Ship of Opportunity Program (SOOP), Volunteer Observing Ships, Expendable Bathythermograph (XBT) and Environmental Data Acquisition Program

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1. PROJECT SUMMARY

This project includes data acquisition, transmission and quality control, 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 acquire ocean and meteorological information and transmitted in real-time to users worldwide called SEAS (Shipboard Environmental Acquisition System).
- Upper ocean temperature observations using expendable bathythermographs (XBTs) deployed broadly across large ocean regions along repeated transect: the frequently repeated/low-density XBT program.
- Upper ocean temperature observations using XBTs deployed closely spaced in order to measure the mesoscale field: the high-density XBT program

This project is necessary and essential to the Department of Commerce's mission as evidenced by two of the three strategic themes that comprise the Department's mission statement:

- Keep America competitive with cutting-edge science and technology and an unrivaled information base; and,
- Provide effective management and stewardship of our nation's resources and assets to ensure sustainable economic opportunities.

1.1. 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. This software is employed on ships of the Ship of Opportunity Program (SOOP) Volunteer Observing Ships (VOS), and on NOAA, University-National Oceanographic Laboratory System (UNOLS), and Coast Guard vessels.

SEAS 2K is a user-friendly software that can be 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 400 ships of the SOOP and of the Voluntary Observing System (VOS). Over three million SEAS meteorological messages are transmitted per year constituting the largest source of marine meteorological observations, which are used in weather forecast prediction models and analysis, such as the National Hurricane Center. Approximately twenty ships of the SOOP participate with NOAA/AOML in deploying about 13,000 XBTs per year using SEAS 2K software. NOAA/AOML and Scripps Institution of Oceanography are the principal users of the software. National Marine Fisheries Service also runs an Antarctic line (AX22) using this software.

These data are transmitted in real-time to the Gateway Telecommunication System (GTS) and to operational databases to be used by scientists. These data are used for ENSO monitoring and prediction and the initialization of climate models at centers for environmental prediction and in delayed mode for research related to 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.

Additionally, 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.

1.2. Frequently Repeated/Low-Density XBT Operations

There are three main modes of deployment of XBT probes: Low Density (LD), Frequently Repeated (FR) and High Density (HD) (Table 1). Most of the probes used in this work are Sippican Deep Blue, which reach depths between 750 and 800m.

Frequently repeated (FR) XBT transects are mostly located in tropical regions. These lines typically run north/south, and cross the equator or intersect the low latitude eastern boundary. These transects are geared to monitor strong seasonal to interannual variability in the presence of intra-seasonal oscillations and other small-scale geophysical noise. 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 preferably covered 18 times per year with an XBT drop every approximately 150 km (or 6 deployments per day). This mode of sampling intends to draw a balance between the spatial undersampling, with good temporal sampling inherent in LD deployments and the good spatial sampling, marginal temporal sampling of HD deployments. Increasing both the temporal and spatial sampling in frequently repeated transects relative to low-density sampling greatly decreases the risk of aliasing in equatorial regions.

The LD or broadly spaced XBT mode is 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 HD mode. Sampling in LD mode has been the dominant mode in the early days of the 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. Occasionally these lines are also sampled through basic research and operational experiments in which XBTs are deployed to observe various oceanographic processes.

Table 1. Spacing and frequency sampling of the three different modes of XBT deployment.

MODE	Spacing	Frequency
Low Density (LD)	~ 250 km	12 times per year
Frequently Repeated (FR)	~ 150 km	18 times per year
High Density (HD)	~25 km	4 times per year

AOML maintains several of the recommended FR and LD transects (Figure 1), with some of them operated in cooperation with international partners from France, Australia, and Noumea. All FR and LD transects lead by the U. S. utilizes SEAS 2K software.

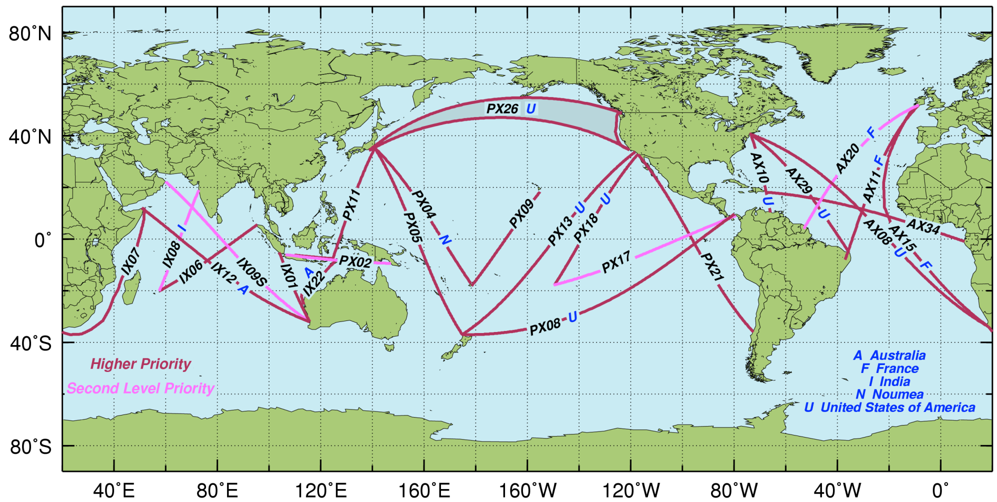

Figure 1. Location of Frequently Repeated and Low Density XBT network recommended by the 1999 Upper Ocean Thermal Review Panel. The blue letters indicate the country that leads the effort of each transect.

1.3. High Density XBT Operations

This program is designed to measure the upper ocean thermal structure in key regions of the Atlantic Ocean (Figure 2). XBTs in HD mode are deployed approximately every three months and are deployed approximately 25 km apart (Table 1) in order to measure the mesoscale structure of the ocean to diagnose the ocean circulation responsible for redistributing heat and other water properties globally. This transects are carried globally (Figure 2), with AOML taking the lead in the operations in the Atlantic Ocean (except for AX03 and AX22).

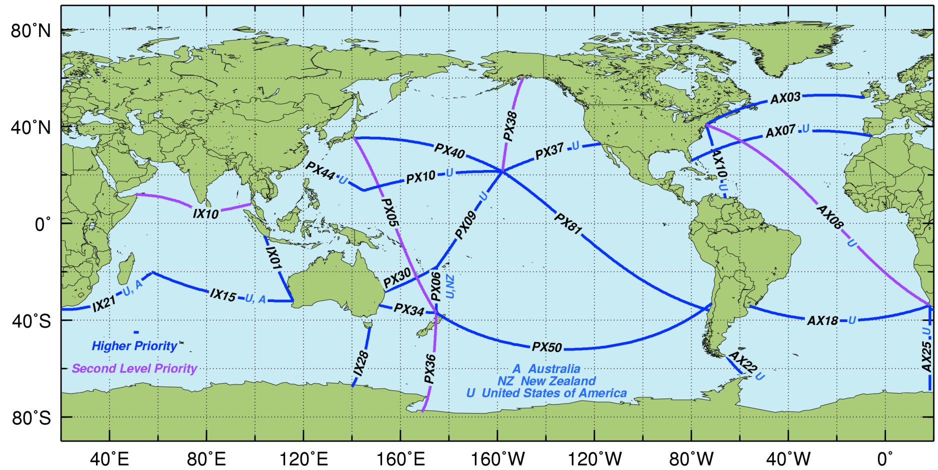

Figure 2. Location of the High Density Repeated XBT transects recommended by the 1999 Upper Ocean Thermal Review Panel. The blue letters indicate the country that leads the effort of each transect.

