Ship of Opportunity Program (SOOP): Volunteer Observing Ships: Expendable Bathythermograph and Enviromental Data Acquisition Program.

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PROJECT SUMMARY

This project includes data acquisition related to the Ship of Opportunity Program (SOOP) using volunteer merchant ships for observations of ocean and atmospheric properties. The project includes three main components:

- A system for the merchant fleet to input ocean and meterological information to be supplied in real-time to users world-wide called SEAS (Shipboard Enviromental Acquisition System).
- Upper ocean temperature observations using expendable bathythermographs (XBTs) deployed broadly across large ocean regions: the low-density/frequently repeated XBT program.
- Upper ocean temperature observations using XBTs deployed closely spaced in order to measure the meso-scale field: the high-density XBT program

A brief description of each of the three components is included below.

SEAS System

SEAS 2K is a Windows based real–time ship and environmental data acquisition and transmission system. The SEAS 2K software acquires atmospheric and oceanographic data and transmits the data in real-time to the GTS and to operational databases to be used by scientists. Additionally, the SEAS 2K software creates a series of reports, which describe point of departure, route and arrival of a ship. These reports are transmitted using Standard-C and include ships in a real-time search and rescue database. SEAS 2K is employed on ships of the Volunteer Observing System (VOS), Ship of Opportunity Program (SOOP) and on NOAA, UNOLS, Coast Guard vessels.

SEAS 2K is operated by a wide variety of users, including users with limited computer competence. The operators are members of the crew of the vessels, who are extremely busy and have little time for computer malfunctions. Thus, SEAS 2K was designed to be easy to use and thoroughly reliable. As new features are added and current features are improved upon, there is a consistent effort to follow this design philosophy.

SEAS 2K is installed on more than 350 ships of the Voluntary Observing System (VOS) and SOOP. Over 200,000 SEAS meteorological messages are transmitted per year. Approximately thirty ships of the SOOP are deploying XBTs using SEAS 2K software. This includes low, frequently repeated and high-density deployment modes. NOAA/AOML and Scripps are the principal users of the software. National Marine Fisheries Service is running an Antarctic line (AX22) using this software.

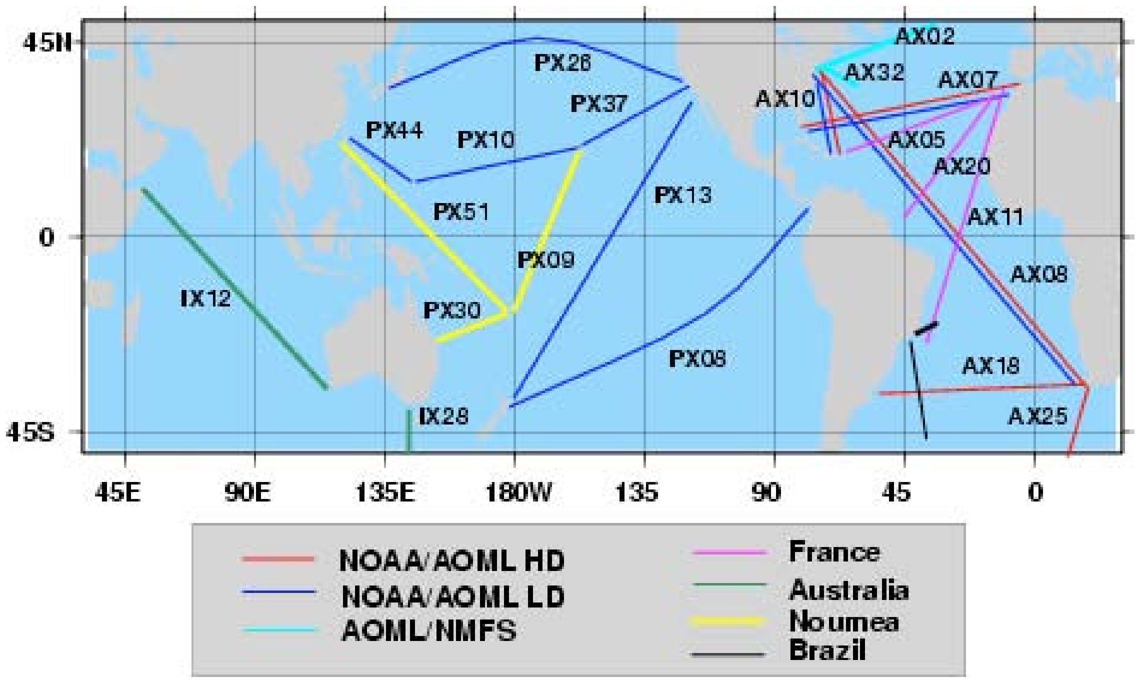

Figure 1. Map showing the network of XBT transects maintained by NOAA/AOML and by NOAA/AOML in collaboration with international partners.

Low-Density/Frequently Repeated XBT Observations

Low-density (broadly spaced) XBT observations are used to investigate the large-scale, low-frequency modes of climate variability, while making no attempt to resolve the energetic, mesoscale eddies that are prevalent in much of the ocean, features that are investigated by XBT transects in high-density (HD) mode. Sampling in low density (LD) mode has been the dominant mode in the early days of the Ship of Opportunity Program (SOOP) network. The current LD network is comprised of data usually from SOOP XBT lines around the globe, where sampling is done on a monthly basis, with four XBT deployments per day along the track of the ship (Figure 1). Occasionally these lines are also sampled through basic research and operational experiments in which XBTs are deployed to observe various oceanographic processes. Some lines are maintained in cooperation with international partners (France, Australia, Noumea, and Brazil). All XBT lines are maintained through an international consortium with oversight by the SOOP Implementation Panel (SOOPIP). Some lines include time series measurements providing more than 30 years of data.

Frequently repeated XBT lines (FRX) are mostly located in tropical regions to monitor strong seasonal to inter-annual (SI) variability in the presence of intra-seasonal oscillations and other small-scale geophysical noise. These lines typically run north/south, and cross the equator or intersect the low latitude eastern boundary. They are intended to capture the large-scale thermal response to changes in equatorial and extra-equatorial winds. Sampling is ideally on an exactly repeating track to allow separation of temporal and spatial variability, although some spread is possible and always expected. These lines are ideally covered 18 times per year with an XBT drop every 100 to 150 km (or approximately 6 drops per day). This mode of sampling tries to draw a balance between the spatial undersampling, with good temporal sampling inherent in low-density deployments and the good spatial sampling, marginal temporal sampling in the high-density (HD) deployments. Increasing both the temporal and spatial sampling in frequently repeated lines relative to low-density sampling greatly decreases the risk of aliasing in equatorial regions.

