# Progress Report
# The AOML XBT Network

Period of Activity: 01 October 2022 – 30 September 2023

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**Budget Summary**
FY 2023: $1,246,285

**The AOML XBT Network**

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## 1. Project Summary

NOAA/AOML support to the Global eXpendable BathyThermograph (XBT) Network includes the design, implementation, maintenance, and evaluation of fixed, repeated, predetermined XBT transects to obtain temperature profiles in the upper 800 m. Work performed at AOML also includes the acquisition, transmission, quality control, and distribution of data from these transects. All the transects that AOML maintains were recommended by the international scientific community. This work is a regional and international effort, with partnerships and collaboration with institutions from the United States, South Africa, Brazil, Bermuda, France, and Argentina. On average, AOML deploys approximately 5,000 XBTs per year. During FY2023 AOML deployed more than 6,100 XBTs as it started to overcome operation issues due to challenges related to COVID19. AOML is also involved in key aspects of the logistics, operations, data processing, etc. of about 80% of the Global XBT Network through transect implementation, instrument design, data management, probe donation and data management. NOAA/AOML leads or co-leads with international partners the implementation and operations of 11 transects in the Atlantic Ocean.

XBT-derived temperature profiles represent around 5% of all global, non-mooring, temperature profiles, and approximately 80% of temperature profiles obtained in boundary currents. The main contribution of the XBT network is to provide temperature measurements to:

- Monitor changes of key surface and subsurface currents,
- Assess meridional heat transports,
- Help initialize and validate climate and weather forecast models,
- Conduct temperature profile observations in US shelf waters in support of hurricane research and forecasts, and
- Provide together with other observational platforms assessments of the variability of the global upper ocean heat content.

This project has developed and currently maintains the Shipboard Environmental data Acquisition System (SEAS) software to collect and transmit observations from XBTs and ThermoSalinoGraphs.SEAS also provides daily reports to the US Coast Guard's Automated Mutual-Assistance Vessel Rescue System (AMVER), which aids in finding ships in the vicinity of vessels in distress. XBT data acquired through SEAS are distributed into the Global Telecommunication System (GTS), generally within 24 hours of their acquisition, therefore providing critical input for weather and climate operational forecast models. Scientific (delayed-time) quality control is carried out at NOAA/AOML to provide data with high quality for research studies and scientific applications. These data are distributed and archived through NOAA/National Centers for Environmental Information (NCEI), and partially served by ERDDAP. We plan to serve all XBT data by ERDDAP in the future. In addition, the XBT Network provides opportunities for the deployment of other observational platforms, such as surface drifters and Argo profiling floats, and supports several engineering aspects of $pCO_2$ monitoring efforts.

## 2. Scientific and Observing System Accomplishments

### *2.1. Goals and Milestones of the XBT Network*

The main focus of the AOML XBT network is to conduct XBT observations along fixed transects or areas in the Atlantic Ocean. The strength of the AOML XBT network lies in its duration and on its ability to monitor key ocean currents and water mass properties, and to estimate heat and mass transports across entire ocean sections and at key choke points. XBT network provides measurements with a spatio-temporal sampling with proven scientific importance that cannot be reproduced with other existing observing platforms. The scientific objectives for the AOML XBT Network are summarized below:

- Assess the seasonal-to-decadal fluctuations in the transport of mass, heat, and freshwater across trans-Atlantic transects.
- Monitor boundary currents and fronts, gyres, and assess their state and variability in relation to large-scale transports.
- Obtain a long time series of temperature profiles and sections at approximately repeated locations and/or regions in order to unambiguously separate temporal from spatial variability.
- Determine the space-time statistics of temperature and geostrophic velocity fields and their variability.
- Provide appropriate in situ data (together with profiling floats, underwater gliders, tropical moorings, air-sea flux measurements, sea level etc.) for testing ocean and coupled weather and climate models.
- Determine the synergy between XBT transects, satellite altimetry, Argo floats, to assess and monitor the state and the variability of ocean currents and water mass properties.
- Provide temperature profile measurements in shelf waters along the east US coast, to provide key observations for hurricane and other extreme weather events.

