118.000 net_mouth_area    0.300 Lge_removed_len    1.000
Tow_speed_avg    1.944

Taxa-Record #1
 Param_number    85263.000      upper_depth     0         lower_depth               100.000
 Taxon_lifestage  25.000        Taxon_count     18.600  Taxon_modifier            2.000
 Units            70.000        CBV_value       18.600  CBV_calc_meth             70.000
 CBV_flag         3.000         BGC_group_code           4282000.000

Taxa-Record #2
 Param_number    -404.000000  upper_depth     0         lower_depth               100.000
 int_value        3100.000      Units     69.000  CBV_value        31.000
 CBV_calc_meth   69.100        CBV_flag        3.000     BGC_group_code            -404.000000

 Taxa-Record #3
 Param_number    85263.000      upper_depth     0         lower_depth               100.000
 Taxon_lifestage  26.000        Taxon_count     0.100    Taxon_modifier            2.000
 Units            70.000        CBV_value       0.100    CBV_calc_meth             70.000
 CBV_flag         3.000         BGC_group_code           4282000.000      etc ……….

 Access#                  772
 Project                  435
 Platform                 199
 Institution              892
 Station_Number           9617720
 Orig_Stat_Num            7
 Bottom_Depth             1413.000
 T-S_Probe                7.000
 NODCorig                 3.000
```

Figure 14.1. An example of a plankton cast in WOD05 (using provided output software).

The alternative way to look at plankton cast is a "csv" (comma-separated value) Excel output file, which is available only through the WODselect – online WOD05 database retrieval system (http://www.nodc.noaa.gov/OC5/SELECT/dbsearch/dbsearch.html).

```
CAST   ,,9617720,WOD Unique Cast Number,WOD code,,,,,,,,,,
NODC Cruise ID,,06-10438      ,,,,,,,,,,,,
Originators Station ID,,7,,,integer,,,,,,,,,
Originators Cruise ID,,,,,,,,,,,,,,
Latitude,,79.0167,decimal degrees,,,,,,,,,,,
Longitude,,-4.8833,decimal degrees,,,,,,,,,,,
Year,,1991,,,,,,,,,,,,
Month,,6,,,,,,,,,,,,
Day,,9,,,,,,,,,,,,
METADATA,,,,,,,,,,,,,,
Country,,6,NODC code,GERMANY, FEDERAL REPUBLIC OF,,,,,,,,,
Accession Number,,772,NODC code,,,,,,,,,,,
Project,,435,NODC code,IAPP (International Arctic Polynya Programme),,,,,,,,,,
Platform,,199,OCL code,POLARSTERN,,,,,,,,,,
Institute,,892,NODC code,ALFRED-WEGENER-INSTITUTE (BREMERHAVEN),,,,,,,,,,
Bottom depth,,1413,meters,,,,,,,,,,,
Database origin,,3,WOD code,GODAR Project,,,,,,,,,,
BIOLOGY METADATA,,,,,,,,,,,,,,
Mesh size,,200,microns,,,,,,,,,,,
Type of tow,,2,WOD code,VERTICAL TOW,,,,,,,,,,
Large plankters removed, ,1,WOD code,yes,,,,,,,,,,
Gear,,118,WOD code,Bongo Net,,,,,,,,,,
Net mouth area,,0.3,m2,,,,,,,,,,,
Min length removed,,1,cm,,,,,,,,,,,
Average tow speed,,2,knots,,,,,,,,,,,
BIOLOGY,Upper Z,Lower Z,Measuremnt Type,ORIGINAL VALUE ,F,Orig unit,WOD CBV value
,F,_unit,_meth,WOD BGC,ITIS TSN,mod,lif,
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(multiple species),LIFE STAGE=C1: COPEPODITE I
2,0. meters,100. meters,Total Dry Mass,3100,0,mg/m2,31,3,mg/m3,69.1,-404,Zooplankton Dry Weight
(mg/unit),,,,,,,,,,,
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(multiple species),LIFE STAGE=C2: COPEPODITE II
......
END OF BIOLOGY SECTION
```

Figure 14.2. An example of a plankton cast in 'csv' output file available on-line through the WODselect

14.2. DATA SOURCES

The plankton data that comprised WOD05 have been contributed by 32 countries, 125 institutions and involved more than 40 projects. Significant amounts of data (49,867 casts) have no information about the submitting organization. Substantial amounts of historical biomass and abundance data are from the archives of the National Oceanographic Data Center (NODC) and the World Data Center for oceanography, Silver Spring.

The largest portion (34,897 casts; 47.56 %) of the zooplankton and biomass data have been acquired through the California Cooperative Oceanic Fisheries Investigations (CALCOFI) project. The CALCOFI project was initiated in 1949 to study the collapse of the U.S. west coast sardine fishery. Hydrographic casts have been occupied from 1950 to the present along cross-shelf transects. Additional information can be found on CALCOFI's Web Page, http://www.calcofi.org .

The Outer Continental Shelf Environmental Assessment Program (OCSEAP) contributed another large portion of the plankton data (7,920 casts; 10.79 %). The OCSEAP was established in 1984 by basic agreement between the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) and the U.S. Department of the Interior (USDOI), Minerals Management Service (MMS) for environmental studies of Alaskan Outer Continental Shelf waters considered for oil development. The OCSEAP office located in Fairbanks issues a monthly Arctic Project Bulletin, Truett, J. C. (ed.), 1985.

A significant amount of data was received through the Eastern Tropical Pacific Ocean (EASTROPAC) program (5,544 casts; 7.56 %). The first EASTROPAC survey (February 1967 through March 1968) was a cooperative effort towards the understanding of the oceanography of the eastern Tropical Pacific Ocean. The main goals were to provide data necessary for a more efficient use of the marine resources of the area, especially tropical tunas, and also to increase knowledge of the ocean circulation, air-sea interaction, and ecology of the region. The U.S. Bureau of Commercial Fisheries (presently National Marine Fisheries Service) NMFS was the coordinating agency. Participating scientists were primarily from the NMFS, Scripps Institution of Oceanography, and the Inter-American Tropical Tuna Commission, (http://swfsc.nmfs.noaa.gov/PRD/atlas/eastropacsplash.html).

The Kuroshio Exploitation and Utilization Research (KER) program provided (4,234 casts; 5.77 %). KER was designed to study the subtropical circulation system, marine ecology, and fishery around Japan. The program was conducted in 1977 – 1995.

Table 14.3 gives project contributions of plankton casts sorted by percent contribution from each project.

Table 14.3 Project contributions of plankton casts sorted by percent contribution from each project.

NODC Project Code	Project Name	# Casts	% of Total
33	CALCOFI: California Cooperative Oceanic Fisheries Investigation	34,897	47.58
81	OCSEAP: Outer continental shelf of environmental assessment program	7,920	10.80
3	EASTROPAC (1967-1968)	5,544	7.56
243	KER: Kuroshio exploitation and utilization research (1977 - 1995)	4,234	5.77
93	BRINE DISPOSAL	4,193	5.72
51	MARMAP: Marine Resource Monitoring Assessment Prediction Program	2,208	3.01
25	IIOE: International Indian Ocean Expedition	2,045	2.79
240	USAP or USARP : United States Antarctic Research Project	1,770	2.41
372	OMEX: Ocean margin exchange project	1,234	1.68
367	GLOBEC: Georges Bank Program	951	1.30
361	JGOFS/AESOPS: US JGOFS Antarctic Environments Southern	943	1.29

NODC Project Code	Project Name	# Casts	% of Total
	Ocean Process Study		
345	North Sea Project	827	1.13
241	BIOMASS: Biological Investigations of Marine Antarctic Systems and Stocks	712	0.97
322	SKIPJACK	684	0.93
365	JGOFS/ARABIAN: Arabian Sea Process Studies	657	0.90
31	CSK: Cooperative Study of the Kuroshio	599	0.82
83	OCS-SOUTH: Texas	533	0.73
275	JGOFS/BATS: Bermuda Atlantic Time Series	495	0.67
82	PSERP: Mesa Puget Sound	396	0.54
200	JGOFS: Joint Global Ocean Flux Study	363	0.49
273	EASTROPIC: Eastern Tropical Pacific 1955	323	0.44
410	TASC: Trans Atlantic Study of Calanus	300	0.41
310	JGOFS/EQPAC: Equatorial Pacific basin study	279	0.38
96	EPA: Buccaneer oil field	214	0.29
321	BOFS: Biogeochemical Ocean Flux Study	180	0.25
443	IMECOCAL: Investigaciones Mexicanas De La Corriente De California	174	0.24
34	MAZATLAN	119	0.16
280	Coastal Transition Zone	100	0.14
245	SEFCAR: South Eastern Florida and Caribbean Recruitment	88	0.12
344	POFI: Pacific Ocean Fish & Inverts	86	0.12
328	SIBEX: Second International Biomass Experiment - Fr	63	0.09
312	CEAREX: Coordinated Eastern Arctic Experiment	63	0.09
435	IAPP: International Arctic Polynya Programme	41	0.06
90	ONR: Office of Naval Research	39	0.05
71	IDOE/CUEA	30	0.04
434	ARCTIC OCEAN SECTION: Canada/U.S. joint expedition	18	0.02
77	SCOPE	11	0.01
447	Marine Food Chain Research Group	10	0.01
444	GSP: Greenland Sea Project	5	0.01
	Total	73,348	100.00

14.3. PLANKTON DATA DISTRIBUTIONS

The WOD05 plankton subset consists of 150,250 globally distributed casts for the period 1905 - 2004. The geographic distribution of plankton casts for WOD05 is shown in Figure 14.4. Table 14.4 gives the yearly counts of plankton casts in the WOD05. Table 14.5 gives national contribution of plankton casts sorted by percent contribution from each country.

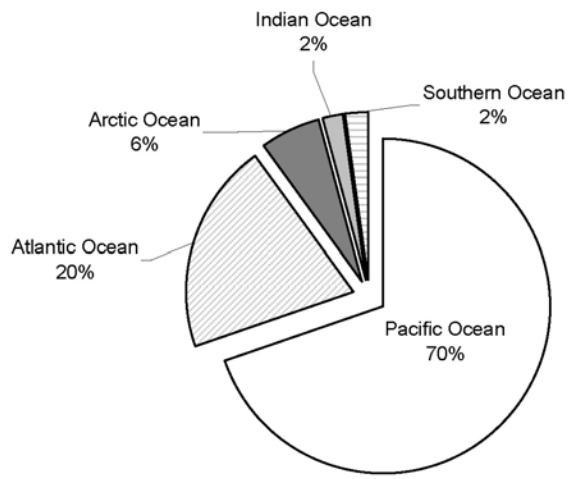

Figure 14.3. Contributions of plankton casts from different basins.

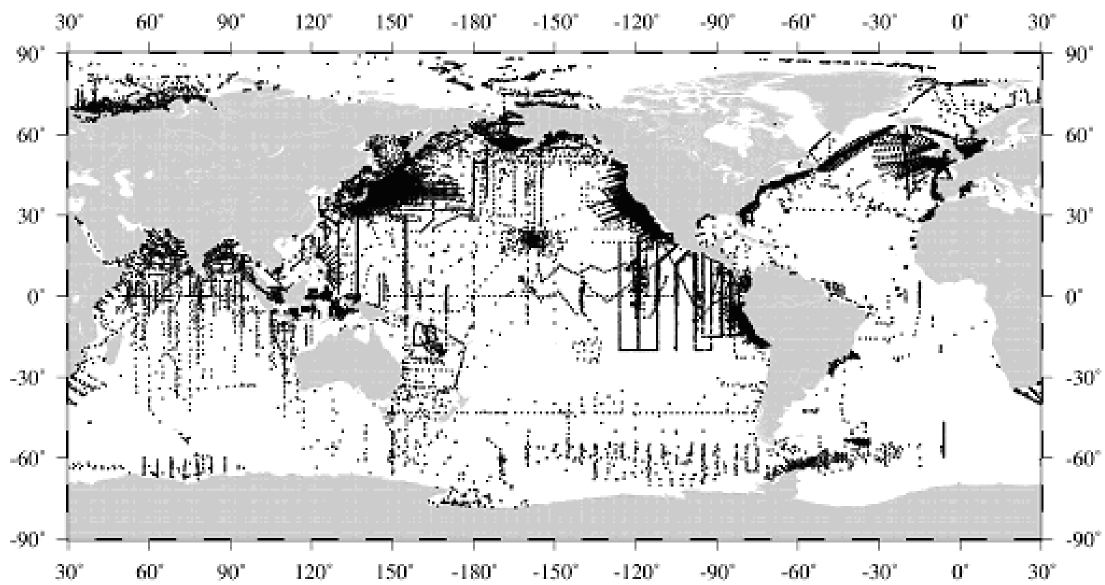

Figure 14.4. Geographic distribution of plankton (150,250 casts) in WOD05.