High-density XBT Observations

This program is designed to measure the upper ocean thermal structure in key regions of the Atlantic Ocean (Figure 2). Along five sections in the Atlantic Ocean expendable bathythermograph (XBT) observations are deployed approximately quarterly in time and measure the temperature as a function of depth from the surface to about 850 meters. The XBTs are deployed between 5-50 km apart in order to measure the meso-scale structure of the ocean. This close spacing is important to measure the meso-scale structure in order to diagnose the ocean circulation responsible for redistributing heat and other water properties globally.

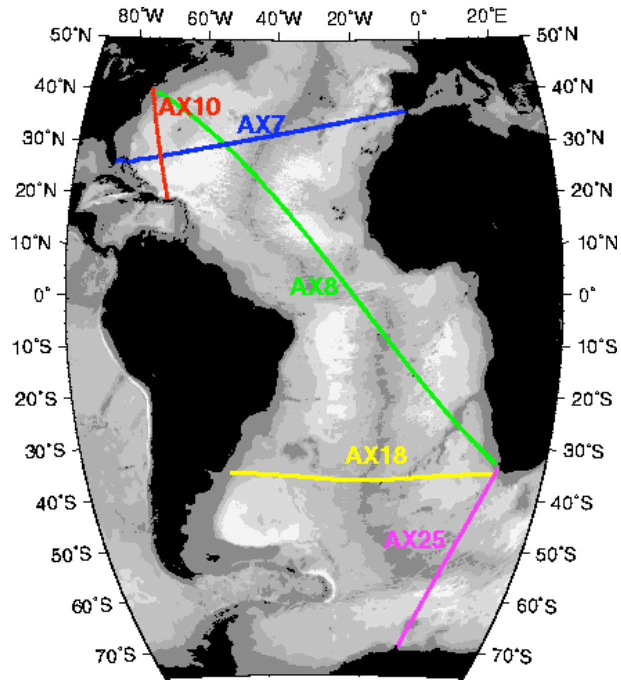

Figure 2. Location of the five high density XBT lines (AX07, AX08, AX10, AX18, and AX25) maintained by NOAA/AOML.

<u>Rationale</u>

The seasonal to interannual variability in upper ocean heat content and transport is monitored to understand how the ocean responds to changes in atmospheric and oceanic conditions and how the ocean response may feedback to the important climate fluctuations such as the North Atlantic Oscillation (NAO). This increased understanding is crucial to improving climate prediction models. This project provides critical data for initializing seasonal to interannual (SI) climate forecasts. The data resulting from this project helps to addresses this objective:

- Document the ocean's storage and global transport of heat and fresh water;

One primary objective of the AOML XBT component of the internationally coordinated Ship of Opportunity Program (SOOP) is to provide oceanographic data needed to initialize the operational SI climate forecasts prepared by NCEP. Specifically, AOML manages a global XBT network that provides subsurface temperature data. Global coverage is now required as the forecast models not only simulate Pacific conditions but global conditions to improve prediction skill. Additional objectives of this project are to provide the resulting data to increase our understanding of the dynamics of the SI and decadal time scale variability and to provide data for model validation studies. Thus, this project addresses both operational and scientific goals of NOAA's program for building a sustained ocean observing system for climate.

Data from these lines have been used extensively (Meyers et al, 1991; Taft and Kessler, 1991). For example, the scales of mode water and the distribution and circulation of associated water properties can be readily captured by LD/FRX sampling (Hanawa and Yoritaka, 1999). XBT data are also used in ocean analysis and in climate model initialization. For instance, for El Nino prediction XBT data complement that from the TAO array and from satellite-derived sea surface temperature and sea height observations. The use of XBT data serves to measure the seasonal and interannual fluctuations in the upper layer heat storage, now being complemented by profiling float measurements. Heat transport and geostrophic ocean circulation can be measured using the high-density XBT data that measures the meso-scale field.

Within this context, five XBT lines have been chosen to monitor properties in the upper layers of the Atlantic Ocean in high-density mode. The continuation of AX07 and AX10 and the implementation of AX08 and AX18 were recommended at the Meeting of the Ocean Observing System for Climate held in St. Raphael in 1999. The location of the lines recommended by the St. Raphael meeting and the GCOS *Implementation Plan* (GCOS-92) are based on specific advantages of each lines location. High-density line AX07 and AX10 have been maintained since 1994 and 1996, respectively, providing a homogeneous data set for more than a decade. Sustained observations from these and the other three high-density lines are required to have observations with adequate spatial and temporal resolution for climate studies. High-density observations in AX08, AX18, and AX25 provide data in poorly surveyed regions.

- The high-density line AX07 is located nominally along 30°N extending from the Straits of Gibraltar in the eastern Atlantic to the east coast of the United States at Miami, Florida. This latitude is ideal for monitoring heat flux variability in the Atlantic because it lies near the center of the subtropical gyre, which has been shown to be the latitude of the maximum poleward heat flux in the Atlantic Ocean.
- The high-density line AX10 is located between New York City and Puerto Rico. This line closes off the United States eastern seaboard, where subtropical temperature anomalies could have the greatest interaction with the atmosphere. This line was chosen to monitor the location of the Gulf Stream and its link to the NAO.
- The high-density line AX08, part of the Tropical Atlantic Observing System, crosses the tropical Atlantic in a NW-SE direction between North America and South Africa. Historical data along AX08 and other historical temperature observations in the tropics exhibit decadal and multi-decadal signals. It has been hypothesized that this large time scale signal may cause atmospheric variability. Given the importance of the tropical Atlantic in climate variability, and the scarcity of observations in this region, data obtained from the measurements along this line are key to improving our understanding of the ocean and our ability to forecast climate. Temperature profiles obtained from this line will help to

monitor the main zonal (east-west) currents and undercurrents in the tropical Atlantic and to investigate their spatial and temporal variability.