1.4. Scientific and Operational Goals

This project addresses both operational and scientific goals of the NOAA program for building a sustained ocean observing system for climate. Specifically, AOML manages a global XBT network that provides subsurface temperature data.

a) Scientific Goals

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). Additional objectives of this project are to provide the resulting data to increase our understanding of the dynamics of the seasonal to interannual and decadal time scale variability and to provide data for model validation studies.

b) Operational Goals

The data resulting from this project helps to document the ocean heat storage and global transport of heat and fresh water, which is crucial to improving climate prediction models that are initialized with temperature profiles. 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 climate forecasts prepared by NCEP. Global coverage is now required as the forecast models not only simulate Pacific conditions but global conditions to improve prediction skill.

1.5. Rationale

Data from these transects have been used extensively (Meyers et al, 1991; Taft and Kessler, 1991; Goni and Baringer, 2002). 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, AOML monitors six XBT transects in HD mode to determine properties in the upper layers of the Atlantic Ocean (Figure 2 and Figure 3). The continuation of AX07 and AX10 and the implementation of AX08 and AX18 were recommended by the Upper Ocean Thermal Review Panel in St. Raphael in 1999. The location of the transects recommended at the St. Raphael meeting and the GCOS *Implementation Plan* (GCOS-92) are based on specific advantages of each lines location. HD transects 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 HD transects are required to have observations with adequate spatial and temporal resolution for climate studies. High-density observations in AX08, AX18, AX25, and AX97 provide observations in poorly surveyed regions. A summary of the justification for each of the HD transect is provided below.

- The HD XBT transect 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 HD XBT transect 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 transect was chosen to monitor the location of the Gulf Stream and its link to the NAO.

- The HD XBT transect AX08, a component 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 transect are key to improving our understanding of the ocean and our ability to forecast climate. Temperature profiles obtained from this transect will help to monitor the main zonal currents, countercurrents and undercurrents in the tropical Atlantic and to investigate their spatial and temporal variability.

- The HD XBT transect 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. Similarly to the AX07 transect in the North Atlantic, the goal of AX18 is to monitor the meridional mass and heat transport in the upper 800 m across 30°S. Given the importance of the South Atlantic and the scarcity of observations in this region, data obtained from the measurements along this transect will be used to investigate the role of the South Atlantic in improving climate forecasts.

- The HD XBT transect AX25 was implemented to monitor 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 monitor the various frontal locations in the region.

- The HD XBT transect AX97 supports the MOVAR Project (from Portuguese: Monitoring the upper ocean transport variability in the western South Atlantic) and evolved out of international collaboration efforts of the low-density program. The fluctuations of the zonally integrated baroclinic transport across this transect will be studied and linked to the variability of the Brazil-Malvinas frontal region. This region is critical since Brazil Current rings are the main mechanism to carry subtropical waters to high latitudes.

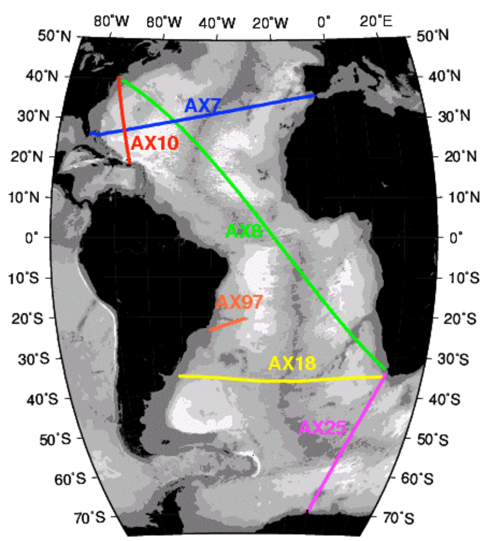

Figure 3. Location of the four High Density transects (AX07, AX08, AX10, and AX18) maintained solely by NOAA/AOML, and the two transects (AX25 and AX97) maintained in collaboration with the University of Cape Town and the Federal University of Rio Grande, respectively.

1.6. Partnerships

AOML maintains several XBT transects and other components of the SEAS operations with the collaboration of domestic and international partners, in order to lower costs and increase efficiency. This collaboration includes:

- Providing probes to oceanographic institutions that have demonstrated reliability in logistics and operations,
- Provide software maintenance,
- Contracting riders (HD transects only) to deploy the probes,

- Providing equipment (computers, antennas, etc) and software, and
- Carrying joint analysis of the data.

The SOOP program and the HD program also partner with other NOAA funded programs and national partners including

- The global drifter program (drifters deployed on HD lines)
- The global ARGO program (ARGO floats deployed on HD lines)
- The United State Coast Guard (AMVER vessel emergency response system is integral to SEAS)
- The National Weather Service (through SEAS transmissions of weather observations and from NWS port meterological officer collaborations for loading and greeting ships).
- For more complete partnerships see the international and domestic collaborations sections below.

1.7. Data Availability and Project Web Sites

Details of this project, such as logistics, equipment, software, and data distribution, are provided through links that can be accessed through the main NOAA/AOML Global Ocean Observing System (GOOS) web page www.aoml.noaa.gov/phod/goos.

- **SEAS:** http://www.aoml.noaa.gov/phod/trinanes/SEAS/
- **HD:** http://www.aoml.noaa.gov/phod/hdenxbt
- **FR/LD:** http://www.aoml.noaa.gov/phod/goos/ldenxbt

Data from the LD, FRX and most HD deployments are transmitted to the GTS 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 on the project web site listed above.

2. ACCOMPLISHMENTS AND HIGHLIGHTS

2.1. SEAS System

The main accomplishment during FY 2008 was to include Iridium transmission for XBT deployments and TSG observations in SEAS 2K.

Every year the focus of our work is to improve, update and support the SEAS 2K program. This includes ongoing development of the following software modules: meteorological (bulletins), automated meteorological, XBT, and Thermosalinograph (TSG) observations. Figure 4 provides the locations of the approximately 13,200 SEAS 2K XBT and 194,000 TSG data transmissions into the GTS during FY2008, respectively.

In addition, time and effort was spent in support of SEAS 2K, by providing training and operational support 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 in this report.

2.2. Meteorological System (VOS ships) and SEAS software

The SEAS 2K meteorological (MET) software is constantly being upgraded with corrections as recommended by the National Weather Service.

The automated MET system is complete for integration with the Woods Hole Oceanographic Institute automated meteorological station. Automated MET continues being developed for the NOAA fleet to integrate SEAS2K with the Scientific Computing System (SCS). The software module is being constantly updated to collect data from the SCS system using socket transfer. Transferring these data into the Automated MET capability of SEAS 2K continue being tested. Once finalized, the data will be transmitted off the ship using ship email.

Approximately 700 merchant ships currently have SEAS software installed, and supported through the NWS/NDBC (Robert Luke) VOS Program. These ships transmitted about 200,000 meteorological bulletins using SEAS software during FY 2008 (Figure 5). This contribution constitutes 10% of non-satellite global marine weather obervations.