Table 14.4. Number of plankton casts in WOD05 as a function of year for the World Ocean
Total Number of Casts = 150,250

YEAR	CASTS	YEAR	CASTS	YEAR	CASTS	YEAR	CASTS
1905	34	1947	24	1968	2613	1988	2735
1913	6	1949	98	1969	2382	1989	1711
1914	5	1950	509	1970	1115	1990	1438
1915	9	1951	2089	1971	2255	1991	914
1921	17	1952	2218	1972	3586	1992	1455
1925	17	1953	3165	1973	2228	1993	978
1927	16	1954	3725	1974	2104	1994	1264
1928	2	1955	3386	1975	3563	1995	3165
1929	71	1956	2497	1976	3520	1996	2500
1930	46	1957	2404	1977	4277	1997	3301
1931	36	1958	2824	1978	8269	1998	2950
1932	18	1959	3412	1979	4586	1999	2728
1933	19	1960	2821	1980	4314	2000	22
1934	179	1961	1834	1981	6685	2001	20
1936	123	1962	2666	1982	4739	2002	22
1938	6	1963	3459	1983	3770	2003	24
1939	10	1964	3662	1984	3217	2004	21
1940	2	1965	3131	1985	3142		
1942	2	1966	3614	1986	2825		
1946	6	1967	5668	1987	1982		

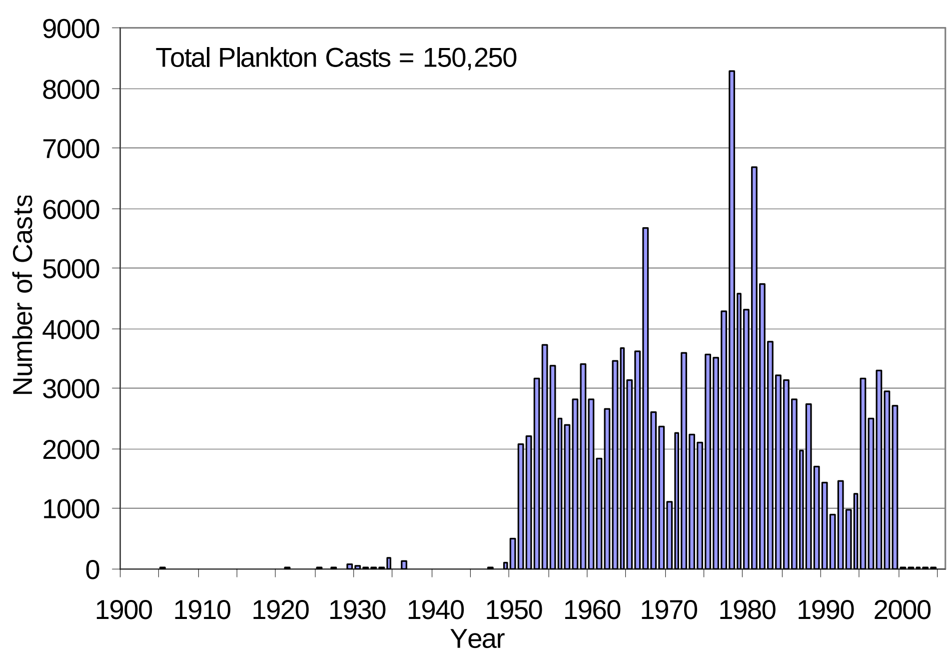

Figure 14.5. Temporal distributions of plankton casts in WOD05 as a function of year.

Table 14.5. National contributions of plankton casts in WODC05.

NODC Country Code	Country Name	# Casts	% of Total
31	United States	71,309	47.46
49	Japan	38,077	25.34
74	United Kingdom	15,680	10.44
90, RU	Union of Soviet Socialist Republics / Russia	8,108	5.40
65	Peru	6,827	4.54
42	Indonesia	2,098	1.40
68	Portugal	1,611	1.07
41	India	970	0.66
06	Germany Federal Republic of	868	0.58
09	Australia	763	0.51
58	Norway	403	0.27
28	Ecuador	352	0.23
57	Mexico	293	0.20
14	Brazil	199	0.13
24	Korea Republic of	193	0.13
66	Philippines	184	0.12
67	Poland	158	0.11
21	Taiwan	141	0.09
91	South Africa	141	0.09
59	New Caledonia	136	0.09
22	Colombia	97	0.06
29	Spain	71	0.05
11	Belgium	38	0.03
64	Netherlands	36	0.02
SI	Singapore	35	0.02
62	Pakistan	22	0.01
08	Argentina	11	0.01
77	Sweden	11	0.01
86	Thailand	10	0.01
	Total	*150,250*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

14.4. PLANKTON CONTENT

The plankton measurements are represented in WOD05 as quantitative and qualitative abundance, and biomass data. The majority (53 %) of plankton measurements are numeric abundance. Contributions of plankton casts from different measurements are shown in Figure 14.6.

14.4.1. Abundance

The majority (89 %) of plankton abundance measurements is numeric (*e.g.*, the number of individuals counted per sample or haul). The descriptive abundance measurements (*e.g.*, individual was "rare", "common", or "abundant" in sample or haul) are present in smaller amount (11 %) of total abundance.

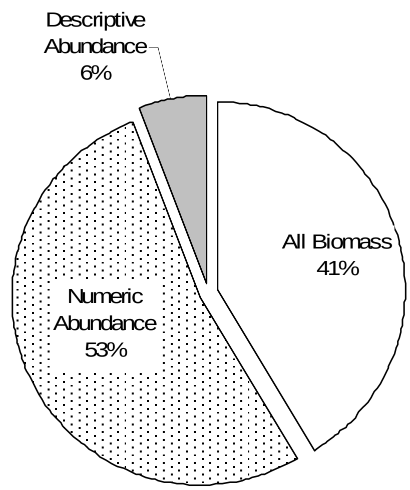

Figure 14.6. Contributions of plankton casts from different measurements.

Table 14.6 WOD05 abundance measurements content.

BGC Code	Taxonomic Description	# of casts. Numeric abundance	# of casts. Descriptive abundance
1000000	**BACTERIOPLANKTON** *all sub-groups*	**1,986**	**26**
1010000	CYANOBACTERIA	974	25
2000000	**PHYTOPLANKTON** *all sub-groups*	**24,344**	**7,223**
2010000	BACILLARIOPHYTA (DIATOMS)	20,622	5,666
2020000	DINOFLAGELLATA	12,582	6,771
2030000	CHRYSOPHYTA (CHROMOPHYTES)	4,919	1,065
2040000	EUGLENOPHYTA (CHLOROPHYTA)	1,357	162
2050000	HAPTOPHYTA (COCCOLITHOPHORES)	3,777	291
3000000	**PROTISTS** *all sub-groups*	**12,773**	**2,400**
3010000	MASTIGOPHORA miscellaneous flagellate protozoa *excludes groups below*	380	9
3020000	AMOEBIDAE	42	0
3030000	FORAMINIFERA	4,215	96
3040000	HELIOZOA	30	53
3050000	RADIOLARIA	3,651	263
3060000	CILIOPHORA	3,727	2,080
4000000	**ZOOPLANKTON** *all sub-groups*	**38,043**	**4,172**
4020000	PORIFERA	1,941	3
4030000	CNIDARIA	12,787	2,184
4040000	CTENOPHORA	3,720	97

BGC Code	Taxonomic Description	# of casts. Numeric abundance	# of casts. Descriptive abundance
4060000	PLATYHELMINTHES	2,038	0
4070000	NERMETEA	2,326	1
4100000	ROTIFERA	3,635	92
4110000	KINORHYNCHA	0	1
4140000	ENTOPROCTA	1	0
4150000	NEMATODA	2,047	7
4170000	BRYOZOA	3,135	27
4180000	PHORONIDA	2,198	0
4190000	BRACHIOPODA	2,012	1
4200000	MOLLUSCA	33,703	1,120
4202500	Gastropoda	12,947	366
4205000	Bivalvia	2,348	115
4206000	Scaphopoda	85	0
4207500	Cephalopoda	4,103	26
4210000	PRIAPULIDA	0	1
4220000	SIPUNCULA	2,075	2
4240000	ANNELIDA	10,716	1,771
4245000	Polychaeta	8,956	1,766
4270000	ARTHROPODA	2,529	31
4280000	CRUSTACEA	32,765	3,947
4281000	Ostracoda	9,017	208
4282000	Copepoda	29,431	3,692
4283000	Cirripedia	6,686	489
4284000	Mysidacea	4,246	26
4286000	Isopoda	3,828	55
4287000	Amphipoda	13,830	1,372
4288000	Euphausiacea	14,773	1,649
4289000	Decapoda	13,177	1,025
4290000	POGONOPHORA	1	0
4300000	ECHINODERMATA	25,282	475
4310000	CHAETOGNATHA	21,605	2,720
4320000	HEMICHORDATA	2,003	0
4330000	TUNICATA	15,309	2,811
4335000	Thaliacea	5,058	53
4337500	Appendicularia	14,003	662
4339000	Cephalochordata	2,458	17
5000000	**ICHTHYOPLANKTON** *all sub-groups*	**49,091**	**177**

The geographic distribution of numerical abundance casts of major plankton groups for WOD05 is shown in Figures 14.7 – 14.11.

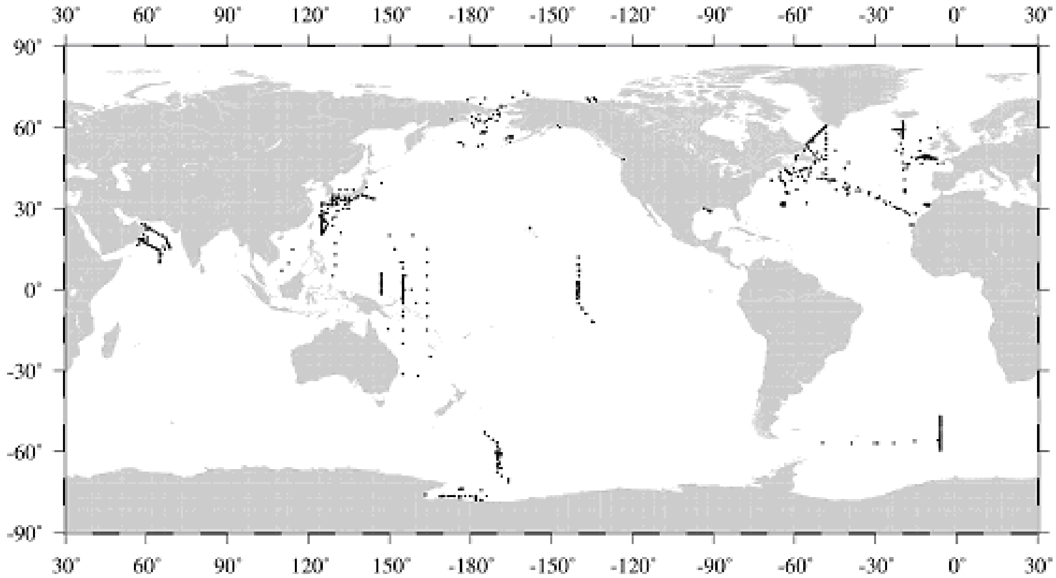

Figure 14.7. Geographic distribution of bacterioplankton numerical abundance (1,986 casts) in WOD05.

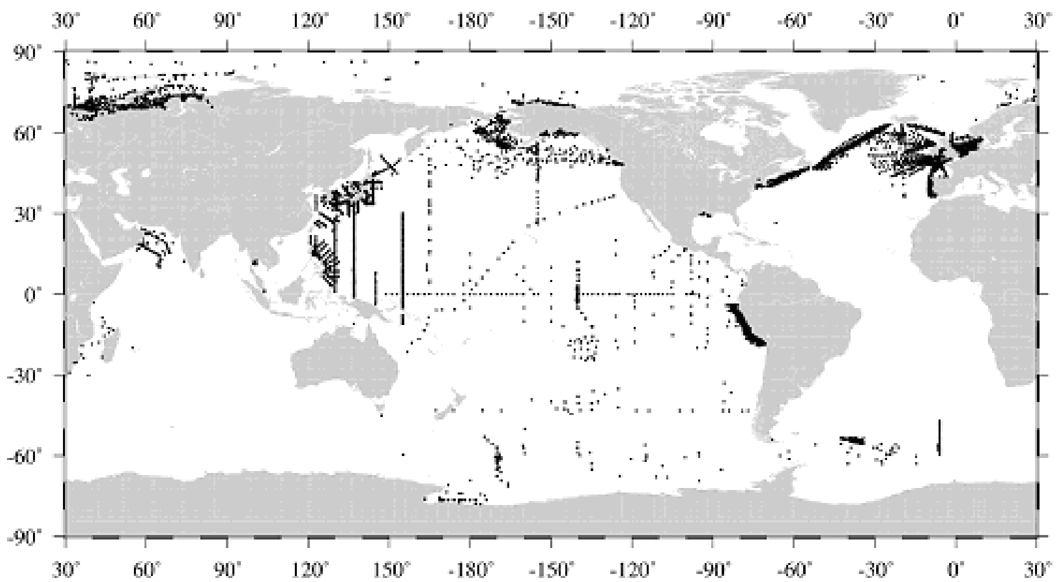

Figure 14.8. Geographic distribution of phytoplankton numerical abundance (24,344 casts) in WOD05.