- The high-density XBT line AX18, which runs between Cape Town and South America (Montevideo, Uruguay, or Buenos Aires, Argentina) is geared towards improving the current climate observing system in the South Atlantic, a region of poor data coverage. The main objective of this line is to monitor the meridional mass and heat transport in the upper 800 m across 30^{o}S. Given the importance of the South Atlantic and the scarcity of observations in this region, data obtained from the measurements along this line will be used to investigate the role of the South Atlantic in improving climate forecasts.
- The AX25 line was implemented to measure changes in the variability in the upper layer interocean exchanges between South Africa and Antarctica on seasonal and interannual time scales. In addition, by exploiting the relationship between upper ocean temperature and dynamic height, XBTs are used to infer velocities and to monitot the various frontal locations in the region.

<u>Interagency and international partnerships</u>
The NOAA/AOML SOOP Program is a participating member of JCOMM and JCOMMOPS. The AOML SOOP XBT program is represented annually at the WMO/IOC Ship Observations Team (SOT) meeting. Participation on these international panels provides an important mechanism for integrating and coordinating with other national or regional programs which, in the long run, improves our national climate mission by making more efficient and effective use of available resources.

Several agencies are currently collaborating with this project. The Argentine Hydrographic Naval Office (SHN) provides the personnel to deploy the XBTs on AX18; the University of Cape Town provides for the deployments along AX08 and AX25. The South African Weather Service is our contact in Cape Town and Durban to store the equipment in between transects and to provide ship riders.

<u>Data availability and project web sites</u>

http://www.aoml.noaa.gov/phod/hdenxbt/
http://www.aoml.noaa.gov/phod/xbt.php
http://www.aoml.noaa.gov/phod/trinanes/SEAS/
http://seas.amverseas.noaa.gov/seas/

Data from the LD, FRX and most HD deployments are transmitted and made available in real-time for operational climate forecast and analyses. Data from the international collaboration are not always available in real-time. HD data is also made available for on the project web site listed above.

FY 2006 Accomplishments

SEAS System
During the last year the focus of our work has been to improve, update and support the SEAS 2K program. This includes ongoing development of the following software

modules: meteorological (MET) observations, automated MET observations, expendable bathy observation (XBT), and thermosalinograph (TSG) data. A flexible and powerful time-server background service was designed and created that provides essential time and position data to SEAS 2K from a wide variety of GPS sources. Figure 3 provides information of the SEAS 2K XBT data transmissions during FY2007.

In addition time and effort was spent in support of SEAS 2K, training and operational support is provided to users in system operations, data tracking during cruises, and trouble shooting problems at sea in real-time. The specific accomplishments for each component within this system are outlined below.

1. Meteorological System (VOS ships)

The MET software required several upgrades and corrections as determined by the Weather Service. It now self corrects for daylight savings time. If the ship computer is set to local time, it gives correct GMT time in the JJVV message. Additional help pages have been added, such as information about VOS climatological data formats.

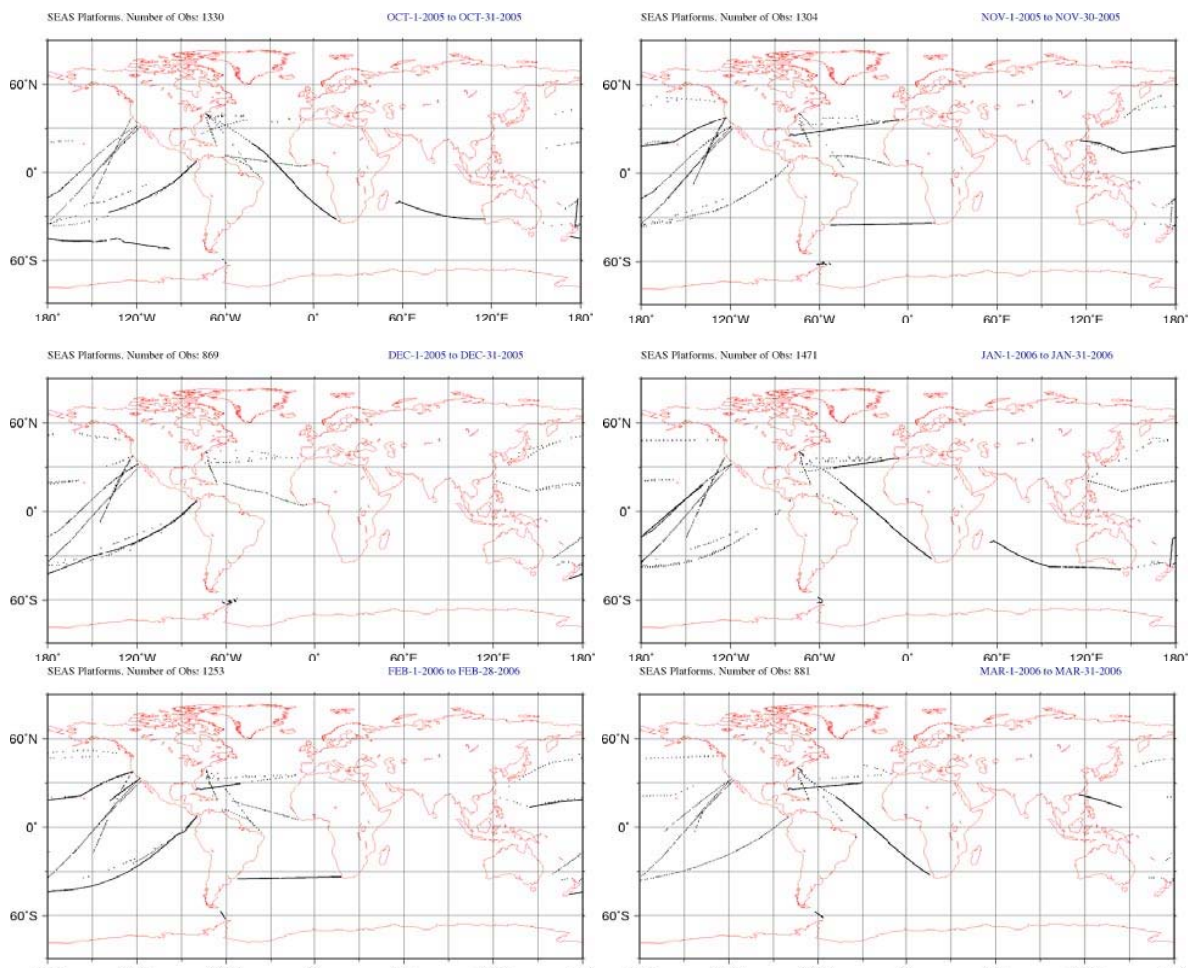

Figure 3a. XBT observations transmitted through the SEAS System for the first six months of FY2006.