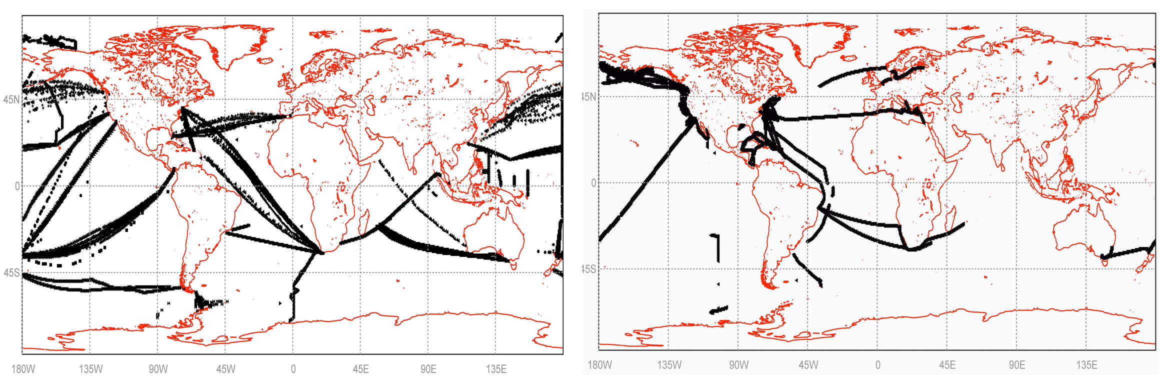

Figure 4. SEAS 2K transmissions of (top) XBTs and (bottom) TSGs into the GTS during FY2008.

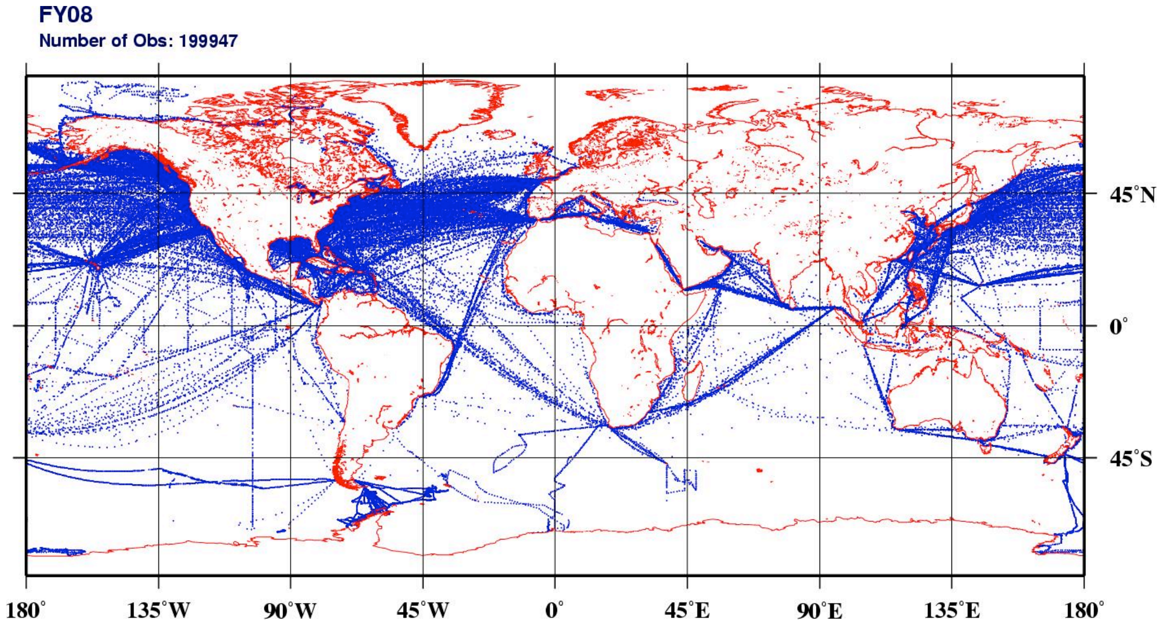

Figure 5. SEAS 2K transmissions of meteorological bulletins into the GTS during FY2008.

2.3. Frequently Repeated/Low-Density XBT Operations

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. Some LD transects contain time series as long as 30 years with much higher horizontal resolution than is available from a fully implemented ARGO program. This time series is longer than 50 years if mechanical BTs are included. A full report of the XBT deployments by transect is shown at: http://www.aoml.noaa.gov/phod/goos/ldenxbt/index.php.

This year LD sampling maintained the reduced levels of the previous year, FRX lines already begun were continued. In view of the seasonal to interannual 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 Ocean, and PX08, PX10, PX13, PX26, PX37 and PX44 in the Pacific Ocean.

The current goal of this project is to have these transects occupied at least 12 (16) times per year in LD (FRX). Some of these transects are also occupied in HD mode, which are carried four times a year, and need to be occupied a lesser number of times per year. The number of XBT deployed in each line is shown in the AOML XBT report that can be obtained from the GOOS web page at: http://www.aoml.noaa.gov/phod/VOS/REPORTS/ (username: tchp, password: uohcval).

2.4. High Density Mode Operations

Figure 6 shows all XBT deployments to date for each of the five HD transects. XBT deployments along HD transects preceded as planned in previous years. Note that AX25 is scheduled for only twice each year due to ice coverage. Several ships were recruited (see Recruitment). Transects AX10 and AX07 are now conducted with new ships. We continue experiencing difficulties with the AX18 route from Cape Town, South Africa to Buenos Aires, Argentina. The shipping company we used has discontinued this transect and there are currently no shipping companies sailing between these ports. We continue to actively search for a new ship with the help of colleagues in Argentina and South Africa. We have identified a slightly shifted route that enters into Santos, Brazil, slightly further north than AX18. Because this section is largely justified based on the ability to provide transoceanic heat transport estimates across the subtropical gyre in the South Atlantic, the exact port locations is less important because the heat transport will not change dramatically between these latitudes in this region. However, ideally since we prefer repeated routes we will continue to search for a replacement vessel for AX18.

The exact locations of XBT deployments along each line during FY2008 are shown on the AOML SOOP web page. A summary of all the cruises conducted in fiscal year 2008 can be found in Table 1. A total of sixteen High Density XBT cruises were conducted, 3146 XBTs deployed, 26 ARGO profilers, 47 SVP Drifting buoys.