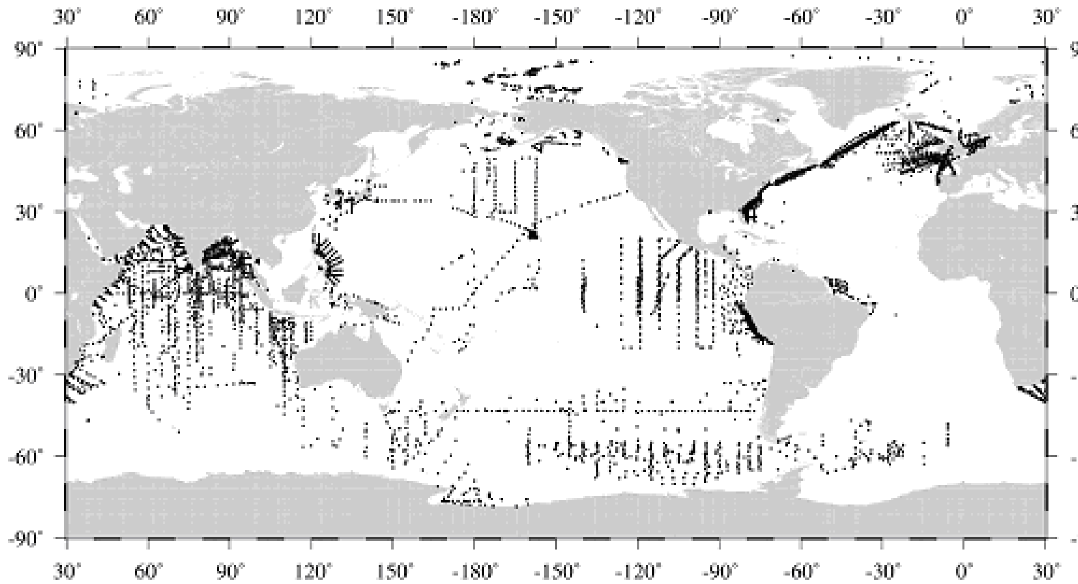

Figure 14.9. Geographic distribution of protists numerical abundance (12,773 casts) in WOD05.

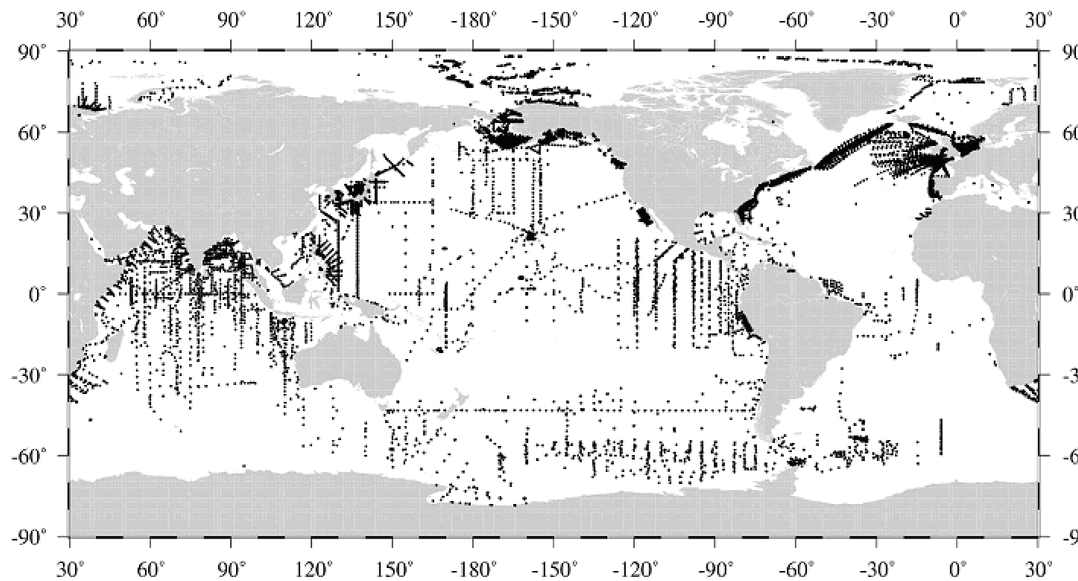

Figure 14.10. Geographic distribution of zooplankton numerical abundance (38,043 casts) in WOD05.

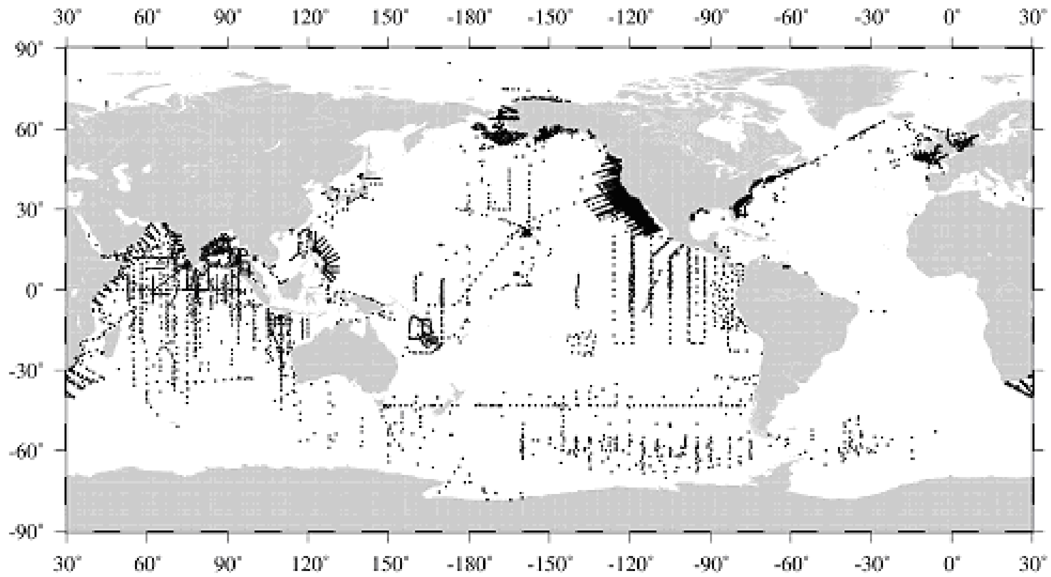

Figure 14.11. Geographic distribution of ichtyoplankton numerical abundance (49,091 casts) in WOD05.

14.4.2. Biomass

Biomass has been expressed by settled volume, displacement volume, wet weight, dry weight, and ash-free dry weight, defined by Omori and Ikeda (1984) as:

"*Settled volume*: the volume of a plankton sample poured into a graduated cylinder or sedimentation tube of 50-100 ml in volume and allowed to settle for 24 hours.

Displacement volume: the volume of plankton estimated by the volume of water displaced after adding the plankton sample into a graduated cylinder.

Wet Weight: the weight of plankton determined after eliminating as much surrounding water as possible.

Dry Weight: the weight of plankton determined after removal of all water and heat dried to a final weight at 60-70^{o}C.

Ash-free Dry Weight: a known weight of the dry sample ashed to a final weight at 450-500^{o}C".

The majority of WOD05 plankton biomass measurements are displacement volumes.

Table 14.7. WOD05 biomass measurements content.

BGC Code	Taxonomic Description	# Casts	% of Total
-401	Total Displacement Volume	62,747	61.62
-402	Total Settled Volume	7,984	7.84
-403	Total Wet Weight	28,988	28.47
-404	Total Dry Weight	1,008	0.99
-405	Total Ash-free Dry Weight	274	0.27
-501	Ichthyoplankton Displacement Volume	216	0.21
-503	Ichthyoplankton Wet Weight	606	0.60

The geographic distribution of biomass casts for WOD05 is shown in Figures 14.12 – 14.18.

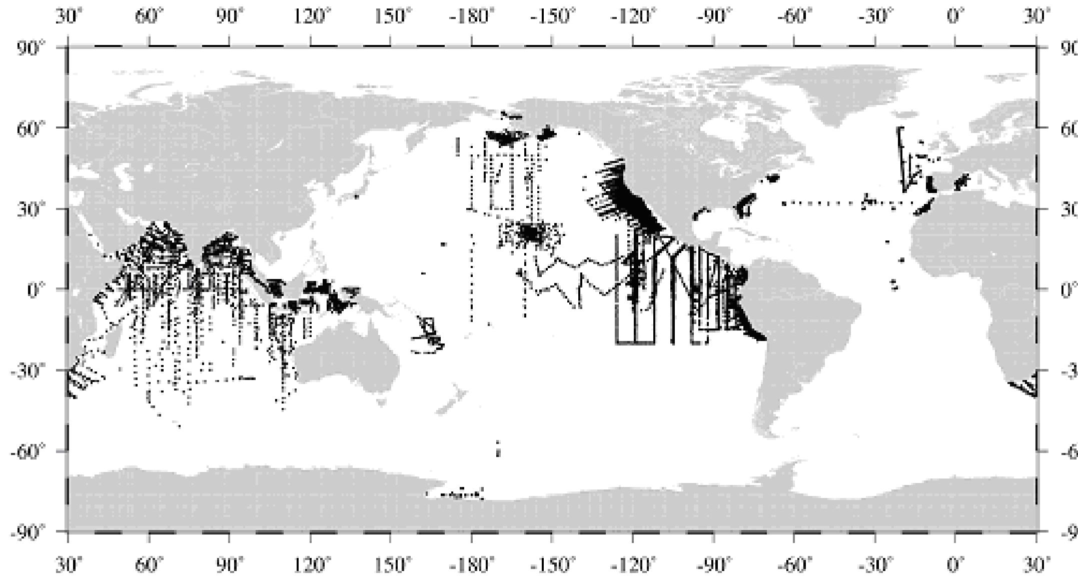

Figure 14.12. Geographic distribution of total displacement volume (62,747casts) in WOD05.

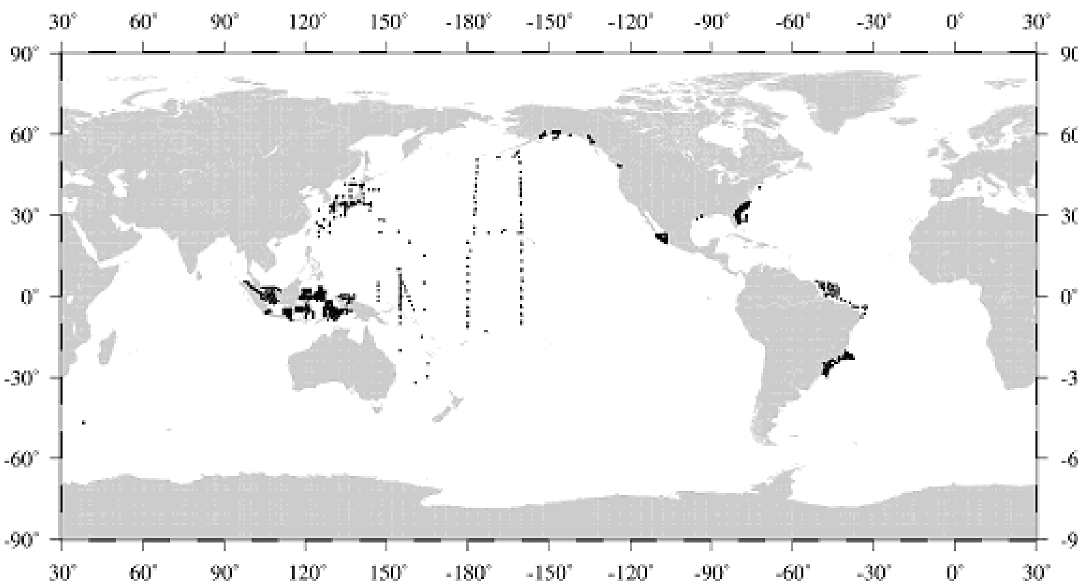

Figure 14.13. Geographic distribution of total settled volume (7,984 casts) in WOD05.