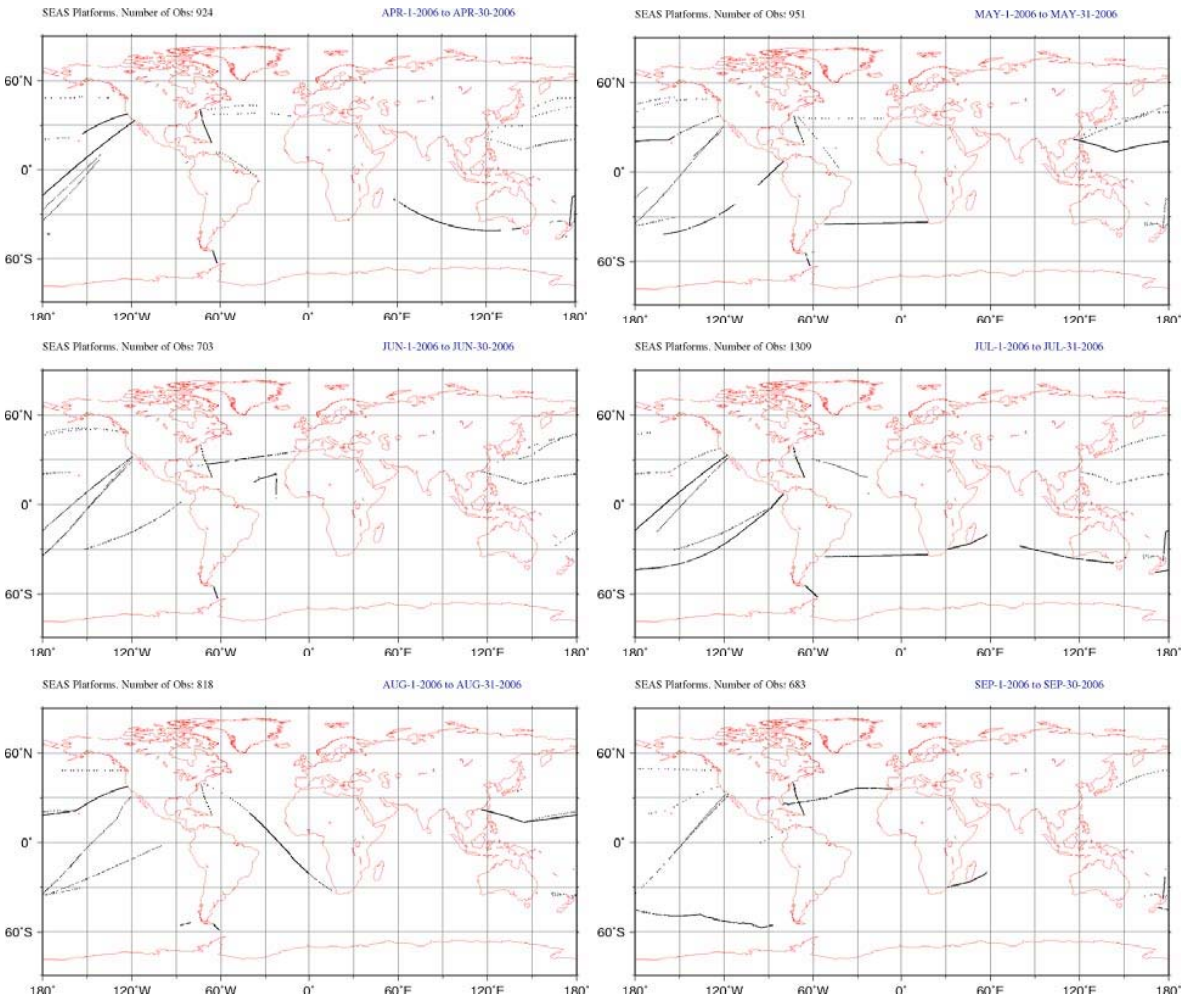

Figure 3b. XBT observations transmitted through the SEAS System during the last six months of FY2006.

The automated MET system is complete for integration with the Woods Hole Oceanographic Institute automated meteorological station. Automated MET is currently under development for the NOAA fleet that integrates SEAS2K with the Scientific Computing System (SCS). A software module has been written that collects data from the SCS system using socket transfer. Transferring these data into the Automated MET capability of SEAS 2K has been designed and is currently being tested. The data will then be transmitted off the ship using ship email.

The SEAS server software was modified to extract BBXX messages from the USCG that were in improperly coded bulletins. The messages were re-encapsulated in SXUS08 bulletins and delivered to the GTS.

2. *XBT System (SOOP ships)*

The XBT Auto Launcher System (XALS) is a multifaceted design that operates three different hardware systems: the hand launcher, the NOAA/AOML auto launcher and the Scripps oceanographic auto launcher.

The fully automated XALS schedules, drops and transmits XBTs, requiring little input from the operators. The XALS provides many features and options to the user: automatic or manual transmission of binary messages, alarms and alerts, and automatic input of meteorological and ship data. Some new features were added and minor bugs were corrected in the XBT program. Some of the upgrades were:

- Hardware checks were included that determine if the NOAA/AOML interface box is connected and will inform operator if it is not. This was a concern of the ship riders and requested by them at the AOML/GOOS meeting in Miami in April.
- A sophisticated re-drop feature was added that operates when running a system using a time plan (already functional for drops using a position plan). This code will engage when a drop is out of bounds from the last successful drop.
- An "End Cruise" button was added that allows the user to end a cruise gracefully with a button press. This button will zip all binary data and status files, clear directories of previous navigation data to insure that a new cruise will not be using data from previous cruises.
- An additional button was added to move the operation from auto launching setup to a hand launching setup.
- A MK21 Error detection code was added to determine if data had dropped out of the MK21 card during an XBT drop. In such cases the user is properly alerted and data collection halted.
- A new probe type, LMP5 (T-12), was included in the probe selection list along with code that calculates correct fall rates for this probe type.
- A new decoder is under development to receive e-mail with attached SEAS 2K delayed mode XBT files. The delayed mode data will be retrieved from the ships and e-mailed. This data will then be automatically unzipped and coded into NDC files. These NDC files will be checked against those transmitted in real-time and will replace bad or missing profiles.