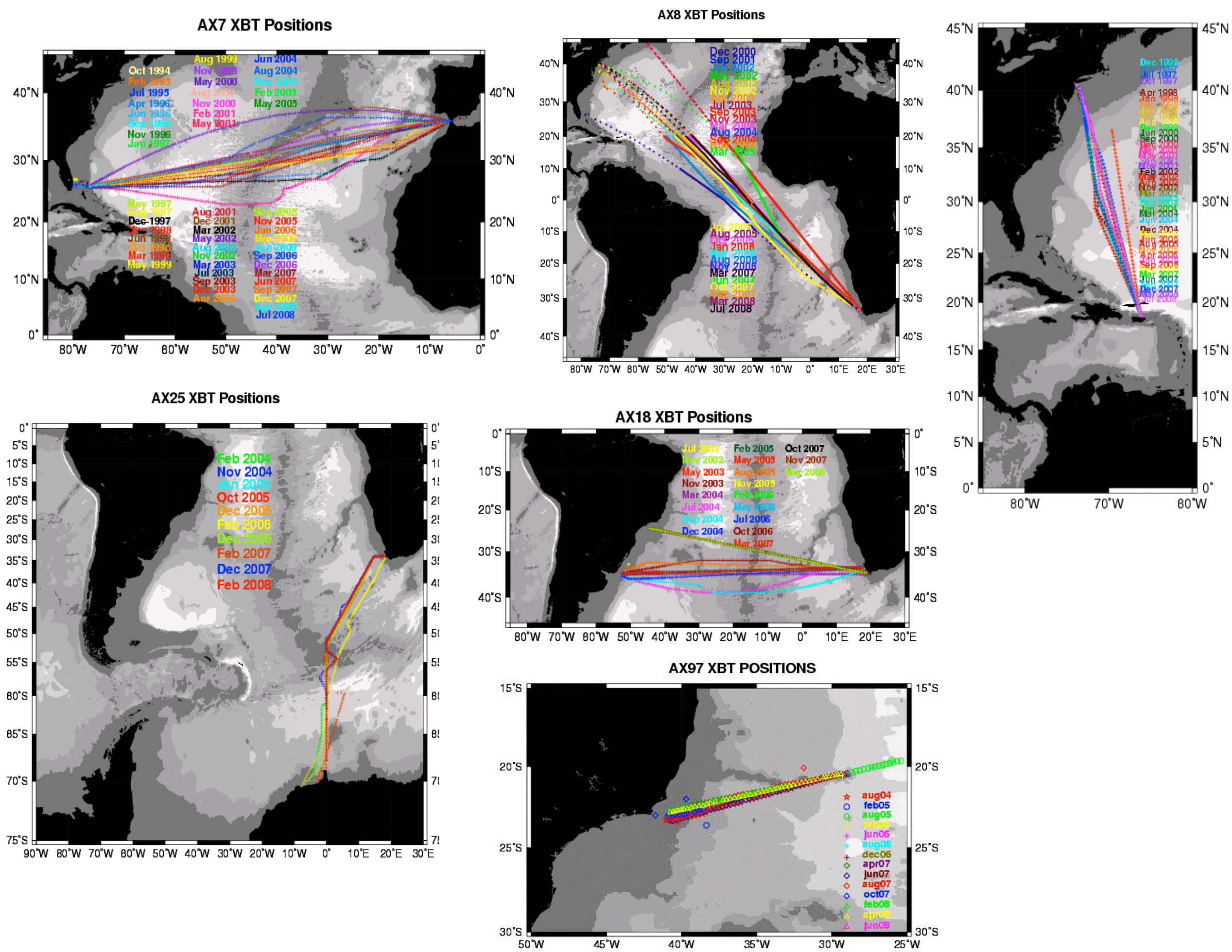

Figure 6. Location of all AOML XBT deployments in HD mode.

Table 2. Table summarizing the XBTs deployed on the five main high-density XBT lines operated by AOML during FY 2008.

Transect Designation	# Sections FY08	# XBTs	Avg # XBTs	Percentage Good	ARGO deployed	Drifters deployed
AX7	3	603	201.0	96.1	0	0
AX10	3	311	103.7	96.8	0	0
AX8	5	1381	276.2	93.6	16	39
AX18	3	523	174.3	97.9	4	4
AX25	2	328	164.0	91.5	6	4
Total	16	3146		94.9	26	47

Note that for Table 2 we use the start date of the cruise for fiscal year reporting, despite the fact that cruises typically take 5 to 25 days to complete. In this past fiscal year only three transects were performed on AX7 and AX10, while five transects were carried out on AX8. This is largely due to slight scheduling shifts in the cruise scheduled for September. The last cruise for AX10 was completed October 11 – 14, 2008 designed to approximately coincide with the last cruise for AX7 which was completed October 2 – 11, 2008. For AX8, the first cruise of the fiscal year was a delayed cruise from FY2007 that was completed in October 2007. Next year AX7 and AX10 will officially report 5 cruises in the fiscal year. This is a caution to note that we do not feel that we have either undersampled or oversampled any of the HD lines. All the lines except AX18 are now operating normally and offer no concerns.

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 AX97 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 small island off the coast of Brazil. In fiscal year 2008 four cruises of data were received from our collaborators and processed by AOML: October 2007 (20 XBTs), February 2008 (35 XBTs), April 2008 (49 XBTs), June 2008 (45 XBTs). We already shipped a SEAS 2000 system to allow real-time transmission of their data directly.

2.5. International Collaboration

AOML Provides probes to oceanographic institutions that have demonstrated reliability in logistics and operations. These probes are used to carry out recommended transects in FR and HD modes. By providing probes to international partners, AOML saves the cost of ship greeting for transects 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.

AOML provides probes to the following international collaborators:
- **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
- **South African Institute for Aquatic Biodiversity,** 0.3 pallets

AOML 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. Most of the data collected from these deployments were submitted to NODC.

These XBTs were deployed in the following transects:
- **Noumea:** PX09, PX30, PX51

- **Brazil:** Sao Paulo-Isla de Trinidade (AX97)
- **France :** AX05, AX20, AX11
- **Australia :** IX12, IX28
- **South Africa:** Mozambique Channel

Additionally, 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. Deployments along AX97 are done in collaboration with the Federal University of Rio Grande, Brazil.

Drs. Gustavo Goni and Molly Baringer are involve in data analysis and scientific collaboration activities with scientists from University of Cape Town, South Africa, and University of Rio Grande, Brazil (see publications).

2.6. Domestic Collaboration

The following is a summary of the domestic collaboration that involves AOML SOOP operations:

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

- NOAA/AOML also provided 3 cases of XBTs in support of the NOAA-funded MASTER (Meso-American System Transport and Ecology Research), off the Mexican and Belizean Yucatan, between 16°-22°N, 90°-80°W. These cruises are performed twice a year.

- NOAA/AOML collaborates with the National Weather Service to provide maintenance of SEAS 2K software to transmit marine meteorological observations.

- Through an agreement with the U.S. Coast Guard, NOAA/AOML maintains the SEAS software, which is used for search and rescue operations.

- Additional collaboration with the Global Drifter and Argo Programs are detailed below.

2.7. Transmissions and data flow

XBT profiles are sent through the Thrane Standard C units. AOML is now continuously using Iridium transmission in the XBT and TSG operations in the Oleander (AX29) using a direct Internet connection and SMTP e-mail. Iridium transmissions are also done continuously from the TSG installed in the M/V Explorer of Semester at Sea. The ratio of XBTs deployed to real time data transmitted is essentially 100%.

For XBT profiles, an operator reviews those profiles that fail the automatic quality control procedures and decides whether or not to send the data to the GTS. 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.

2.8. Data Tracking

The data tracking operation is currently being transitioned from NOAA HQ to AOML. This operation is aimed to the verification of data flows from the source (observation platform) to the processing centers, where the data is analyzed, quality controlled, and sent to the Telecommunication Gateway at NWS from where the data is inserted into the GTS. Since this is a very complex process, the tracking of these data ensure that the information obtained by different observation platforms are received and that they are generated with the correct codification so that it can be successfully inserted into the GTS. Otherwise the data cannot be used or, if communication problems are not detected, lost. We verify the flow of different kinds of oceanographic data, including XBT, TSG, buoys, drifters and TAO/PIRATA arrays.

Among the several problems that may occur, the most common are:

- Specified platform type not expected from a specific group of headers,
- Data is received from ships with unknown Call Sign,
- Observations are transmitted with wrong date/time,
- Duplicate data is being sent, and
- Data drops: the data is transmitted but it is not reaching its destination.

When an encoding or transmission problem is found, the type of data and the source is determined and the person responsible is contacted. This process is performed daily. Software is currently under development at AOML to automate this task. The software is based on the comparison of several data sources from AOML, the SEAS team, the NWS Communication Gateway and the GTS. The code allows the detection of several ofisthe previously cited most frequent problems, creating a daily report of the oceanographic data flow state. This represents a great improvement for the data-tracking task since many issues can be detected quickly reducing the operator effort. Nevertheless new types of errors occur all the time, requiring the intervention of the operator to ensure the success of the operation.