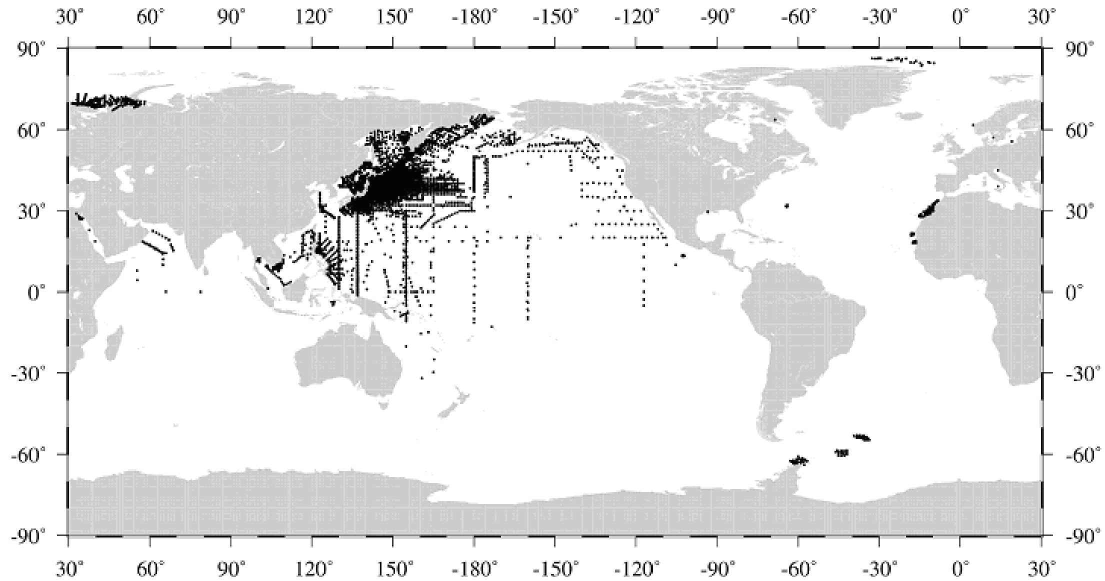

Figure 14.14. Geographic distribution of total wet weight (28,988 casts) in WOD05.

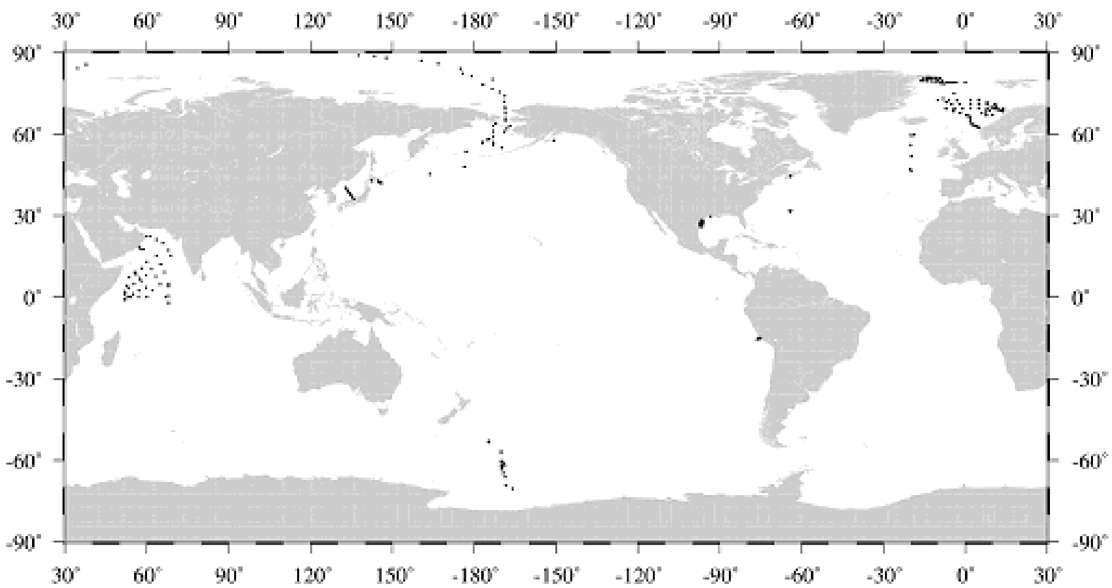

Figure 14.15. Geographic distribution of total dry weight (1,008 casts) in WOD05.

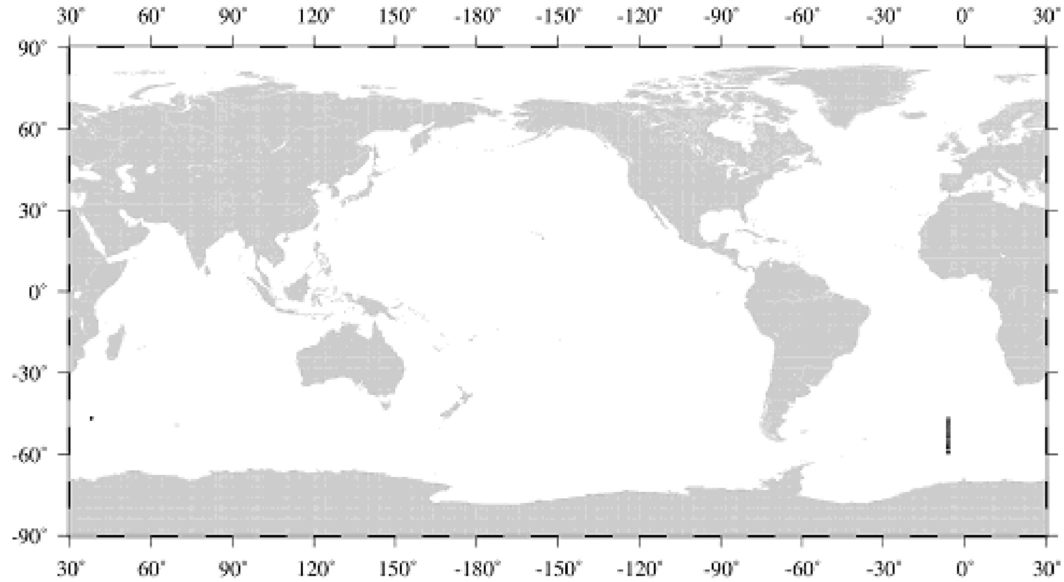

Figure 14.16. Geographic distribution of total ash-free dry weight (274 casts) in WOD05.

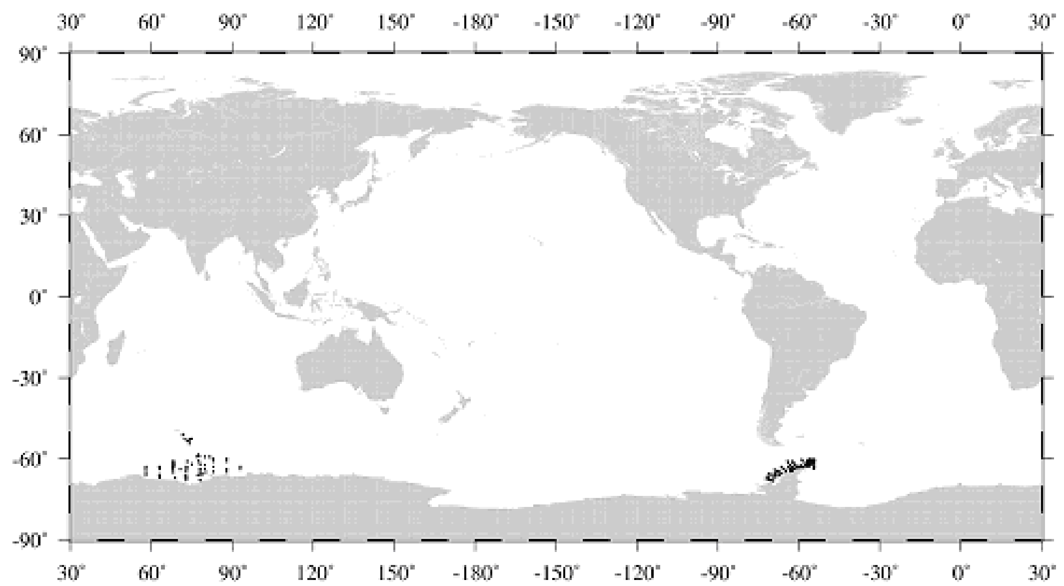

Figure 14.17. Geographic distribution of ichtyoplankton displacement volume (216 casts) in WOD05.

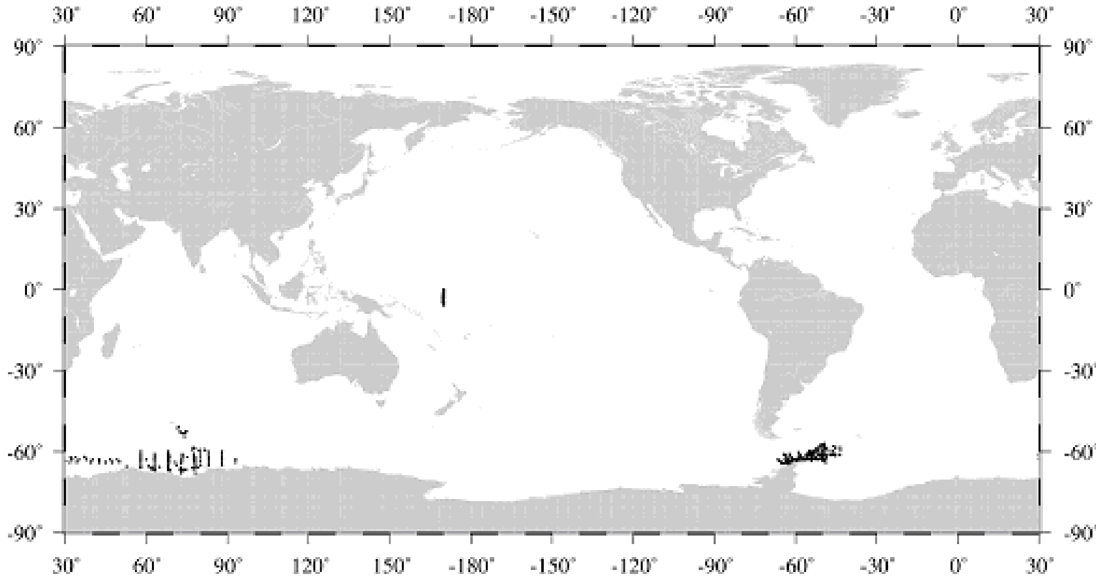

Figure 14.18. Geographic distribution of ichtyoplankton wet weight (606 casts) in WOD05.

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CHAPTER 15: GLIDER DATA (GLD)

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Silver Spring, MD

15.1. INTRODUCTION

A glider is an autonomous underwater vehicle (AUV) that moves from the ocean's surface along a slant trajectory through the water column to a programmed depth and back to the surface while measuring oceanographic parameters (Eriksen *et al*., 2001; Rudnick *et al*., 2004). Gliders can carry various high resolution sensors to measure oceanographic parameters such as pressure, temperature, conductivity, transmissivity, fluorescence, and oxygen. Battery-powered and thermal gliders can travel several thousands kilometers while making several hundred descents and ascents underway, thus achieving high vertical and horizontal resolution. Since gliders can be retrieved and reused, they represent one of the most cost-effective tools to collect oceanographic data. The annual operation cost of a glider is equivalent to a fraction of one ship day (Eriksen *et al*., 2001).

The original concept for the glider was invented by Douglas Webb in 1986 and was based on the thermal engine, intended for global range (Dan Webb, personal communication, May 2006). In 1986 Douglas Webb described to Henry Stommel the ideas of a glider with buoyancy engine harvesting propulsion energy from ocean thermal gradient. Stommel later became an enthusiastic supporter and funding for a contract was received through the Office of Naval Technology (Douglas Webb, personal communication, May 2006). The glider using a battery-powered buoyancy engine was tested at Wakulla Springs, FL, in 1991 and in Seneca Lake, NY in 1991 (Simonetti, 1992; Webb and Simonetti, 1997; Webb *et al*., 2001). A U.S. patent for this concept was received by Douglas Webb in 1994 (Douglas Webb, personal communication, May 2006).