3. *Time Server Service*

A Time Server Service was created as an essential part of the SEAS 2K system. The Time Server Service runs as a background service, which is different from the previous Time Serve that was a graphical interface. This new Time Server Service also increases the flexibility of the Time Server by allowing for 4 possible inputs for GPS. This includes Thrane and Thrane NMEA serial (4800 or 9600 baud), another Time Server on the network, and another server which would typically be the TSG Server software module. This Time Server distributes data to SEAS 2K and to the TSG Server. This software uses named pipes in a server client arrangement. The software system is flexible and provides for multiple methods of cabling. In fact, if the GPS fails in the engine room the Time Server Service is capable of reading the GPS via internet from the bridge.

The Time Server Service has been successfully tested on the Cap Victor along with the TSG Server module. It is important to note that the SeaBird manufactured TSG junction box on the Cap Victor was unable to recognize the ship's GPS NMEA string, but that the SEAS 2K Time Server Service was able to read this and time/position stamp the TSG data correctly.

4. Thermosalingraph (TSG) System

The TSG transmission system was designed and created. This system has been tested successfully at sea on the Cap Victor in September 2006. This software is easy to setup and requires no user input once started. It resides in the engine room and collects data from the TSG junction box and time/position stamps the TSG data. The TSG Server can read GPS data in two possible ways either from the Time Server or from the TSG junction box. If the TSG module collects GPS data from the junction box it can pass on this GPS data to the Time Server for use by SEAS2K if necessary. The TSG data is transferred to the bridge over the ship intranet and can then be transmitted.

Low-Density/Frequently Repeated XBT Observations

In view of the implementation of the Argo Program and the availability of satellite altimetry data, the international SOOP community decided in 1999 to gradually phase out LD transects while maintaining sections operated in FRX and HD modes. However, the ability of other observing systems, such as of profiling floats, to continue the important records initiated by mechanical BTs and by XBTs is still unknown (see Progress report for determination of the information content in long-occupied Voluntary Observing Ship (VOS) Expendable Bathythermograph (XBT) Transects, by G. Goni and R. Molinari): some LD lines contain time series as long as 30 years (longer than 50 years including mechanical BTs) with much higher horizontal resolution than is available from a fully implemented ARGO program.

	GOAL		ACTUAL	
Line	XBTs/year	XBTs per transect	AOML transects FY06 *	AOML XBTs FY06**
AX10	96	12	15	311
AX07	280	35	12	134
AX08	504	63	4	0
PX13	416	52	13	1143
PX37-PX10-PX44	544	48	15	519
PX26	468	39	15	461
PX08	408	60	17	867

Table I. Goals and actual deployments of XBTs in LD mode by NOAA/AOML. (*) includes HD transects. (**) LD/FRX deployments only.

This year LD sampling was reduced, FRX lines already begun were continued and several new FRX lines were initiated. In view of the SI emphasis for the use of the XBT data, most transects that cross the equator and are located in the subtropics were maintained. Some of these transects were maintained exclusively by AOML and others were maintained as a partnership between AOML and international collaborators with probes provided by AOML.

AOML currently maintains the following transects in LD/FRX mode (Figure 1): AX07, AX08 and AX10 in the Atlantic and PX08, PX10, PX13, PX26, PX37 and PX44 in the Pacific. In the Atlantic, AX04, AX29 and AX32 were discontinued and in the Pacific PX06, PX09 and PX18 were discontinued. Because the transition was started in January 2006 and finalized during the summer of 2006 some of the lines that were discontinued still appear in the FY2006 deployment report.

The current goal of this project is to have all the lines occupied at least 12 (16) times per year in LD (FRX) mode while deploying 4 (6) XBTs per day, this is 1 XBT every approximately 100km (60km). Some of these lines are also occupied in HD mode (which are carried four times a year) and need to be carried out a lesser number of times per year. The target for each of the lines in LD mode is shown in Table I. The goals have been reached in six of the seven transects. For one of the lines (AX08), we were not able to find ships willing to deploy XBTs. However, we have recently recruited one ship that will start sampling this line in LD mode in December 2006. Some of the lines (AX10, PX37-10-44, and PX26) are occupied in near FR mode. A total of 3435 XBTs were deployed by NOAA/AOML in LD/FRX mode from 28 participating ships during FY2006.

High-density XBT Observations

XBT deployments along HD lines proceeded as planned in previous years: 4 sections each year for AX7, AX10, AX8 and AX18, two sections per year for AX25 (Figure 2). Note that AX25 is occupied only twice each year due to ice coverage. Figure 4 shows all XBT deployments to date for each of the five HD lines. The exact locations of XBT deployments along each line during FY2006 are shown on the web. A summary of all the cruises conducted in fiscal year 2006 can be found in Table II. A total of nineteen HD cruises were conducted, 3612 XBTs deployed, 70 ARGO profilers, 67 SVP Drifting buoys and an average XBT failure rate of less than 8% (see Table II). Of note was that five HD cruises were conducted on AX7 due to a major equipment malfunction in September 2005, resulting in only three complete sections for FY2005. Because the AX7 line is so important for quarterly heat transport estimates, a replacement section during November 2005 (which falls in FY2006) was conducted: hence a total of five sections occurred during FY2006 along AX7.

This past fiscal year, increased communications between our LD/FRX international partners has led us to discover one XBT line that could potentially be incorporated into the set of HD lines that AOML maintains. In particular the AX98 line grew out of our international cooperation with Brazilian scientists who have been studying the intensity and variability of the Brazil Current between Rio de Janeiro and the Island of Trinidade, a