#### 2.1.1. The SEAS System Goals

The Shipboard Environmental data Acquisition System (SEAS) is a real-time application software developed and maintained at NOAA/AOML, which combines acquisition and transmission of environmental data collected over several observing platforms. The SEAS system acquires atmospheric and oceanographic data, such as marine meteorological parameters (air temperature, pressure, humidity, clouds, waves, etc.), sea surface salinity and temperature and operates on cargo ships, NOAA vessels, and Coast Guard vessels. NOAA, Scripps Institution of Oceanography (SIO), and the U.S. Coast Guard are the main users of this software. SEAS is installed on more than 50 ships of the XBT network, which participate with NOAA/AOML in acquiring and transmitting data from more than 10,000 XBTs per year. The data acquired by the SEAS system are transmitted in real-time to the GTS and to global data distribution centers (NOAA/NCEI, Coriolis) and used by scientists and operational centers. The

SEAS software is also installed on cargo ships and in the ships of the NOAA fleet to acquire and transmit TSG data in support of $pCO_2$ observations.

### 2.1.2. XBT Operations Goals

The XBT operations address both operational and scientific goals of the NOAA program for building a sustained ocean observing system for climate. The XBT operations comprise the design, implementation, and maintenance of the XBT network, including data acquisition, transmission, quality control, and distribution. XBT deployments have been historically performed in three different main modes:

- High Density (HD) with deployments every 10-50 km (18-35 deployments per day) and transects repeated approximately 4 times per year,
- Frequently Repeated (FR) with deployments every 100-150 km (6-8 deployments per day) and transects repeated 18 or more times per year, and
- Low Density (LD) with deployments every 150-200 km (4 deployments per day) and transects repeated 12 times per year.

The AOML XBT network (Figure 1) comprises 11 fixed transects, as recommended by the scientific community and by NOAA science needs. The AOML XBT network is a component of multinational (US, France, Australia, Italy, South Africa, Brazil, Germany, Japan, Argentina, India, Canada, China, and Taiwan), multi-institutional Global XBT Network. NOAA/AOML and its regional and international partners play an active and a continuous lead role in the deployment of XBTs, data transmission, data quality control, and data distribution through web pages and data centers (Table I). During FY2023, NOAA/AOML continued its collaboration with partners by providing probes, equipment, logistics, and/or data processing and transmission capabilities.

In order to accommodate for impacts caused by the COVID-19 pandemic, several changes in the operations were implemented in the current sampling strategy. The most important change was implemented along the AX07 and AX08 transects. Historically, we have deployed XBTs eastward along AX07 and northward along AX08. Starting in 2020, XBTs in each of these transects were continuously deployed by the crews of the ships eastward (Miami to Straits of Gibraltar) and westward (Straits of Gibraltar to New York) along AX07, and northward and southward along AX08. The AX07 transect from Miami to Straits of Gibraltar, combined with Florida Current volume transport from submarine cable, has been used for meridional heat transport calculation, for this purpose, these transects Straits of Gibraltar to New York are referred to as AX04 (Figure 1). In addition, the sampling was enhanced by conducting XBT observations along the east US shelf waters in support of hurricane research and forecasts.

Starting in April 2020, and continuing to FY2023, efforts were directed towards the installation of XBT systems in a number of ships to conduct XBT deployments in FR/HD modes, with deployments done by the ship crew at least 6 times per day, approximately every 70-80 km. AOML currently operates 2 ships along AX08/AXCOAST, 3 ships along AX04/AX07/AXCOAST, 4 ships along AX97, 2 ship along AX10, 1 ship along AX32, 1 ship along AX18, and 1 ship along AX25. XCTDs were deployed along the AX07 transect (Miami to Gibraltar) during the HD mode in order to obtain salinity measurements near the boundary with strong ocean currents, which has been shown to be critical to improve meridional heat transport estimates.  Additionally, AOML is currently working on the recruitment of additional ships to cover the AX04/AX07/AXCOAST, AX08, and AX18 transects, respectively.