On a visit to Silver Spring, Dr. Francis Bringas was introduced to Mr. Allan Darling, Chief of NWS Telecommunications Software Branch. Mr. Darling gave Dr. Bringas a detailed description of the data flow through the NOAA Telecommunications Gateway (TG). Dr. Bringas was also given several points of contact with TG data managers. During this visit, Dr. Bringas was invited to CLS North America in Largo, MD, to discuss CLS operations. Consequently, Dr. Bringas is interacting routinely with CLS personnel to resolve data delivery issues, such as duplicate processing between CLS in Largo and CLS in Toulouse, France. CLS is responsible for the decoding of NOAA polar orbiting satellite data and delivering it to the TG for GTS distribution. This data includes drifting buoy, TAO/Pirata moored platform, and profiling float data, which are monitored at AOML.

2.9. Data Base

The SEAS XBT Auto-QC System (XBTRT) and the automatic transfer of *ndc* files from SEAS to AOML were operational except for downtime due to hardware/software maintenance. The tasks being performed are: maintain the XBTRT system, management of the XBTRT operational database residing in a commercial Database Management System, review the daily electronic mail sent by the XBTRT system to detect and report possible problems, assist in identifying data tracking problems, and provide advice regarding software issues.

2.10. New Visual Quality Control (VQC)

The Visual Quality Control (VQC, Figure 7) is a Graphical User Interface (GUI) developed at AOML Miami that allows a user to approve or reject XBT profiles that have not met the minimum specified standards of the Automatic Quality Control System. Accepted profiles are automatically sent to the GTS. When the operator rejects a profile, the data-flow process automatically receives a message to not place that profile in the GTS. AOML does a VQC for an average of 2 profiles every day, which can vary dramatically if there are high-density cruises being done or communication problems. A useful advantage of the VQC is the real-time ability to recognize systemic and random problems with the XBT operations, such as electrical faults in the XBT hand-launchers, or bad weather carrying the XBT wires to contact the hull of the ship.

The AOML VQC system is an upgrade to the previous VQC Matlab script used in Silver Spring, with additions of incorporating geographical position, proximity to other profiles in time or position, and an easy to use GUI. The VQC GUI allows the user to evaluate the profile based on seeing error envelopes for both 5 and 10 standard deviations. Additionally, all flagged profiles in the queue are shown in a secondary graph to easily visually compare physical features. The GUI also has user-friendly mouse enabled features such as zoom and profile selection.

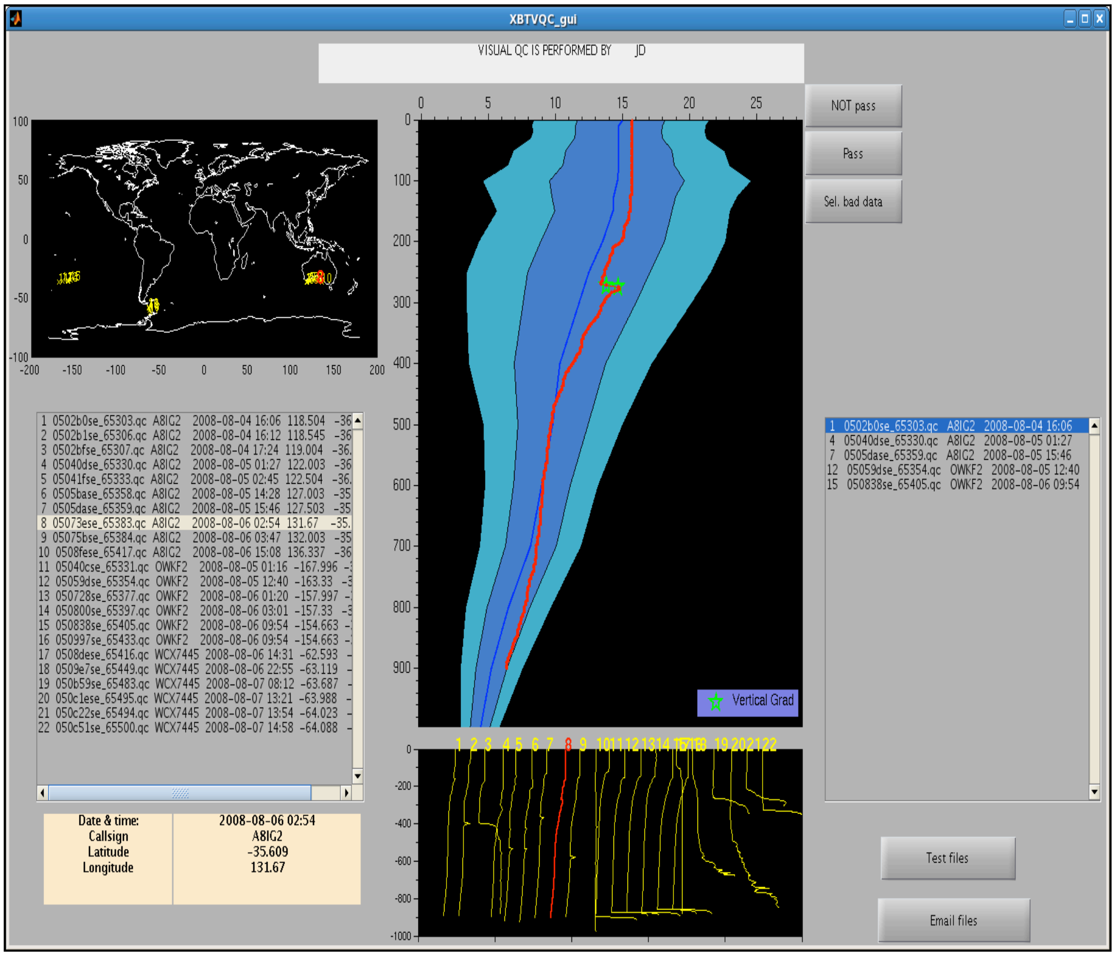

Figure 7. Screen shot of the new AOML Visual Quality Control (VQC) for XBT profiles. The main graph displays an envelope of 5 and 10 standard deviations, the climatology (blue line) and the XBT profile (red line).

2.11. SEAS Updates

The following are updates were performed as part of the SEAS operations:

- Finish conversion of AMVER/SEAS server software to new system and DBMS,
- Install Backup server in Miami and establish appropriate VPN's between AOML and Vizada,
- Replace machines at Gateway with new servers once converted, and
- Write software to allow SMTP e-mail communication from vessels by the ship riders.

2.12. Metadata and BUFR

XBT data are being tested coded in BUFR format, using templates that have been specifically designed to serve operational needs. We are using both BUFR Edition 3 and Edition 4 specifications. A similar approach is underway to migrate TSG data to BUFR. This effort seeks to improve the future migration from the Traditional Alphanumeric

Codes (TACs) to Table-Driven Code Forms (TDCFs), as required by WMO. The testing will provide the feedback necessary to detect, identify and correct problems that can arise in the migration process, providing a robust framework for near-real-time collection, quality control and distribution of SOOP data.

2.13. XBT Reports

Monthly reports are generated showing the temporal and spatial distribution of the SEAS XBT transects, identifying and tracking the FR and HD XBT lines managed by NOAA/AOML. In addition to a web interface, this project provides CSV files with data and metadata information about individual measurements as well as PDF bulletins comprising information about the last 12 months of data, including line coverage and mode, both in text and graphical formats. Future work will focus on improving the quality of metadata presented, advance on the automatic generation of the reports, enhance the input dataset with profiles not sent for QC, and reduce the error rate. These reports can be obtained from the GOOS web page.