Table 15.1. Glider capabilities

Glider	Max depth, m	Max speed, $m \cdot s^{-1}$	Duration, days
Seaglider	1000	0.5	200
Slocum	2000	0.5	20
Spray	1500	0.5	330

Gliders are equipped with a Global Positioning System (GPS) navigation to locate the vehicle. A satellite data relay is used to send its position and other data to shore-based computers while the operators program the gliders depth and mission. Gliders' depth capabilities range between 0 and 2000 m. Their battery lifetime ranges from a few weeks to several months. Gliders' speed is typically 0.5 $m \cdot s^{-1}$ (Eriksen *et al*, 2001; Davis *et al*., 2002; Rudnick *et al*., 2004). Gliders are growing in number and use to perform scientific missions ranging from monitoring ocean vertical and horizontal structure to military applications, each requiring the use of a different type of instrument with unique specifications that would meet various needs.

There are several types of operational gliders developed thus far (Table 15.1): Seaglider (Eriksen *et al*., 2001) built at the University of Washington, Slocum Gliders (Webb *et al*., 2001) manufactured by Webb Research Corp, and Spray (Sherman *et al*., 2001) built at Scripps Institution of Oceanography (Rudnick *et al*., 2004). Detailed information on gliders specifications and their functions can be found in Rudnick *et al*. (2004), Eriksen *et al*. (2001), Sherman *et al*. (2001), Webb *et al*. (2001), and at the web links provided below.

15.2. GLIDER DESIGN AND OPERATION

The WOD05 includes a single dataset collected by Seaglider-019 (SG-019), submitted by the University of Washington (Marc Stewart, principal investigator). This seaglider is 1.8 m long, has a wing span of 1 m, 1.4 m antenna mast, and weighs 52 kg (Eriksen *et al*., 2001). It was designed to operate with pitch angles from 10° to 75°. The vehicle alternately dives and climbs to a commanded depth and dive from the surface down to a maximum depth of 1 km and back to the surface every 3 to 9 hours. It remains at the surface for 5 minutes and during that time the Iridium/GPS antenna is raised above the air-sea surface by pitching the vehicle nose down (at 75°). The seaglider obtains its GPS fixes, transmits collected data at 180 bytes s^{-1}, relays its position, and receives instructions via the Iridium satellite phone network before diving again (Rudnick *et al*., 2004). It travels at a speed of 0.5 knot, driven by buoyancy control: a hydraulic system that moves oil in and out of an external rubber bladder to force the glider to move, respectively, up or down. Shifting its battery pack relative to its body, causes it to pitch its nose up or down or roll its wings to change compass heading (Rudnick *et al*., 2004).

A seaglider oceanographic package includes a Sea-Bird Electronics conductivity-temperature-depth (CTD) instrument mounted above the wing and a fluorometer/optical backscatter sensor (Davis *et al*., 2002; Rudnick *et al*., 2004). Output of the pressure sensor is used for controlling the vehicle as well as recording the depth at which the measurements are taken (Eriksen *et al*., 2001). Seaglider dynamics and performance are discussed at length by Eriksen *et al*. (2001) and further details can be found on the Seaglider web page at http://www.apl.washington.edu/projects/seaglider/summary.html.

Included in the sensor pack used on the SG-019 is a Sea-Bird Electronics CTD. The accuracy of a CTD instrument varies with instrument design. Typically, the accuracy of salinity measurement is approximately 0.003 to 0.02 and accuracy of temperature measurement is from 0.001°C to 0.005°C for a standard CTD profile. For detailed information on CTDs and their accuracy, refer to section 3.2 of this document.

15.3. GLIDER CAST DISTRIBUTIONS

Figure 15.1 shows the geographic distribution of GLD profiles *(i.e.* SG-019 tracks) and figure 15.2 shows the GLD data distribution as a function of depth at standard depth levels. The seaglider data were acquired during a six-week cruise in support of the U.S. Navy activity known as RIMPAC-04 (Pacific Rim Military Exercises) – an international project involving navies from eight nations. The SG-019 was launched from the U.S. Navy torpedo retriever *Chaparral* TWR-7 into the waters south of Oahu, Hawaii (http://www.defence.gov.au/rimpac04/). A total of 338 temperature and salinity profiles were submitted to the National Oceanographic Data Center/Ocean Climate Laboratory and included in WOD05.

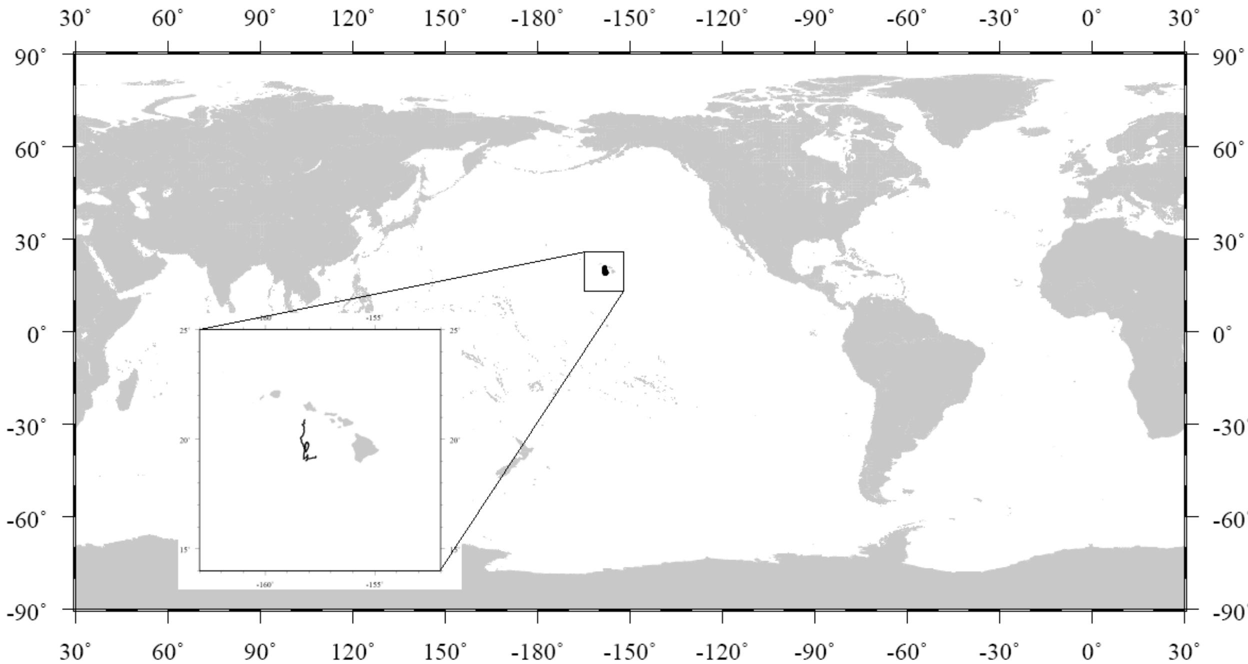

Figure 15.1. Geographic distribution of Seaglider (GLD) profiles in WOD05.

Other known projects that have used seagliders are: AUVFEST 2005, launched SG-022, and SG-023 in the central north Pacific Ocean; TASWEX-04, launched SG-017 in the East China Sea (http://www.apl.washington.edu/projects/seaglider/asw_exercise.html); WA Coast Boundary Currents launching SG-012, SG-002 and SG-005 off of Cape Flattery-Grays Harbor and Grays Harbor-Newport; Subpolar Atlantic Surveys launching SG-004, SG-015, SG-008, SG-014, and SG-016 into Davis Strait/Labrador Sea; Biological O2 Production: Hawaii launched SG-020 and SG-021 for the HOT Area Surveys, and the GLOBEC Alaska Stream Project launching SG-009, SG-010, SG-011, and SG-016 off of the Gulf of Alaska (https://seaglider.ocean.washington.edu/cgi-bin/all_missions.cgi?AT=1).

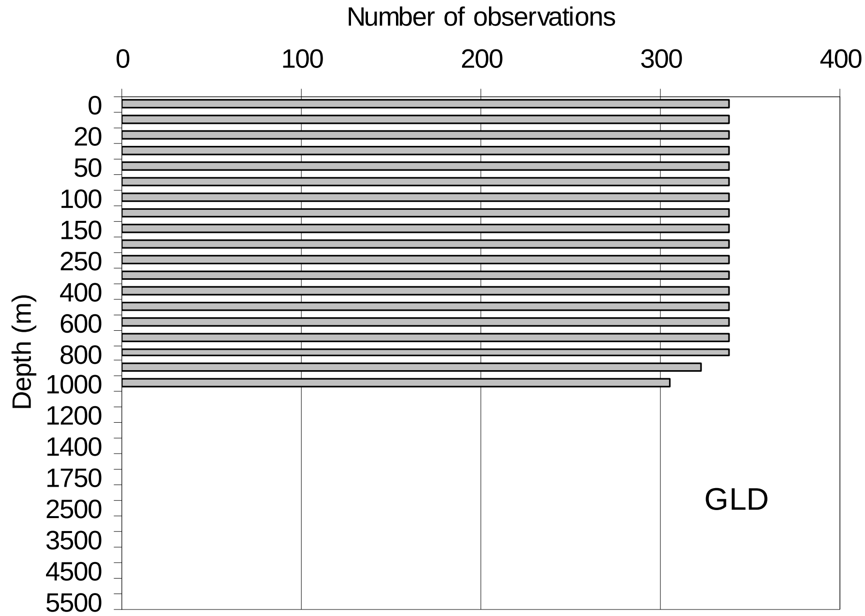

Figure 15.2. Distribution of Glider (GLD) data at standard depth levels in WOD05.

15.4. RELEVANT WEB SITES

Applied Physics Laboratory, University of Washington, Seaglider:
http://www.apl.washington.edu/projects/seaglider/summary.html.

Autonomous Systems Laboratory, Woods Hole Oceanographic Institute:
http://asl.whoi.edu/news.html#

AUV Laboratory, Massachusetts Institute of Technology, Sea Grant College Program:
http://auvlab.mit.edu/MURI/1997_Rprtfinal.html

CTD Instrument: www.windows.ucar.edu/tour/link=/earth/Water/CTD.html&edu=high

Glider Information and Navigation Assistant (GINA):
https://seaglider.ocean.washington.edu/cgi-bin/all_missions.cgi?AT=1

Mediterranean Forecasting System:
http://www.ifm.uni-kiel.de/fb/fb1/po2/research/mfstep/product.html

Navy News (NewsStand): http://www.news.navy.mil/search/display.asp?story_id=21139

RIMPAC-04: http://www.defence.gov.au/rimpac04/

Rutgers University, Coastal Ocean Observation Lab, Institute of Marine and Coastal Sciences:
http://marine.rutgers.edu/cool/projects/oceanrobots.htm/

SBE 911 plus CTD:
http://www.seabird.com/pdf_documents/datasheets/911plusbrochureFeb05.pdf

SCRIPPS Institute of Oceanography, Spray: http://spray.ucsd.edu/

Webb Research Corporation: http://www.webbresearch.com/

15.5. REFERENCES AND BIBLIOGRAPHY

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Webb, D.C., P.J. Simonetti, and C.P. Jones, 2001. SLOCUM: An underwater glider propelled by environmental energy, *IEEE J Oceanic Eng*., 26(4): 447-452.

CHAPTER 16: SURFACE-ONLY DATA (SUR)

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16.1. INTRODUCTION

Collection of surface-only data is not a priority for WOD05. The major focus of the WOD05 is subsurface profile data. Therefore, surface data are included in WOD05 only if they were collected together with measurements of specific oceanographic variables of interest (*e.g.* from cruises with CO_2 or chlorophyll measurements) or they cover undersampled time periods (*e.g.,* ICES Atlantic data for 1900-1939) or provided by scientific ship-of-opportunity programs (*e.g.,* ORSTROM surface salinity data for the Tropical Pacific) (Henin and Grelet, 1996).

Note that specific, surface-only data oriented projects exist, which hold much more comprehensive surface data collection than WOD05 [*e.g.,* The International Comprehensive Ocean-Atmosphere Data Set (ICOADS), which contains more than 169 million sea surface temperature (SST) measurements mainly from merchant ships (Worley *et al.,* 2005) or Global Ocean Surface Underway Data Pilot Project (GOSUD, www.gosud.org)].

The earliest surface temperature data included in WOD05 were collected in 1867 by Norwegian sailors from the ships *Isbjornen* and *Ishavet* in the North Sea, Norwegian Sea, and in the North Atlantic waters around Iceland. Since then, surface data covering most parts of the World Ocean have been gathered. The majority of data are salinity, temperature, and carbon dioxide concentrations. Table 16.1 lists all variables observed at the sea surface (or near-surface) and their counts as stored in SUR dataset.