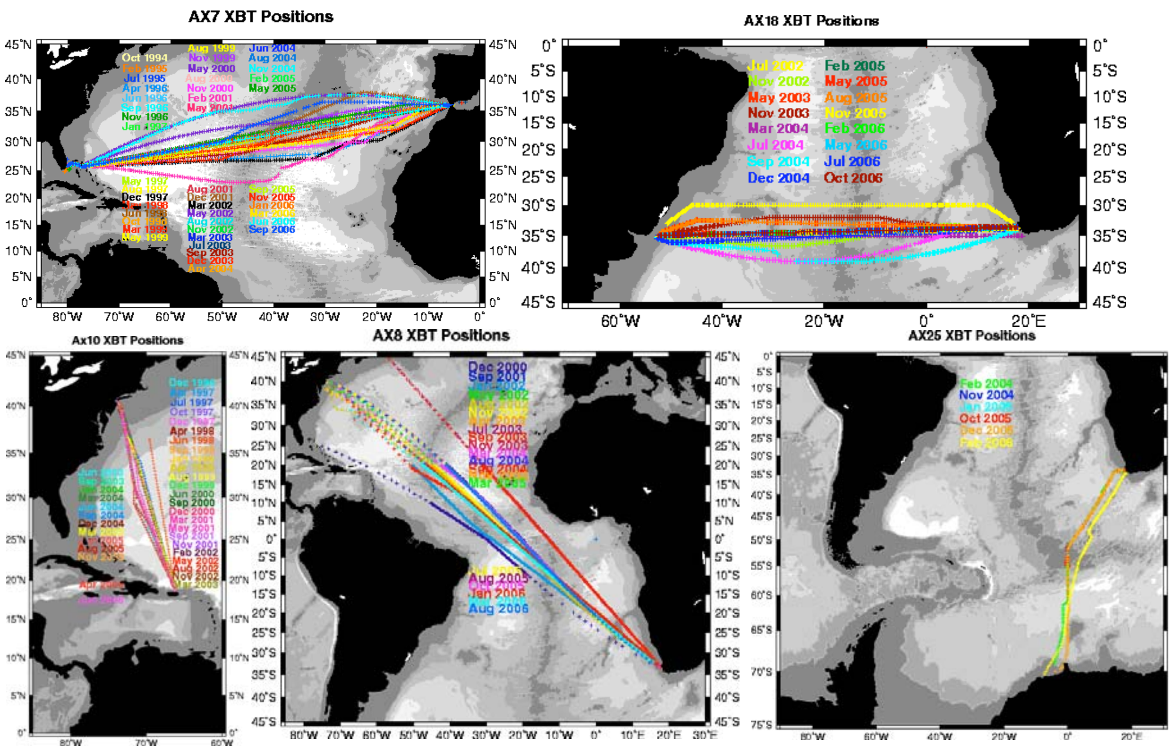

Figure 4. Location of XBT deployments for XBT lines AX07(top left), AX18 (top right), AX10 (bottom left), AX8 (bottom middle), and AX25 (bottom right) from the high-density XBT web

small island off the coast of Brazil. During fiscal year 2006 Brazilian researchers were deploying XBTs with sufficient frequency to be considered a new high-density XBT line and hence we have begun to recover and process these data. To date three cruises of data have been provided and processed by AOML: August 2004 (56 XBTs), February 2005 (59 XBTs) and August 2005 (49 XBTs) whose deployment locations are shown in Figure 5.

Line Designation	# Sections FY06	# XBTs	Avg # XBTs	Percentage Good	ARGO deployed	Drifters deployed
AX7	5	1124	224.8	88.3	18	18
AX10	4	391	97.8	89.5	4	0
AX8	4	1036	259.0	94.9	22	25
AX18	4	698	174.5	96.0	12	15
AX25	2	363	181.5	92.8	14	9
Total	19	3612		92.3	70	67

Table II. Summary of deployment information for HD lines maintained by AOML.

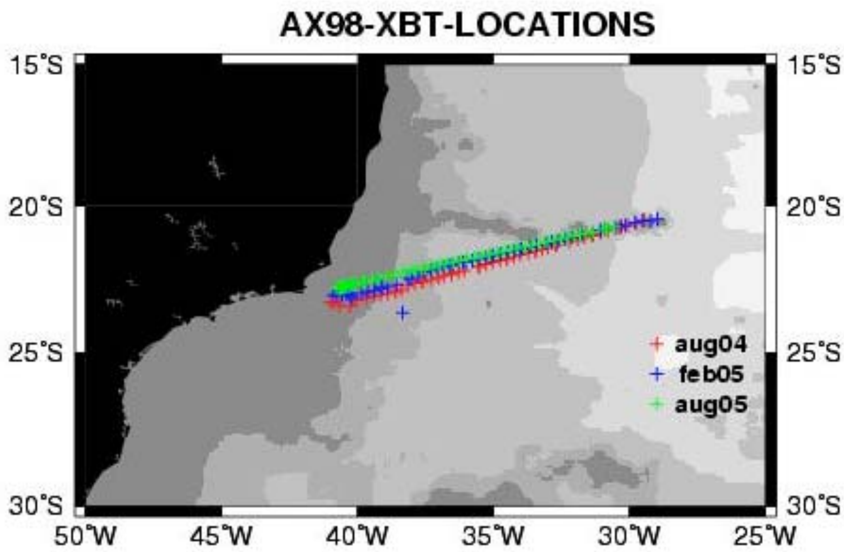

Figure 5. Deployment locations of XBTs on the line AX98 located off the coast of Brazil.

<u>General</u>

Real-time XBT data were transmitted via Inmarsat Standard C. Automatic quality control tests are applied to the data and those profiles that pass are distributed on the GTS. An operator reviews those profiles that fail the automatic quality control procedures and decides whether or not to send the data to the GTS. Full resolution data are stored on disks and obtained by ship greeters when the ship returns to port. The data are forwarded to AOML, placed in established formats and then sent to the National Oceanographic Data Center (NODC). The ratio of XBTs deployed to real time data transmitted is essentially 100%. Probe failure (as measured by the auto QC procedure) remains consistently between 2 % and 5 % with greater higher failure rates in the higher latitudes during the hemispheric winters. Note that the HD failure rate averaged about 8% in FY2006, due in part to aging autolaunching equipment and some intermittent instrument failure and not the XBTs themselves. All XBT data are archived at the NODC and a subset of all Atlantic XBT data are archived at a DAC located at AOML

These XBT data are used in real time for ENSO monitoring and prediction and the initialization of climate models at centers for environmental prediction and in delayed mode for research concerning seasonal to decadal climate studies of the upper ocean thermal layer. There are no restrictions on sharing this information as it is distributed in real time on the GTS.