2.14. Thermosalinograph (TSG) System

During this fiscal year the TSG Iridium transmission system was successfully tested in the M/V Explorer and on the Oleander. The SEAS 2000 software was implemented for easy setup and to require no user input once started. The TSG computer 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 SEAS 2K if necessary. The TSG data is transferred to the bridge over the ship intranet and can then be transmitted. TSG collection and transmission was added as a standalone component interfacing to the SEAS 2K Time/Position Server.

NOAA/AOML in collaboration with NOAA/AMAO started real-time transmission of TSG observations into the GTS in the following ships: Ronald Brown, David Starr Jordan, Miller Freeman, Gordon Gunter, Oscar Dyson, Nancy Foster, Oregon II, Fairweather, Rainier, Ka'imimoana, and Hi'ialakai. The location of theses transmissions are included in Figure 4, bottom. The collaboration with AMAO is particularly important since the R/V Gordon Gunter, Ron Brown and Ka'imimoana have pCO_2 systems installed.

2.15. Full Water Column calibration cruises

Two-day cruises on RV Walton Smith are generally scheduled four times per year to coincide with the AX7 high density XBT line in order to obtain boundary current transport information for the heat transport calculations. Sufficient ship-time funds for only three of the cruises were provided in FY07 (the final cruise of FY07 was postponed into early FY08 due to ship availability). All cruises include nine stations with full water column CTD, lowered ADCP, and continuous shipboard ADCP. The station locations are shown in Figure 8. Table 3 below includes the cruise dates and number of water samples taken for oxygen concentration and salinity.

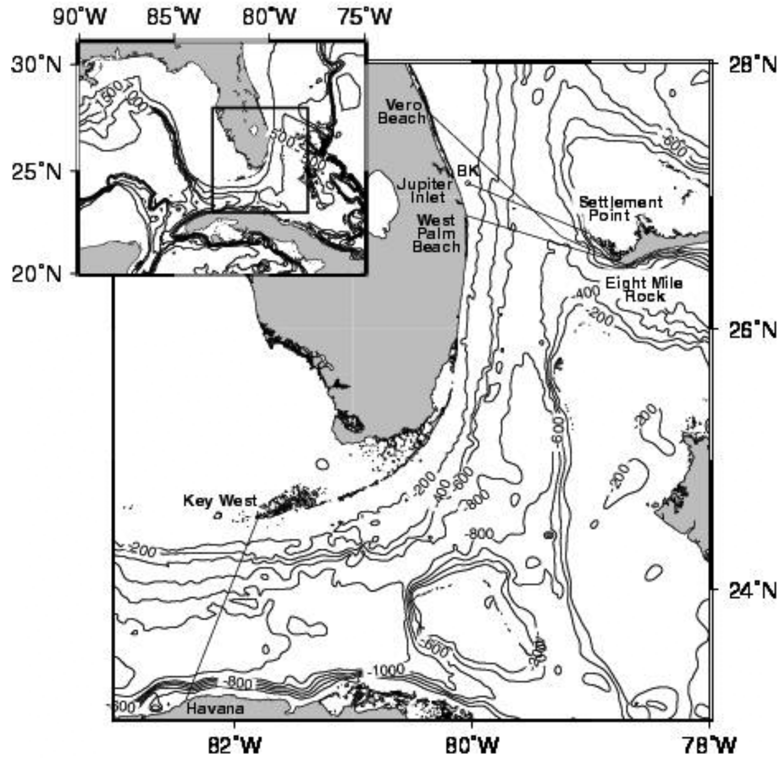

Figure 8. Location of submarine telephone cables (solid black) and nine stations (red) occupied during calibration cruises.

Table 3. Cruise dates for 2-day calibration cruises on the R/V Walton Smith. Note FY2005: The last cruise planned for in FY 2005 was postponed for early FY 2006. Note FY 2007: Only three cruises were completed due to lack of ship-time charter funds. Note FY 2008: Only two cruises carried FY2008 due to lack of ship-time funds.

FY2008		FY2007		FY2006		FY 2005		FY 2004	
Date	Samples	Date	Samples	Date	Samples	Date	Samples	Date	Samples
Dec 2007	19-20, 60 O2, 48 S	Dec 2006	13-14, 60 O2, 48 S	Dec 2005	14-16, 60 O2, 48 S	Dec 3-4, 2004	58 O2, 44 S	Jan 2003	8-9, 55 O2, 46 S
Jul 2007	7-9, 60 O2, 48 S	Jun 2007	28-29, 60 O2, 48 S	Jan 2006	29-31, 60 O2, 48 S	Jun 2005	3-4, 58 O2, 45 S	May 2004	6-7, 47 O2,
		Oct 2007	4-5, 60 O2, 48 S	Jun 2006	25-27, 60 O2, 48 S	Jul 2005	11-12, 58 O2, 45 S	Jul 4-5, 2004	56 O2,
				Sep 2006	18-19, 68 O2, 48 S	Nov 2005	20-23, 60 O2, 48 S	Aug 2004	27-28, 55 O2, 42 S
50% of planned cruises		75% of planned cruises		100% of planned cruises		100% of planned cruises		100% of planned cruises	

2.16. Web Pages

An extensive update of the AOML GOOS center and the Frequently Repeated XBT Lines websites has been completed during FY2008 (Figure 9). Data are available online at: www.aoml.noaa.gov/phod/goos and www.aoml.noaa.gov/phod/goos/ldenxbt, respectively. The Frequently Repeated XBT Lines websites features the latest information on operational XBT lines in both FR and HD modes along with specific webpages showing the latest XBT, Meteorological, and TSG observations, available online at: http://www.aoml.noaa.gov/phod/goos/seas/latest/.

The GOOS center website now features a Google Earth layer displaying Global Marine and Meteorological Observations available online at:
http://www.aoml.noaa.gov/phod/VOS/GE/GE_AOML_DT.kmz.

This application is a potent tool to visualize the global extent of ocean and meteorological observations interactively.

2.17. SEAS and High Density Installation Manuals

An extensive effort documenting the operations of the SOOP was carried out during FY08. This documentation is available online at: www.aoml.noaa.gov/phod/goos/docs in support of our global operations with collaborators from the US and countries around the world. For instance, a handbooks including hardware setup and software operation of the semi-automatic equipment developed in-house and used in high density lines is now available to all ship-riders though this website. This handbook has substantially simplified the training of new ship riders. A handbook for operation and troubleshooting of the TSG installations is also available.

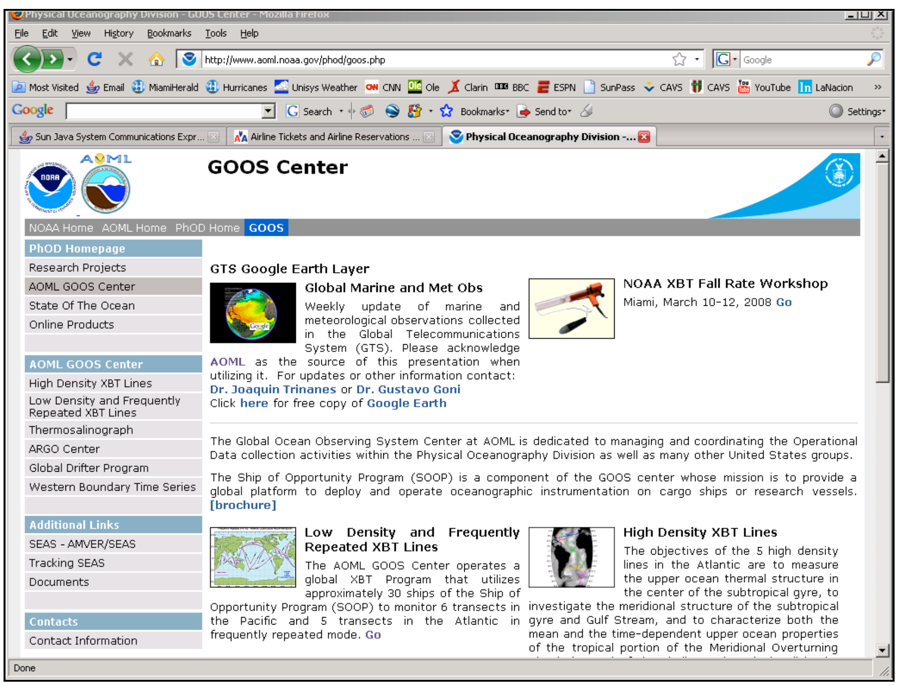

Figure 9. Global Ocean Observing System web page maintained by the SOOP at NOAA/AOML: www.aoml.noaa.gov/phod/goos.php.