16.2. SUR DATA PRECISION AND ACCURACY

The accuracy of SUR data depends on performance of the instrument used. Samples of the sea water may have been collected from the continuous flow of water pumped from subsurface depths or have been drawn from a bucket.

A comprehensive review of the sampling techniques and its influence on the collected data precision can be found in Reverdin et al. (1994). When data came from the bucket samples, the accuracy of the sea surface salinity is believed to be of the order of 0.1 (Delcroix and Picaut, 1998; Delcroix *et al.,* 2005). When data were collected by Thermosalinograph (TSG) sea surface salinity and temperature readings are recorded approximately every 10 seconds (Thomas *et al.,* 1999). Data accuracy is limited by characteristics of the SeaBird SBE-21 SEACAT instrument (which is widely used and makes measurement onboard the ship using a water intake) and data averaging - it is believed that in this case the sea surface accuracy is of the order of 0.02 on the PSS (Delcroix *et al.,* 2005).

Table 16.1. List of all variables and cruises / observation counts in the WOD05 SUR dataset.

Measured Variables	Cruises / Observations
Temperature	5,788 / 502,358
Salinity	8,914 / 1,949,525
pH	1 / 80
Chlorophyll	1,232 / 44,256
Phaeophytin	1 / 118
Primary Production	1 / 119
Alkalinity	1 / 77
pCO_2	10 / 36,217
XCO_2sea	139 / 120,910
Air Temperature	154 / 49,648
CO_2warm	61 / 59,680
xCO_2atm	152 / 106,654
Air Pressure	149 / 127,680
Latitude	9,150 / 2,096,531
Longitude	9,150 / 2,096,531
Julian Day	9,150 / 2,096,531

16.3. SUR OBSERVATION DISTRIBUTIONS

Table 16.2 gives the yearly counts of SUR observations for the World Ocean and figure 16.1 illustrate this graphically. As can be seen, substantial amount of data were gathered in the 19th century (see insert on Figure 16.1). These data consist of 207 cruises, mostly distributed over Arctic and North Atlantic, where the majority of the water and air temperature measurements were performed by sailors from Norway (91% of 19th century data), United Kingdom (6.5%), and Denmark (1.6%). Surface data collected before 1955 are bucket samples, data acquired after 1957 are, most often, - TSG measurements.

There are noticeable gaps of data after the First World War and during and after the Second World War. A large increase in surface data (mainly SST and SSS measurements) occurred in the 1990s. These data mainly were acquired by the TSG instruments mounted on ships-of-opportunity (see http://www.ifremer.fr/ird/soopip/index.html). Data collected over that period comprised more that 70% of the entire SUR dataset content with almost all data being collected along shipping routes in the Pacific Ocean and contributed mainly by France (41.8% of all data) and Australia (32.5%).

Table 16.3 gives a detailed view of national input to the SUR dataset by country. The majority of SUR data were collected along the main ship routes of the Atlantic and Pacific oceans. The geographic distribution of SUR observations is shown in Figure 16.2.

More than 96% of the SUR data collected in WOD05 were acquired from three main sources: International Council for the Exploration of the Sea (ICES – 46.2% of all cruises), Ship of Opportunity Programme (Oceanic Lab of the Institute of French Oceania in Noumea, New Caledonia – 36.6%), and Institut Francais de Recherche Scientifique pour le developpement en Cooperation (ORSTOM – 13.4%). The remaining 3.8% came from the Scripps Institute of Oceanography (0.5%), National Institute for Environmental Studies (0.5%), Institute of Ocean Sciences, Sidney, Australia (0.4%), and several others.

Table 16.2. The number of all SUR observations as a function of year in WOD05.
Total number of observations = 2,096,531

YEAR	OBSERV.	YEAR	OBSERV.	YEAR	OBSERV.	YEAR	OBSERV.
1867	398	1901	4,820	1934	10,173	1967	0
1868	0	1902	1,294	1935	7,355	1968	0
1869	44	1903	2,242	1936	16,058	1969	767
1870	2,421	1904	3,695	1937	7,488	1970	3,159
1871	4,261	1905	8,621	1938	10,858	1971	3,126
1872	2,366	1906	7,897	1939	5,745	1972	2,791
1873	2,029	1907	5,781	1940	48	1973	6,504
1874	2,240	1908	5,170	1941	0	1974	6,422
1875	1,480	1909	5,557	1942	0	1975	6,571
1876	2,691	1910	4,502	1943	0	1976	10,402
1877	725	1911	3,585	1944	0	1977	13,719
1878	187	1912	2,478	1945	0	1978	13,018
1879	780	1913	7,881	1946	0	1979	14,033
1880	68	1914	5,961	1947	0	1980	13,950
1881	41	1915	1,882	1948	0	1981	17,897
1882	15	1916	1,753	1949	0	1982	15,412
1883	1,075	1917	1,659	1950	0	1983	17,411
1884	1,884	1918	55	1951	0	1984	12,643
1885	861	1919	113	1952	26	1985	15,480
1886	601	1920	2,838	1953	22	1986	16,250
1887	1,475	1921	3,702	1954	0	1987	20,553
1888	3,589	1922	5,532	1955	0	1988	14,288
1889	2,013	1923	3,945	1956	0	1989	12,022
1890	2,523	1924	4,150	1957	839	1990	11,975
1891	1,197	1925	5,666	1958	0	1991	66,242
1892	468	1926	7,143	1959	0	1992	122,114
1893	214	1927	8,633	1960	0	1993	109,400
1894	1,003	1928	13,579	1961	555	1994	146,742
1895	570	1929	8,935	1962	2,961	1995	204,435
1896	2,777	1930	9,921	1963	2,972	1996	206,211
1897	3,005	1931	15,847	1964	0	1997	242,401
1898	1,885	1932	6,975	1965	0	1998	209,981
1899	1,885	1933	7,590	1966	0	1999	247,364
1900	1,975						

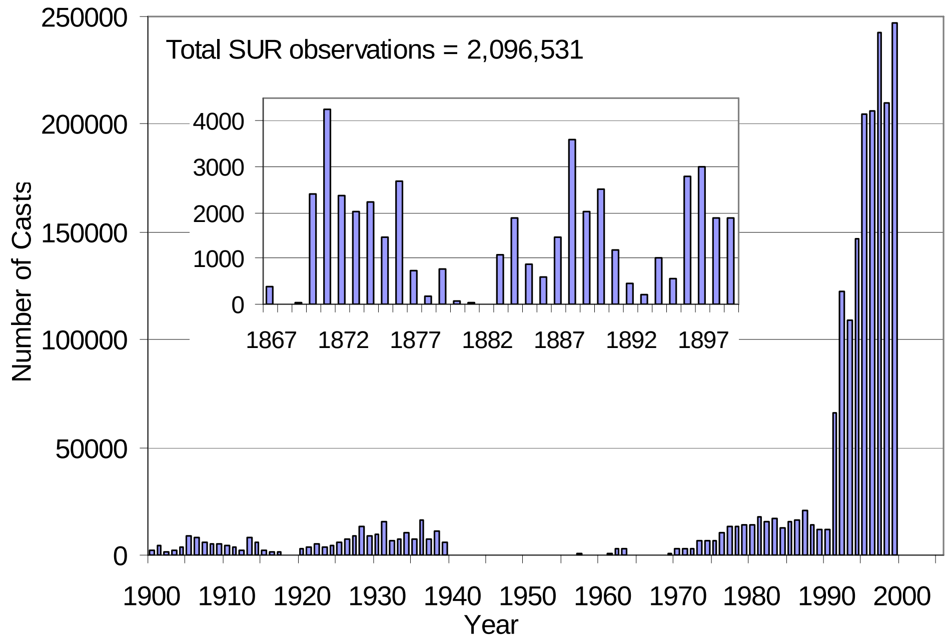

Figure 16.1. Temporal distribution of SUR observations in WOD05.

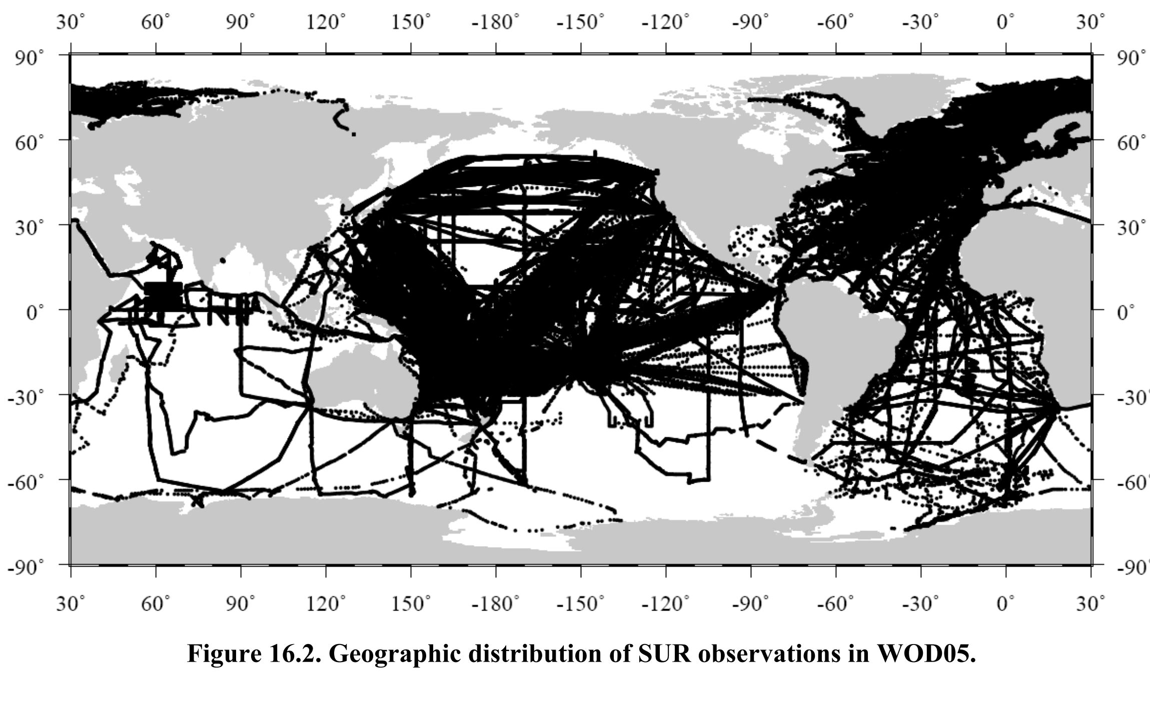

Figure 16.2. Geographic distribution of SUR observations in WOD05.

Table 16.3. National contributions of SUR cruises and observations in WOD05.

NODC Country Codes	Country Name	SUR Cruises	SUR observations	% of Total observations
35	France	3,272	876,382	41.80
09	Australia	85	681,879	32.52
99	Unknown	3,378	161,543	7.71
31,32,33	United States	63	100,492	4.79
06	Germany, Federal Republic of	93	63,698	3.04
58	Norway	245	59,714	2.85
49	Japan	66	57,406	2.74
59	New Caledonia	1,229	41,655	1.99
18	Canada	34	18,682	0.89
74	United Kingdom	345	16,514	0.79
26	Denmark	178	8,274	0.39
67	Poland	23	2,824	0.13
34	Finland	18	2,593	0.12
64	Netherlands	21	1,309	0.06
90, RU	Union of Soviet Socialist Republics / Russia	1	1,068	0.05
LA	Latvia	38	1,010	0.05
77	Sweden	15	710	0.03
11	Belgium	3	283	0.01
68	Portugal	9	199	0.01
45	Ireland	27	164	0.01
ES	Estonia	3	84	<0.01
41	India	4	48	<0.01
	Total	*9,150*	*2,096,531*	*100.00*

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

16.4. RELEVANT WEB SITES

Ship of Opportunity Programme (SOOP) http://www.ifremer.fr/ird/soopip/index.html.

ICES program: http://www.ices.dk/indexfla.asp.

The International Comprehensive Ocean-Atmosphere Data Set (ICOAD): http://dss.ucar.edu/pub/coads/.

Global Ocean Surface Underway Data Pilot Project (GOSUD): www.gosud.org.