<u>International and Domestic Collaboration</u>

By providing probes to international partners, AOML saves the cost of ship greeting for lines that would be difficult and expensive to maintain from the U.S. The probes provided to Noumea are being deployed along lines that cross the equator in the western Pacific to complement PX13 and PX08 in the central and eastern Pacific. The probes provided to Australia are used to a basin wide transect in the Indian Ocean that crosses the equator and to partly support a high density transect between Tasmania and Antarctica. The XBTs provided to Brest are used along lines that cross the equator in the Atlantic Ocean and those provided to Brazil along a line in the subtropical South Atlantic that monitors the Brazil Current.

The international collaborators are:

IRD, Noumea, 1 pallet, collaborator: Mr. David Varillon
FURG, Brazil, 1 pallet, collaborator: Dr. Mauricio Mata
IRD, France, 1.75 pallets, collaborator: Mr. Denis Diverres
CSIRO and Bureau of Meteorology, Australia, 2 pallets, collaborator: Ms. Lisa Cowen

We provided a total of 5.75 pallets (1863 XBTs) to these partners. Most of the data obtained from these XBTs were placed into the GTS in real-time. For those ships that are not currently transmitting the data in real-time, we are exploring the possibility of installing computers and transmitting antennas for real-time data distribution. All of the data were submitted to NODC.

These XBTs were deployed in the following transects:

Noumea: PX09, PX30, PX51
Brazil: Sao Paulo-Isla de Trinidade, Rio de Janeiro-Antarctica
France : AX05, AX20, AX11
Australia : IX12, IX28

Additionally, in support of the NOAA-funded "Surface pCO_2 Measurements from Ships" (Drs. Rik Wanninkhof and Richard Feely, PIs), we provided 1.5 pallets (486 XBTs) to NOAA/NMFS in Rhode Island to be deployed along the pCO_2 transects AX32 and AX02.

Research Highlights

1. Data from the AOML SOOP Program is available to researchers producing Quarterly reports on the "state of the ocean" using XBT data to estimate heat transport from two of its high-density lines and heat content from all XBTs and ARGO profiles (Figure 4). Quarterly reports are a means to present to managers and decision makers summary information on the state of the ocean, in this case the intensity of the temperature transported by the meridional overturning circulation and the ability of the current network to document heat content changes (see research analysis projects "Meridional Heat Transport Variability in the Atlantic Ocean" and "Global Heat Content" for more details). Temperature content and transport variability is an important indicator of climate variability since oceanic temperature transported poleward heats the atmosphere.

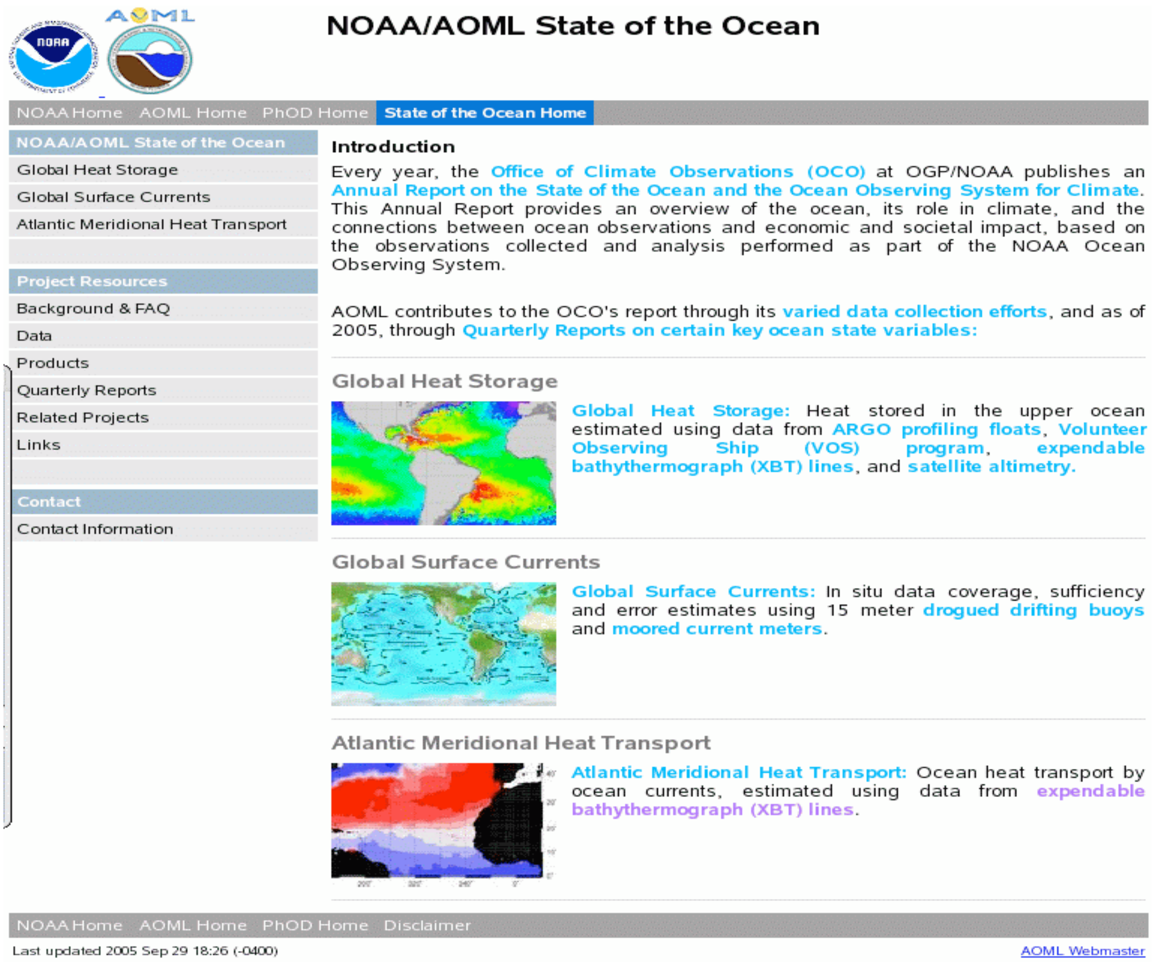

Figure 6: Main title page developed for the dissemination of products developed to provide input into the state of the ocean reports for NOAA's Office of Climate Observations.