2.18. Portable Integrated Data and Transmission Platform

The HD briefcase prototype (Figure 10) is an attempt to consolidate many of the components needed for a high density cruise in a lightweight portable briefcase reducing setup time and user setup error. Included in the briefcase is a laptop, a MK-21, an auto-launcher power supply, MK-21 power supply, and a power supply that will power both the TL-3026 (Mini-C) transceiver and the Iridium modem. These components are powered via a single power connector that accepts both 120 and 240 volts AC eliminating the need for a power converter that is typically needed on foreign vessels. The briefcase is compatible with the older T&T transceivers and was designed with the newer Mini-C transceiver and Iridium modem in mind.

2.19. XBT and TSG Test Bench

The TSG\XBT test bench (Figure 11) includes all of the components for a low density installation and most of the components needed for a TSG installation and a high density installation. Cabling to the roof allows us to test real-time transmissions with our different transmitters and modems without having to leave the bench. The components of this test bench are:

- Two shuttle computers,
- A shared monitor\keyboard\mouse,
- MK-21,
- Hand launcher,

Figure 10. Main components of the recently developed Portable Integrated Data and Transmission Platform.

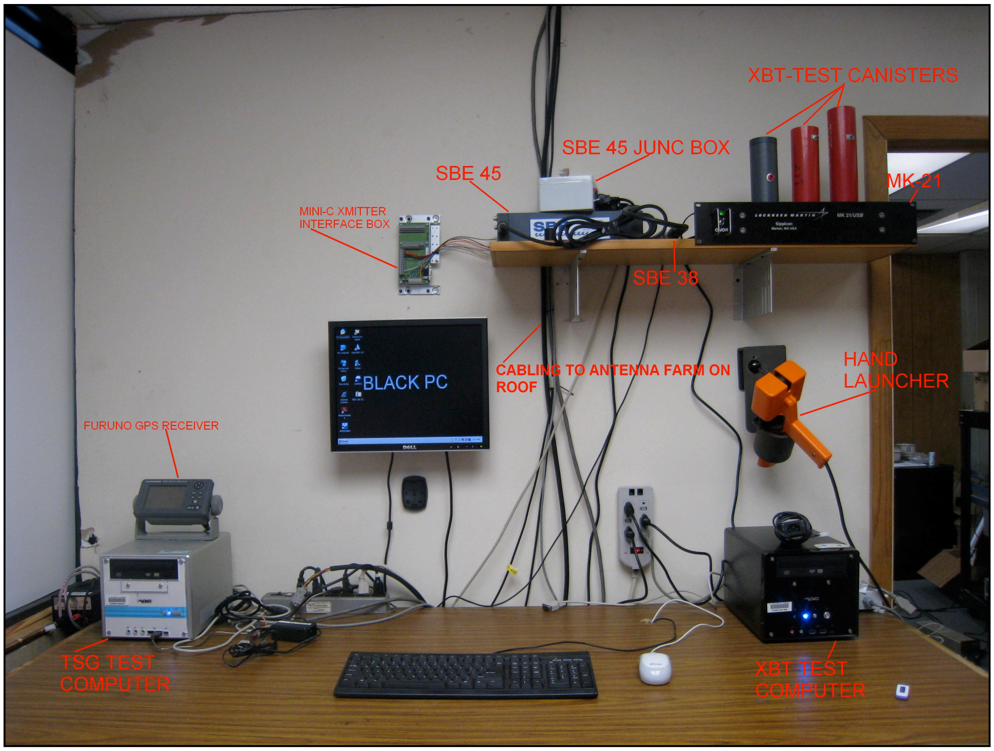

Figure 11. Components of the recently developed XBT and TSG test bench.

- Test canisters,
- TSG SBE-45,
- SBE-45 Junction box,
- External temperature sensor SBE-38,
- Furuno GPS receiver, and
- Cabling to antenna farm on the roof.

2.20. Fast Deep XBT Autolauncher

A total of 33 boxes (396 probes) of Fast Deep XBTs were purchased to use the new autolauncher in applications where increased depth is desired, particularly on the heat transport lines AX7 and AX18. One XBT was tested using a hand launcher and it was quickly determined that a redesigned autolauncher would be required for use of these new probes. AOML undertook a base-funded operation to redeign and build this new autolauncher system. The newly redesigned AOML 8-shooter autolauncher (Figure 12) is currently being assembled and tested. The main improvement in the new 8-shooter is that it is capable of launching not only the Deep Blue probes but also the Fast Deep probes. Structurally, this new autolauncher is 5 inches longer than the current AOML autolauncher and they will all be built to carry 8 probes. The anodizing of the redesigned autolauncher is done outside AOML. For the Deep Blue XBT the maximum rated depth is 760 meters. For the Fast Deep XBT the maximum rated depth is 1000 meters.

Figure 12. New Fast Deep XBT autolauncher being constructed at AOML is placed to the left of the Deep Blue XBT autolauncher at NOAA/AOML.

2.21. Collaboration with Global Drifter Program

The Surface Drifter Program would not be able to maintain the drifter array without contributions from national and international partners who deploy the drifters worldwide. Many drifters are deployed from vessels cooperating with the NOAA Ship Of Opportunity Program (see Table 2 for HD deployed drifters). SOOP personnel (J. Trinanes) also support AOML's efforts to collect the hurricane drifter data for subsequent quality control and redistribution.

2.22. Collaboration with the Argo Program

Ships recruited through SOOP to deploy XBTs are also used as a platform to deploy Argo profiling floats. Betweeen October 2007 and September 2008, a total of 26 floats were deployed from ships of the SOOP (see Table 2).

XBT temperature profiles have also been used to identify problems in Argo floats (Willis *et al.*, 2008) highlighting the importance of maintaining independent observing systems for ocean subsurface temperature.

2.23. Google Earth Application

A Google Earth-based application was implemented to display the status of the ocean observing system network, including SOOP platforms. Through this interface, users can easily monitor the different data streams received operationally through the GTS, identifying possible data gaps affecting data distribution, tracking specific platforms and generating animations including field measurements overlaid on top of the daily global SST fields. This application is freely available to the public at: http://www.aoml.noaa.gov/phod/goos.php.

2.24. SOOPIP

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.

Dr. Gustavo Goni continues being the Chairman of the WMO/IOC Ship Of Opportunity Program Implementation Plan (SOOPIP) and Dr. Joaquin Trinanes is a member of the Meta-T panel.

2.25. Recruiting

AX-7, AX-8, AX-10, and AX-18 are on container ships, and optimally run 4 times per year, and AX-25 is staffed by University of Cape Town personnel on their research vessel, and it is carried out twice a year.