SeaBird Electronics Inc. - Shipboard Thermosalinographs: http://www.seabird.com/products/ThermoS.htm

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APPENDIX

Table A.1. National contributions of OSD, MBT, XBT, CTD casts sorted by NODC Country Code

NODC Country Code	Country Name	OSD Count	% of Total	MBT[1] Count	% of Total	XBT Count	% of Total	CTD Count	% of Total
0	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
1	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
2	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
3	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
4	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
5	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
6	Germany, Federal Republic of	64,488	2.86	25,005	1.03	62,611	3.24	30,417	6.85
7	Germany, Democratic Republic of	15,209	0.67	0	0.00	67	0.00	824	0.19
8	Argentina	3,502	0.16	12,090	0.50	2,213	0.11	354	0.08
9	Australia	35,222	1.56	18,474	0.76	88,500	4.58	12,387	2.79
10	Austria	488	0.02	0	0.00	0	0.00	0	0.00
11	Belgium	9,327	0.41	1,218	0.05	0	0.00	212	0.05
12	Burma	0	0.00	0	0.00	0	0.00	0	0.00
13	Bolivia	0	0.00	0	0.00	0	0.00	0	0.00
14	Brazil	9,556	0.42	82	0.00	345	0.02	0	0.00
15	Bulgaria	0	0.00	0	0.00	0	0.00	0	0.00
16	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
17	Cameroon	0	0.00	0	0.00	0	0.00	0	0.00
18	Canada	111,556	4.94	195,946	8.09	50,384	2.61	120,942	27.24
19	Sri Lanka	0	0.00	0	0.00	0	0.00	0	0.00
20	Chile	4,914	0.22	4,161	0.17	2,438	0.13	6,067	1.37
21	Taiwan	3,027	0.13	0	0.00	743	0.04	23,744	5.35
22	Colombia	1,331	0.06	747	0.03	32	0.00	0	0.00
23	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
24	Korea, Republic of	39,707	1.76	847	0.03	53	0.00	363	0.08
25	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
26	Denmark	32,136	1.42	0	0.00	7,870	0.41	2,251	0.51
27	Arab Republic of Egypt	258	0.01	0	0.00	0	0.00	0	0.00
28	Ecuador	3,469	0.15	885	0.04	492	0.03	217	0.05
29	Spain	2,990	0.13	195	0.01	2,995	0.16	5,207	1.17
30	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
31	United States	302,843	13.41	1,105,779	45.66	551,704	28.58	102,413	23.07
32	United States	14,357	0.64	46,628	1.93	254,119	13.16	30,900	6.96
33	United States	6,350	0.28	23,119	0.95	13,982	0.72	3,014	0.68
34	Finland	46,379	2.05	0	0.00	0	0.00	251	0.06
35	France	37,952	1.68	13,538	0.56	49,465	2.56	25,887	5.83
36	Greece	324	0.01	327	0.01	1,174	0.06	336	0.08
37	Guatemala	0	0.00	0	0.00	0	0.00	0	0.00

NODC Country Code	Country Name	OSD Count	% of Total	MBT[1] Count	% of Total	XBT Count	% of Total	CTD Count	% of Total
38	Haiti	0	0.00	0	0.00	0	0.00	0	0.00
39	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
40	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
41	India	4,478	0.20	540	0.02	362	0.02	143	0.03
42	Indonesia	4,283	0.19	0	0.00	1,214	0.06	159	0.04
43	Iraq	0	0.00	0	0.00	0	0.00	0	0.00
44	Iran	0	0.00	0	0.00	0	0.00	0	0.00
45	Ireland	2,980	0.13	0	0.00	0	0.00	10	0.00
46	Iceland	18,780	0.83	0	0.00	4,574	0.24	1,816	0.41
47	Israel	3,051	0.14	0	0.00	0	0.00	195	0.04
48	Italy	10,159	0.45	6,268	0.26	1,219	0.06	8,109	1.83
49	Japan	528,037	23.38	364,493	15.05	285,786	14.81	11,016	2.48
50	Jordan	0	0.00	0	0.00	0	0.00	0	0.00
51	Japan	0	0.00	0	0.00	0	0.00	0	0.00
52	Lebanon	0	0.00	0	0.00	0	0.00	0	0.00
53	Libya	0	0.00	0	0.00	0	0.00	0	0.00
54	Liberia	0	0.00	0	0.00	41,994	2.18	0	0.00
55	Malagasy Republic	2,524	0.11	405	0.02	62	0.00	0	0.00
56	Morocco	0	0.00	0	0.00	0	0.00	0	0.00
57	Mexico	1,457	0.06	0	0.00	2,234	0.12	59	0.01
58	Norway	93,472	4.14	913	0.04	7,256	0.38	16,096	3.63
59	New Caledonia	1,283	0.06	0	0.00	0	0.00	0	0.00
60	Japan	40	0.00	0	0.00	0	0.00	0	0.00
61	New Zealand	1,917	0.08	2,435	0.10	5,593	0.29	102	0.02
62	Pakistan	167	0.01	0	0.00	0	0.00	0	0.00
63	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
64	Netherlands	26,227	1.16	8,088	0.33	14,251	0.74	1,966	0.44
65	Peru	10,827	0.48	5,212	0.22	714	0.04	74	0.02
66	Philippines	235	0.01	0	0.00	2,298	0.12	0	0.00
67	Poland	16,459	0.73	0	0.00	1,320	0.07	1,546	0.35
68	Portugal	6,471	0.29	2,628	0.11	732	0.04	1,289	0.29
69	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
70	Dominican Republic	0	0.00	0	0.00	0	0.00	0	0.00
71	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
72	Albania	0	0.00	0	0.00	0	0.00	0	0.00
73	Romania	0	0.00	0	0.00	0	0.00	0	0.00
74	United Kingdom	132,324	5.86	118,643	4.90	194,086	10.05	11,464	2.58
75	El Salvador	0	0.00	0	0.00	0	0.00	0	0.00
76	China, The Peoples Republic of	5,590	0.25	0	0.00	4,810	0.25	2,772	0.62
77	Sweden	51,876	2.30	0	0.00	4,552	0.24	55	0.01
78	Switzerland	0	0.00	0	0.00	0	0.00	0	0.00
79	Surinam	0	0.00	0	0.00	0	0.00	0	0.00
80	Syria	0	0.00	0	0.00	0	0.00	0	0.00
81	Not Used	0	0.00	0	0.00	0	0.00	0	0.00

NODC Country Code	Country Name	OSD Count	% of Total	MBT[1] Count	% of Total	XBT Count	% of Total	CTD Count	% of Total
82	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
83	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
84	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
85	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
86	Thailand	2,801	0.12	77	0.00	29	0.00	0	0.00
87	Togo	0	0.00	0	0.00	0	0.00	0	0.00
88	Tunisia	280	0.01	0	0.00	0	0.00	0	0.00
89	Turkey	301	0.01	0	0.00	220	0.01	199	0.04
90	Union of Soviet Socialist Republics	414,162	18.34	444,142	18.34	14,494	0.75	14,187	3.20
91	South Africa	28,051	1.24	20	0.00	8,297	0.43	6,259	1.41
92	Uruguay	0	0.00	0	0.00	146	0.01	0	0.00
93	Venezuela	3,590	0.16	673	0.03	0	0.00	0	0.00
94	Vietnam	0	0.00	0	0.00	0	0.00	0	0.00
95	Yugoslavia	5,404	0.24	0	0.00	306	0.02	0	0.00
96	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
97	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
98	Not Used	0	0.00	0	0.00	0	0.00	0	0.00
99	Unknown	100,903	4.47	16,393	0.68	150,236	7.78	60	0.01
AG	Antigua	0	0.00	0	0.00	8,501	0.44	0	0.00
AL	Algeria	0	0.00	0	0.00	0	0.00	0	0.00
AN	Angola	621	0.03	0	0.00	0	0.00	0	0.00
BA	Barbados	0	0.00	0	0.00	3,236	0.17	0	0.00
BH	Bahamas	0	0.00	0	0.00	9,882	0.51	0	0.00
BN	Bonaire	0	0.00	0	0.00	0	0.00	0	0.00
CA	Curacao	0	0.00	0	0.00	0	0.00	0	0.00
CI	Cayman Islands	0	0.00	0	0.00	0	0.00	0	0.00
CR	Costa Rica	0	0.00	0	0.00	29	0.00	0	0.00
CU	Cuba	969	0.04	0	0.00	0	0.00	0	0.00
CV	Cape Verde	0	0.00	0	0.00	0	0.00	0	0.00
CY	Cyprus	0	0.00	0	0.00	3,115	0.16	0	0.00
ES	Estonia	0	0.00	0	0.00	0	0.00	0	0.00
ET	Ethiopia	0	0.00	0	0.00	0	0.00	0	0.00
FJ	Fiji Islands	0	0.00	0	0.00	866	0.04	0	0.00
GA	Gabon	0	0.00	0	0.00	0	0.00	0	0.00
GH	Ghana	2,670	0.12	12	0.00	0	0.00	0	0.00
GM	Gambia	0	0.00	0	0.00	0	0.00	0	0.00
GN	Guinea-Bissau	0	0.00	0	0.00	0	0.00	0	0.00
GR	Grenada	0	0.00	0	0.00	0	0.00	0	0.00
GU	Guinea-Bissau	0	0.00	0	0.00	0	0.00	0	0.00
GY	Guyana	0	0.00	0	0.00	0	0.00	0	0.00
HK	Hong Kong	0	0.00	0	0.00	3,210	0.17	0	0.00
HO	Honduras	0	0.00	0	0.00	12	0.00	0	0.00
HR	Croatia	0	0.00	0	0.00	16	0.00	0	0.00
IC	Ivory Coast	3,068	0.14	100	0.00	43	0.00	0	0.00

NODC Country Code	Country Name	OSD Count	% of Total	MBT[1] Count	% of Total	XBT Count	% of Total	CTD Count	% of Total
IN	International	0	0.00	0	0.00	0	0.00	0	0.00
JA	Jamaica	0	0.00	0	0.00	0	0.00	0	0.00
KE	Kenya	0	0.00	0	0.00	0	0.00	0	0.00
KU	Kuwait	0	0.00	0	0.00	1,812	0.09	0	0.00
LA	Latvia	0	0.00	0	0.00	0	0.00	0	0.00
LT	Lithuania	869	0.04	0	0.00	0	0.00	0	0.00
MA	Mauritius	0	0.00	0	0.00	77	0.00	0	0.00
MH	Marshall Islands	0	0.00	0	0.00	463	0.02	0	0.00
ML	Malta	0	0.00	0	0.00	713	0.04	0	0.00
MO	Monaco	2,087	0.09	97	0.00	0	0.00	0	0.00
MS	Malaysia	154	0.01	0	0.00	83	0.00	0	0.00
MU	Mauritania	1,217	0.05	0	0.00	0	0.00	0	0.00
MZ	Mozambique	0	0.00	0	0.00	0	0.00	0	0.00
NC	Nicaragua	0	0.00	0	0.00	0	0.00	0	0.00
NI	Nigeria	759	0.03	89	0.00	0	0.00	0	0.00
OM	Oman	0	0.00	0	0.00	0	0.00	0	0.00
PA	Panama	139	0.01	0	0.00	37,823	1.96	0	0.00
QA	Qatar	0	0.00	0	0.00	0	0.00	0	0.00
RC	Congo	1,836	0.08	1,234	0.05	0	0.00	0	0.00
RU	Russia	18,062	0.80	0	0.00	1	0.00	27	0.01
SA	Saudi Arabia	0	0.00	0	0.00	197	0.01	0	0.00
SC	Seychelles	0	0.00	0	0.00	11	0.00	0	0.00
SE	Senegal	1,975	0.09	245	0.01	0	0.00	0	0.00
SI	Singapore	412	0.02	0	0.00	16,083	0.83	0	0.00
SL	Sierra Leone	0	0.00	187	0.01	0	0.00	0	0.00
SM	Somalia	0	0.00	0	0.00	0	0.00	0	0.00
SO	Solomon Islands	0	0.00	0	0.00	0	0.00	0	0.00
SU	Sudan	0	0.00	0	0.00	0	0.00	0	0.00
SV	Saint Vincent	0	0.00	0	0.00	5,598	0.29	0	0.00
TN	Tonga	0	0.00	0	0.00	2,328	0.12	0	0.00
TT	Trinidad/Tobago	0	0.00	0	0.00	6	0.00	0	0.00
UA	U. Arab Emirates	0	0.00	0	0.00	0	0.00	0	0.00
UR	Ukraine	0	0.00	0	0.00	33	0.00	0	0.00
WS	Western Samoa	0	0.00	0	0.00	94	0.00	0	0.00
YM	Yemen	85	0.00	0	0.00	0	0.00	0	0.00
ZA	Tanzania	0	0.00	0	0.00	0	0.00	0	0.00
ZZ	Miscellaneous Organizational Units	0	0.00	0	0.00	195	0.01	564	0.13
	Total	***2,258,437***		***2,421,935***		***1,930,413***		***443,953***	

[1] WOD05 MBT dataset includes data from 80,212 DBT profiles and 5,659 Micro-BT profiles.