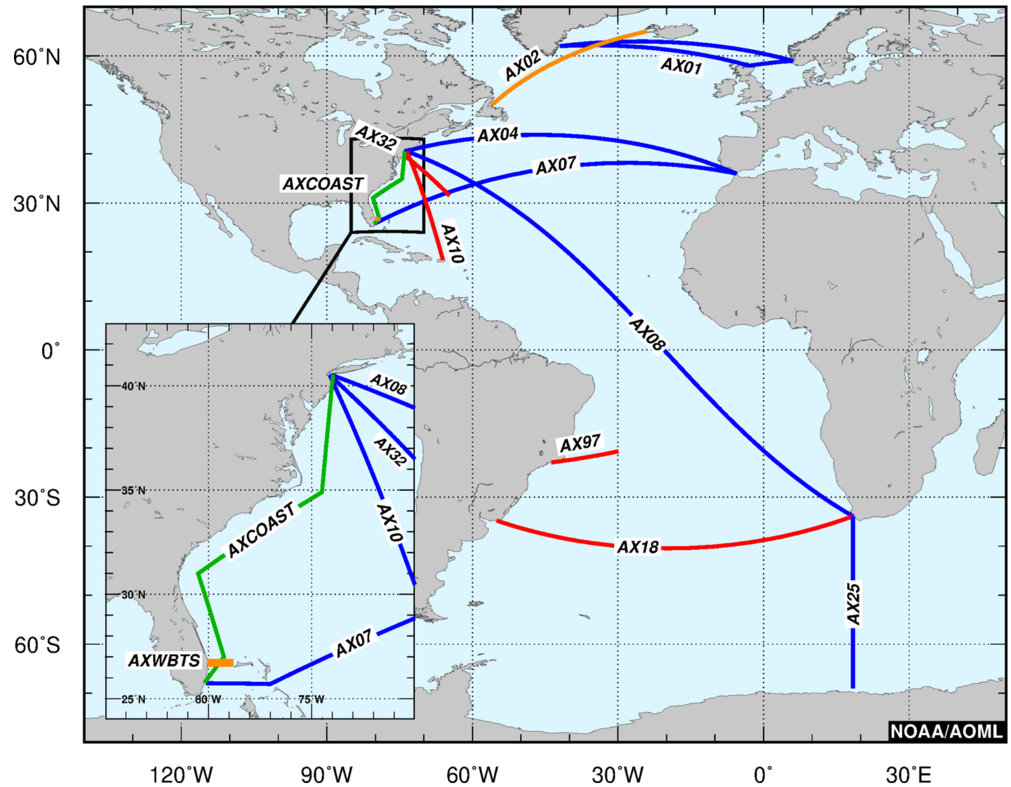


***Figure 1.*** *Schematic diagram showing the location of XBT transects operated by NOAA/AOML or in partnerships with national and international institutions, including High Density (red), High Density/Frequently Repeated (blue), and coastal deployments in support of hurricane research (green). Recruitment efforts continued to reinstate deployments along AX02 and AXWBTS (orange); similar efforts allowed the reinstatement of AX01 and AX18 during FY2023. The countries leading the efforts to carry out each transect are indicated in Table I.*

In addition to the XBT deployments, AOML installed a newly developed weather station on MV Chicago Express and MV Bremen Express along AX04/AX07/AXCOAST, which provides continuous real-time observations of atmospheric variables (surface air temperature, relative humidity, and barometric pressure) along the ship route for study of air-sea interactions and weather forecast.  These observations are now being collected with the goal of improving air-sea turbulent heat fluxes and oceanic heat budget estimates in the northwest Atlantic basin and are submitted into the GTS in real-time.

| Transect | Country | Mode | Year |
|---|---|---|---|
| **AX01** | 1, 5 | FR | 1997 |
| **AX04** | 1 | FR | 2020 |
| **AX07** | 1 | FR/HD | 1995 |
| **AX08** | 1 | FR | 2000 |
| **AX10** | 1 | HD | 1997 |
| **AX25** | 1, 2 | HD | 2004 |
| **AX18** | 1 | HD | 2002 |
| **AX32** | 1, 3 | HD | 1981 |
| **AX97** | 1, 4 | HD | 2004 |
| **AXCOAST** | 1 | FR | 2020 |
| **AXWBTS** | 1 | HD | 1995 |

***Table I.*** *The AOML XBT Network during FY2023 was maintained by (1) NOAA/AOML in partnership with (2) University of Cape Town - South Africa, (3) Bermuda Institute of Ocean Sciences - Bermuda, (4) Federal University of Rio de Janeiro - Brazil, and (5) Institut de Recherche pour le Développement (IRD) and Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER) - France. The year indicates when these transects were first implemented. Transects highlighted in light blue are completely maintained and operated by NOAA/AOML.*