Typically, we can keep with a particular ship company on a specific transect for approximately 2 to 3 years. When they discontinue their service on a given route, a new recruitment process begins. The following ships were recruited during this last fiscal year:
AX-08: Safmarine Ngami, 1st cruise: Jul 08.
AX-10: Horizon Navigator, 1st cruise: Apr 08.
AX-18: CMA CGM Santos.

2.26. Collaboration with SeaKeepers

Seakeepers TRACKOB data (with international location indicator KWUM) was not accomplishing the objective of full, global and public distribution. NOAA/AOML and Environment Canada were two of the intended destinations not having access to these bulletins. Two action items were established during a meeting with SeaKeepers management: modify the distribution designator (ii) for testing the dissemination scheme of a limited set of bulletins, and contact the NWSTG in order to update the distribution tables and reach the same global distribution scheme as the SOVX01 KWBC header, being used with NOAA TRACKOB datasets. Finally, and with the essential intervention of NDBC (Robert Luke), NWSTG modified the route of SeaKeepers TSG measurements and KWUM bulletins started being globally distributed, solving the problem.

2.27. AOML contribution to the Oleander Project

AOML provided hardware equipment (computer for data acquisition and transmission antenna) for the Oleander. Approximately 350 XBTs are deployed by this ship between New York and Bermuda.

2.28. Fall Rate Equation Studies

There is evidence that there is a systematic depth dependant error in XBT temperature profiles, which is likely due to an error in the XBT fall-rate equation. This error has introduced a warm bias in the global XBT data base. A workshop was organized by G. Goni and M. Baringer to discuss the findings related to this issue by different groups. As a consequence, a new fall rate equation may need to be developed and applied to both past and future XBT data. Information on this workshop is at: http://www.aoml.noaa.gov/phod/goos/meetings/2008/XBT

A workshop report is currently being written. AOML is currently involved in two research efforts to identify systematic biases in XBT temperature profiles: a) Comparison between simultaneous XBT and CTD deployments, and b) Comparison between simultaneous XBT and Argo float observations using sea height anomaly fields derived from altimetry to quantify the biases.

Two manuscripts are currently being written:

- Snowden, D., G. Goni and M. Baringer, A comparison of six expandable bathythermograph data acquisition systems: Temperature and fall rate errors, to be submitted to *J. Geophys. Res.*, 2008.
- DiNezio, P., and G. Goni, Identifying and estimating biases between XBT and Argo observations using satellite altimetry, to be submitted to *J. of Clim.*, 2008.

2.29. Contribution to Heat Storage quarterly reports

XBT observations provide approximately 25% of all global temperature profile data and are used to create quarterly reports of heat storage: http://www.aoml.noaa.gov/phod/soto/ghs/reports.php.

This work is funded by NOAA/CPO under the project: Evaluating the Ocean Observing System: Performance Measurement for Heat Storage, by C. Schmid and G. Goni.

2.30. SOOP Brochure

A new brochure was created for recruiting and general information purposes. They can be obtained from the SOOP web site at: http://www.aoml.noaa.gov/phod/goos/docs/.

2.31. Peer-reviewed Publications

Swart, S., S. Speich, I. Ansorge, G. Goni, S. Gladyshev, J. Lutjeharms, 2007: Transport and variability of the Antarctic Circumpolar Current south of Africa, *J. Geophys. Res.*, in press.

Mainelli, M., M. DeMaria, L. Shay, G. Goni, 2007: Application of oceanic heat content estimation to operational forecasting of recent Atlantic category 5 hurricanes. *Weather and Forecasting*, in press.

2.32. Presentations

Goni, G., M. Baringer, R. Molinari, D. Snowden, and S. Garzoli. The status of the XBT network, 2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida.

Baringer, M. Heat transport changes from High-Density XBT lines in the North Atlantic, 2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida.

Johns, W. E., H. L. Bryden, M. O. Baringer, L. M. Beal, S. A. Cunningham, T. Kanzow, J. Hirschi, J. Marotzke, Z. Garraffo, C. S. Meinen, Observations of Atlantic Meridional Heat Transport Variability at 26.5°N from the RAPID-MOC Array, 2008, 2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida.

Baringer, M. and S. L. Garzoli, 2007. The Meridional Heat Transport in the South Atlantic Ocean AGU Joint Assembly, Acapulco (Mexico), 22-25 May 2007.

Baringer, M. O., 2006. Heat transport variations in the subtropical North Atlantic, Rapid Climate Change International Conference, October 24-27, 2006, Birmingham, United Kingdom.

Johns, W; S. Cunningham, T. Kanzow, H. Bryden, J Marotzke, M. Baringer, L. Beal; C. Meinen, J. Hirschi, D. Rayner, 2007. Variability of the Atlantic meridional overturning circulation during 2004-2005 as observed from the 26° N RAPID- MOC Array. AGU Joint Assembly, Acapulco (Mexico), 22-25 May 2007.

Observations of the Brazil Current baroclinic transport variability near 22S, M. Mata, M. Cirano, M. Caspel, G. Goni and M. Baringer, EGU 2008 General Assembly, Austria, April 2008.

2.33. Worshops

Two SEAS/XBT workshops were held at NOAA/AOML during FY 2008:

- NOAA/AOML SEAS, XBT, and TSG Operations. Miami, Florida, June, 2008.
- XBT Fall Rate Equation Workshop, Miami, March 10-12, 2008.

2.34. Publications that use NOAA XBT observations

1. Aoki, Shigeru; Akitomo, Kazunori. Observations of small-scale disturbances of the Subantarctic Front south of Australia. Deep Sea Research (Part I, Oceanographic Research Papers) [Deep Sea Res. (I Oceanogr. Res. Pap.)]. Vol. 54, no. 3, pp. 320-339. Mar 2007.

2. Baringer, MO; Garzoli, SL. The Meridional Heat Transport in the South Atlantic Ocean. Proceedings of the American Geophysical Union 2007 Joint Assembly. [np]. 2007.

3. Baringer, MO; Garzoli, SL. Meridional heat transport determined with expendable bathythermographs-Part I: Error estimates from model and hydrographicdata. Deep Sea Research (Part I, Oceanographic Research Papers) [Deep Sea Res. (I Oceanogr. Res. Pap.)]. Vol. 54, no. 8, pp. 1390-1401. Aug 2007.

4. Cornuelle, B; Hoteit, I; Koehl, A; Stammer, D. Strong Adjoint Sensitivities in Tropical Eddy-Permitting Variational Data Assimilation. Proceedings of the American Geophysical Union 2007 Joint Assembly. [np]. 2007.

5. Douglass, E M; Roemmich, D; Stammer, D. North Pacific Variability From a Data-Assimilating Model. Proceedings of the American Geophysical Union 2007 Joint Assembly. [np]. 2007.

6. Garzoli, SL; Baringer, MO. Meridional heat transport determined with expandable bathythermographs-Part II: South Atlantic transport. Deep Sea Research (Part I, Oceanographic Research Papers) [Deep Sea Res. (I Oceanogr. Res. Pap.)]. Vol. 54, no. 8, pp. 1402-1420. Aug 2007.

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10. Korotenko, KA. A regression method for estimating salinity in the Ocean. Oceanology, Volume 47, Number 4, Aug 2007.

11. Kovach, R; Keppenne, C; Rienecker, M; Marshak, J; Jacob, J. Assimilation of Temperature, Salinity, and Sea Surface Height Data into the GMAO Ensemble Kalman

Filter and its Impact on Seasonal Hindcast Skill. Proceedings of the American Geophysical Union 2007 Joint Assembly. [np]. 2007.

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