2. Temperature sections obtained from the AX08 transects are being used to investigate the zonal currents in the tropical Atlantic (Figure 7). The currents are identified from the slope of the isotherms. A correlation was found between the slope of the isotherms and the dynamic height in the NECC region along each transect. The dynamic heights can also be found from altimetric measurement, where the sea height anomalies are added to the mean dynamic height (Levitus 2000) referenced to 800m. Time series of the location of the core of the NECC and its transports can then be derived from altimetric measurements. The key result that was found in this study is that the motion of the core of the NECC exhibits a semiannual and annual component, while the transport has only an annual component. Our results also indicate that the motion of the core of the NECC is mostly semiannual in the western side of the basin, while it is annual on the eastern side of the basin.

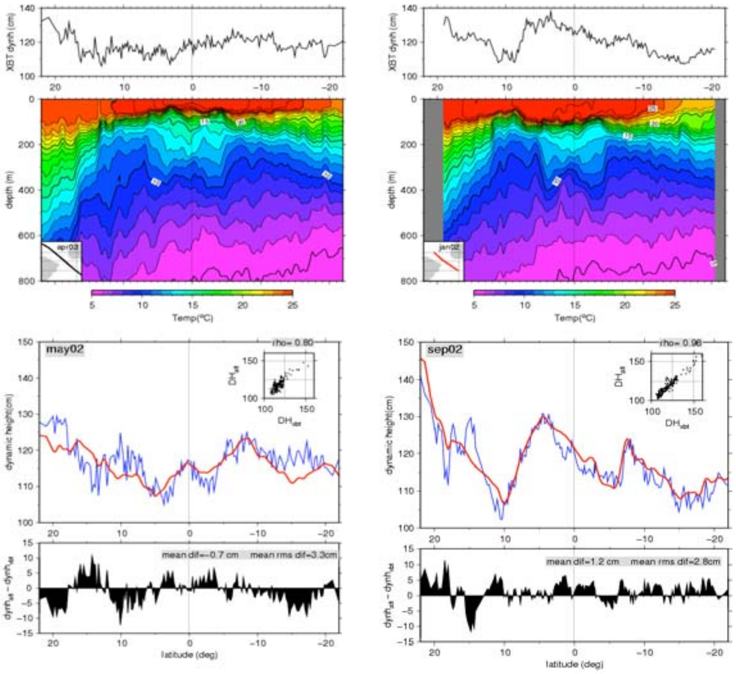

Figure 7. Temperature sections (second panels from the top) for two transects (September 2002 and May 2002, left and right, respectively) with the dynamic height (upper panels) derived from XBT deployments and climatological T-S relationships. The dynamic height derived from altimetry (in red) and XBTs (in blue) and their differences are shown in the lower panels.

3. XBT data are being used to determination of regional patterns of upper layer temperature variability in well sampled areas. Figure 8 shows an analysis of decadal temperature changes in the North Pacific (Robert Molinari, personal communication) in the form of a space-time diagram of the temperature at 150 m along the transect PX26. The decadal variability in the temperature, which can be seen as basin wide changes in the sign of anomalies after 1988 and 1998, are probably related to the Pacific Decadal Oscillation. Lines that cross the intense boundary currents and that have been occupied continuously for more than 10 years provide a unique source of information on the variability at time scales greater than interannual and, in some cases, decadal. It is speculated that data from other platforms may not be able to provide similar information because of the high advective speeds in these currents.

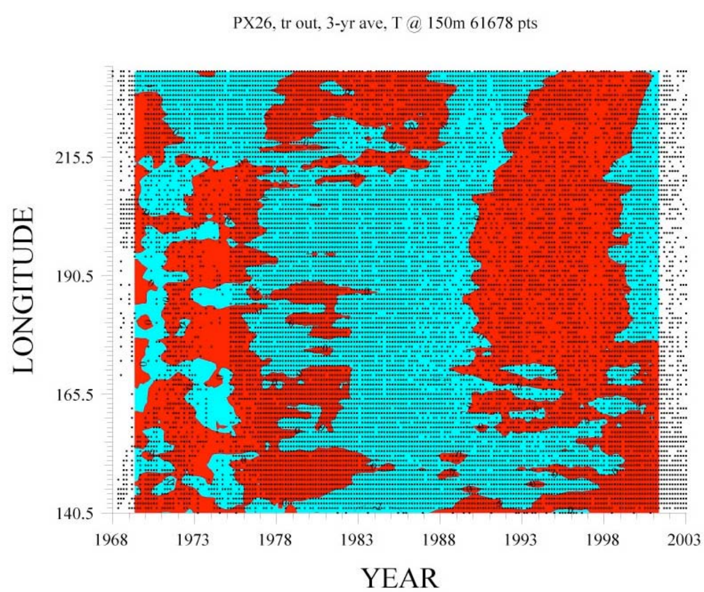

Figure 8. Decadal temperature anomalies showing warm (red) and cold (blue) periods at 150 m along the Pacific line PX26.

Publications:

Peer-reviewed

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2. Legeais, J.-F., S. Speich, M. Arhan, I. Ansorge, E. Fahrbach, S.L. Garzoli, and A. Klepikov. The baroclinic transport of the Antarctic Circumpolar Current south of Africa. *Geophysical Research Letters,* 32(24):L24602, doi:10.1029/2005GL023271 (2005).
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1. Baringer, Molly O. and Silvia L. Garzoli, 2006. Meridional Heat Transport using Expendable Bathythermographs. Part 1: Error Estimates, *Deep Sea Research, Submitted.*
2. Garzoli, Silvia L. and Molly O. Baringer, 2006. Meridional Heat Transport using Expendable Bathythermographs Part II: South Atlantic Ocean. *Deep Sea Research, Submitted.*

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1. Baringer, M. O., C. S. Meinen and S. Garzoli, 2006. The Meridional Overturning Circulation and Oceanic Heat Transport, In *Annual Report on the State of the Ocean and the Ocean Observing System for Climate (FY-2005),* J.M. Levy, D.M. Stanitski, and P. Arkin (eds.). NOAA Office of Climate Observation, Silver Spring, MD, 68-73.
2. Baringer M., S. Garzoli, G. J. Goni, C. Thacker and R. Lumpkin, 2006. Quarterly Reports on the State of the Ocean: Meridional Heat transport Variability in the Atlantic Ocean. In *Annual Report on the State of the Ocean and the Ocean Observing System for Climate (FY-2005),* J.M. Levy, D.M. Stanitski, and P. Arkin (eds.). NOAA Office of Climate Observation, Silver Spring, MD, 265-268.
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