### *2.2. Scientific and Observing System Accomplishments*

The main accomplishments of work carried out by the NOAA/AOML XBT network during FY2022 were:

- Maintenance of 11 NOAA/AOML XBT transects, including the deployment of 6,100 XBTs;
- Real-time transmission into the GTS of approximately 9,000 XBT profiles (includes SIO's XBTs and XBTs deployed by ships of the NOAA fleet), representing approximately 80% of all global XBT deployments;
- Data transmissions into the GTS were never interrupted or negatively impacted due to the pandemic;
- Automatic quality control of all NOAA/AOML and SIO XBT profiles;
- Support the data flow, including insertion into GTS, of the following transects maintained by SIO: AX22, IX21, PX05, PX13, PX37, and PX40
- Scientific quality control of all AOML XBT profiles and submission of these data to NCEI;
- Strong scientific use of XBT data for studies of surface, subsurface, and boundary currents, meridional heat transport, attributions of coastal sea-level changes and XBT fall rate; and
- Design and development of web pages in order to provide easy access to AOML XBT operations and XBT data.

Scientific research work currently taking place at NOAA/AOML using the data within the XBT Network Project includes studies on:

- North and South Atlantic Meridional Heat Transport (MHT);
- Variability of Atlantic surface and subsurface current systems;
- Investigating oceanic heat budget and impact of ocean heat content on climate and weather;
- Southeast US coastal sea-level changes;
- Assessing physical linkages between MHT and extreme weather events;
- Assessing reanalysis turbulent flux products using concurrent shipboard measurements (XBTs and weather stations).
- Assessing the vertical structure of the dominant tripole mode of the North Atlantic Ocean
- Applying machine learning to derive salinity profile from XBT temperature profiles
- Studies of XBT probes and their dynamics in the water to improve data quality

Specifically, the NOAA/AOML XBT observations are currently geared towards the measurement of the variability of the:

- Meridional Heat Transport in the South Atlantic (AX18)
- Meridional Heat Transport in the North Atlantic (AX07, AX04)
- Gulf Stream (AX32, AX10, AX08, AX04)
- Water mass properties in the east US continental shelf (AXCOAST)
- Florida Current (AXWBTS, AX07)
- Agulhas Current and rings (AX08, AX18, AX25)
- Brazil Current (AX18, AX97)
- Tropical Atlantic zonal equatorial currents (AX08)
- Antarctic Circumpolar Current (AX25)
- South Atlantic subtropical gyre (AX08, AX18, AX97)
- North Atlantic subtropical gyre (AX32, AX08, AX07, AX04)

### 2.2.1. AOML XBT Transects

AOML XBT transects are designed to measure the upper ocean thermal structure in regions of the Atlantic Ocean with the objective of investigating the temporal variability of key surface and subsurface currents, water mass properties, and meridional heat transport in the Atlantic Ocean. XBT transects in HD/FR mode are repeated several times a year with XBTs deployed between 10-100 km apart in order to capture the state of the ocean and water mass properties, to assess ocean circulation changes.

HD/FR XBT transects are carried out globally with NOAA/AOML taking the lead in most of the operations in the Atlantic Ocean. In addition, NOAA/AOML contributes with the XBT data transmission and distribution of SIO XBT operations and maintains strong international collaboration efforts for the deployment of XBTs with France, Brazil, Argentina, Bermuda, South Africa, and Italy.