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.

Table A.2. National contributions of OSD, MBT, XBT, CTD casts sorted alphabetically by country name.

NODC Country Code	Country Name	OSD Count	% of Total	MBT[1] Count	% of Total	XBT Count	% of Total	CTD Count	% of Total
72	Albania	0	0	0	0	0	0	0	0
AL	Algeria	0	0	0	0	0	0	0	0
AN	Angola	621	0.03	0	0	0	0	0	0
AG	Antigua	0	0	0	0	8,501	0.44	0	0
27	Arab Republic of Egypt	258	0.01	0	0	0	0	0	0
8	Argentina	3,502	0.16	12,090	0.5	2,213	0.11	354	0.08
9	Australia	35,222	1.56	18,474	0.76	88,500	4.58	12,387	2.79
10	Austria	488	0.02	0	0	0	0	0	0
BH	Bahamas	0	0	0	0	9,882	0.51	0	0
BA	Barbados	0	0	0	0	3,236	0.17	0	0
11	Belgium	9,327	0.41	1,218	0.05	0	0	212	0.05
13	Bolivia	0	0	0	0	0	0	0	0
BN	Bonaire	0	0	0	0	0	0	0	0
14	Brazil	9,556	0.42	82	0	345	0.02	0	0
15	Bulgaria	0	0	0	0	0	0	0	0
12	Burma	0	0	0	0	0	0	0	0
17	Cameroon	0	0	0	0	0	0	0	0
18	Canada	111,556	4.94	195,946	8.09	50,384	2.61	120,942	27.24
CV	Cape Verde	0	0	0	0	0	0	0	0
CI	Cayman Islands	0	0	0	0	0	0	0	0
20	Chile	4,914	0.22	4,161	0.17	2,438	0.13	6,067	1.37
76	China, The Peoples Republic of	5,590	0.25	0	0	4,810	0.25	2,772	0.62
22	Colombia	1,331	0.06	747	0.03	32	0	0	0
RC	Congo	1,836	0.08	1,234	0.05	0	0	0	0
CR	Costa Rica	0	0	0	0	29	0	0	0
HR	Croatia	0	0	0	0	16	0	0	0
CU	Cuba	969	0.04	0	0	0	0	0	0
CA	Curacao	0	0	0	0	0	0	0	0
CY	Cyprus	0	0	0	0	3,115	0.16	0	0
26	Denmark	32,136	1.42	0	0	7,870	0.41	2,251	0.51
70	Dominican Republic	0	0	0	0	0	0	0	0
28	Ecuador	3,469	0.15	885	0.04	492	0.03	217	0.05
75	El Salvador	0	0	0	0	0	0	0	0
ES	Estonia	0	0	0	0	0	0	0	0
ET	Ethiopia	0	0	0	0	0	0	0	0
FJ	Fiji Islands	0	0	0	0	866	0.04	0	0
34	Finland	46,379	2.05	0	0	0	0	251	0.06
35	France	37,952	1.68	13,538	0.56	49,465	2.56	25,887	5.83

NODC Country Code	Country Name	OSD Count	% of Total	MBT[1] Count	% of Total	XBT Count	% of Total	CTD Count	% of Total
GA	Gabon	0	0	0	0	0	0	0	0
GM	Gambia	0	0	0	0	0	0	0	0
7	Germany, Democratic Republic of	15,209	0.67	0	0	67	0	824	0.19
6	Germany, Federal Republic of	64,488	2.86	25,005	1.03	62,611	3.24	30,417	6.85
GH	Ghana	2,670	0.12	12	0	0	0	0	0
36	Greece	324	0.01	327	0.01	1,174	0.06	336	0.08
GR	Grenada	0	0	0	0	0	0	0	0
37	Guatemala	0	0	0	0	0	0	0	0
GN	Guinea-Bissau	0	0	0	0	0	0	0	0
GU	Guinea-Bissau	0	0	0	0	0	0	0	0
GY	Guyana	0	0	0	0	0	0	0	0
38	Haiti	0	0	0	0	0	0	0	0
HO	Honduras	0	0	0	0	12	0	0	0
HK	Hong Kong	0	0	0	0	3,210	0.17	0	0
46	Iceland	18,780	0.83	0	0	4,574	0.24	1,816	0.41
41	India	4,478	0.2	540	0.02	362	0.02	143	0.03
42	Indonesia	4,283	0.19	0	0	1,214	0.06	159	0.04
IN	International	0	0	0	0	0	0	0	0
44	Iran	0	0	0	0	0	0	0	0
43	Iraq	0	0	0	0	0	0	0	0
45	Ireland	2,980	0.13	0	0	0	0	10	0
47	Israel	3,051	0.14	0	0	0	0	195	0.04
48	Italy	10,159	0.45	6,268	0.26	1,219	0.06	8,109	1.83
IC	Ivory Coast	3,068	0.14	100	0	43	0	0	0
JA	Jamaica	0	0	0	0	0	0	0	0
49	Japan	528,037	23.38	364,493	15.05	285,786	14.81	11,016	2.48
51	Japan	0	0	0	0	0	0	0	0
60	Japan	40	0	0	0	0	0	0	0
50	Jordan	0	0	0	0	0	0	0	0
KE	Kenya	0	0	0	0	0	0	0	0
24	Korea, Republic of	39,707	1.76	847	0.03	53	0	363	0.08
KU	Kuwait	0	0	0	0	1,812	0.09	0	0
LA	Latvia	0	0	0	0	0	0	0	0
52	Lebanon	0	0	0	0	0	0	0	0
54	Liberia	0	0	0	0	41,994	2.18	0	0
53	Libya	0	0	0	0	0	0	0	0
LT	Lithuania	869	0.04	0	0	0	0	0	0
55	Malagasy Republic	2,524	0.11	405	0.02	62	0	0	0
MS	Malaysia	154	0.01	0	0	83	0	0	0
ML	Malta	0	0	0	0	713	0.04	0	0

NODC Country Code	Country Name	OSD Count	% of Total	MBT[1] Count	% of Total	XBT Count	% of Total	CTD Count	% of Total
MH	Marshall Islands	0	0	0	0	463	0.02	0	0
MU	Mauritania	1,217	0.05	0	0	0	0	0	0
MA	Mauritius	0	0	0	0	77	0	0	0
57	Mexico	1,457	0.06	0	0	2,234	0.12	59	0.01
ZZ	Miscellaneous Organizational Units	0	0	0	0	195	0.01	564	0.13
MO	Monaco	2,087	0.09	97	0	0	0	0	0
56	Morocco	0	0	0	0	0	0	0	0
MZ	Mozambique	0	0	0	0	0	0	0	0
64	Netherlands	26,227	1.16	8,088	0.33	14,251	0.74	1,966	0.44
59	New Caledonia	1,283	0.06	0	0	0	0	0	0
61	New Zealand	1,917	0.08	2,435	0.1	5,593	0.29	102	0.02
NC	Nicaragua	0	0	0	0	0	0	0	0
NI	Nigeria	759	0.03	89	0	0	0	0	0
58	Norway	93,472	4.14	913	0.04	7,256	0.38	16,096	3.63
0	Not Used	0	0	0	0	0	0	0	0
1	Not Used	0	0	0	0	0	0	0	0
2	Not Used	0	0	0	0	0	0	0	0
3	Not Used	0	0	0	0	0	0	0	0
4	Not Used	0	0	0	0	0	0	0	0
5	Not Used	0	0	0	0	0	0	0	0
16	Not Used	0	0	0	0	0	0	0	0
23	Not Used	0	0	0	0	0	0	0	0
25	Not Used	0	0	0	0	0	0	0	0
30	Not Used	0	0	0	0	0	0	0	0
39	Not Used	0	0	0	0	0	0	0	0
40	Not Used	0	0	0	0	0	0	0	0
63	Not Used	0	0	0	0	0	0	0	0
69	Not Used	0	0	0	0	0	0	0	0
71	Not Used	0	0	0	0	0	0	0	0
81	Not Used	0	0	0	0	0	0	0	0
82	Not Used	0	0	0	0	0	0	0	0
83	Not Used	0	0	0	0	0	0	0	0
84	Not Used	0	0	0	0	0	0	0	0
85	Not Used	0	0	0	0	0	0	0	0
96	Not Used	0	0	0	0	0	0	0	0
97	Not Used	0	0	0	0	0	0	0	0
98	Not Used	0	0	0	0	0	0	0	0
OM	Oman	0	0	0	0	0	0	0	0
62	Pakistan	167	0.01	0	0	0	0	0	0
PA	Panama	139	0.01	0	0	37,823	1.96	0	0
65	Peru	10,827	0.48	5,212	0.22	714	0.04	74	0.02

NODC Country Code	Country Name	OSD Count	% of Total	MBT[1] Count	% of Total	XBT Count	% of Total	CTD Count	% of Total
66	Philippines	235	0.01	0	0	2,298	0.12	0	0
67	Poland	16,459	0.73	0	0	1,320	0.07	1,546	0.35
68	Portugal	6,471	0.29	2,628	0.11	732	0.04	1,289	0.29
QA	Qatar	0	0	0	0	0	0	0	0
73	Romania	0	0	0	0	0	0	0	0
RU	Russia	18,062	0.8	0	0	1	0	27	0.01
SV	Saint Vincent	0	0	0	0	5,598	0.29	0	0
SA	Saudi Arabia	0	0	0	0	197	0.01	0	0
SE	Senegal	1,975	0.09	245	0.01	0	0	0	0
SC	Seychelles	0	0	0	0	11	0	0	0
SL	Sierra Leone	0	0	187	0.01	0	0	0	0
SI	Singapore	412	0.02	0	0	16,083	0.83	0	0
SO	Solomon Islands	0	0	0	0	0	0	0	0
SM	Somalia	0	0	0	0	0	0	0	0
91	South Africa	28,051	1.24	20	0	8,297	0.43	6,259	1.41
29	Spain	2,990	0.13	195	0.01	2,995	0.16	5,207	1.17
19	Sri Lanka	0	0	0	0	0	0	0	0
SU	Sudan	0	0	0	0	0	0	0	0
79	Surinam	0	0	0	0	0	0	0	0
77	Sweden	51,876	2.3	0	0	4,552	0.24	55	0.01
78	Switzerland	0	0	0	0	0	0	0	0
80	Syria	0	0	0	0	0	0	0	0
21	Taiwan	3,027	0.13	0	0	743	0.04	23,744	5.35
ZA	Tanzania	0	0	0	0	0	0	0	0
86	Thailand	2,801	0.12	77	0	29	0	0	0
87	Togo	0	0	0	0	0	0	0	0
TN	Tonga	0	0	0	0	2,328	0.12	0	0
TT	Trinidad / Tobago	0	0	0	0	6	0	0	0
88	Tunisia	280	0.01	0	0	0	0	0	0
89	Turkey	301	0.01	0	0	220	0.01	199	0.04
UA	U. Arab Emirates	0	0	0	0	0	0	0	0
UR	Ukraine	0	0	0	0	33	0	0	0
90	Union of Soviet Socialist Republics	414,162	18.34	444,142	18.34	14,494	0.75	14,187	3.2
74	United Kingdom	132,324	5.86	118,643	4.9	194,086	10.05	11,464	2.58
31	United States	302,843	13.41	1,105,779	45.66	551,704	28.58	102,413	23.07
32	United States	14,357	0.64	46,628	1.93	254,119	13.16	30,900	6.96
33	United States	6,350	0.28	23,119	0.95	13,982	0.72	3,014	0.68
99	Unknown	100,903	4.47	16,393	0.68	150,236	7.78	60	0.01
92	Uruguay	0	0	0	0	146	0.01	0	0
93	Venezuela	3,590	0.16	673	0.03	0	0	0	0
94	Vietnam	0	0	0	0	0	0	0	0

NODC Country Code	Country Name	OSD Count	% of Total	MBT[1] Count	% of Total	XBT Count	% of Total	CTD Count	% of Total
WS	Western Samoa	0	0	0	0	94	0	0	0
YM	Yemen	85	0	0	0	0	0	0	0
95	Yugoslavia	5,404	0.24	0	0	306	0.02	0	0
	Total	***2,258,437***		***2,421,935***		***1,930,399***		***443,953***	

[1] WOD05 MBT dataset includes data from 80,212 DBT profiles and 5,659 Micro-BT profiles.

The United States, Russia, and Japan have multiple country codes. This is because the NODC Institution Code is limited to two digits and these countries each have more than 99 institutions that can potentially transfer data to NODC/WDC.