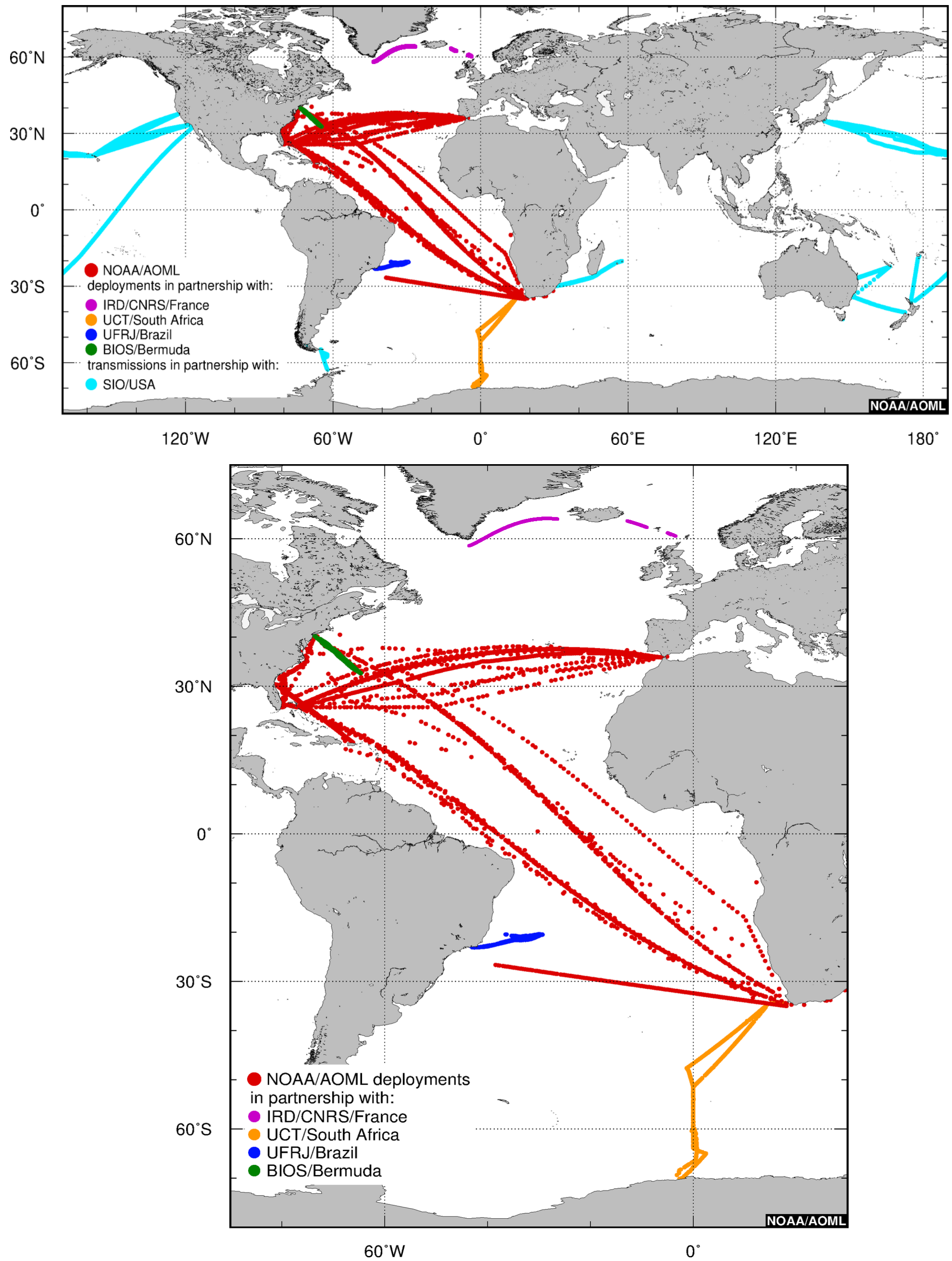


***Figure 2****. (top) Location of the NOAA/AOML XBT deployments and NOAA/AOML-supported XBT deployments and transmissions during FY2023 carried out by NOAA/AOML or in partnership with national and international collaborators. (bottom) Detail of the Atlantic basin deployments by NOAA/AOML and partners.*

The locations of AOML XBT deployments along each transect during FY2023 are shown in Figure 2, and on the NOAA/AOML HD XBT web page (*www.aoml.noaa.gov/phod/hdenxbt*). Data can be also accessed from these web pages or from NOAA/NCEI Global Temperature and Salinity Profile Programme (GTSPP). A summary of all the observations conducted in FY2023 can be found in Table II.

2.2.2. The Oleander Project (AX32)

During FY2023 NOAA/AOML continued its long-standing partnership with the University of Rhode Island, Stony Brook University, Woods Hole Oceanographic Institution, and the Bermuda Institute for Ocean Sciences, in support of the operations in the MV Oleander covering the route between New York and Bermuda. Operations onboard MV Oleander started in 1981 with the collection of XBT and Continuous Plankton Recorder (CPR) observations, and since then the project expanded to include Acoustic Doppler Profiler (ADCP), TSG and partial pressure of carbon dioxide ($pCO_2$). Deployments are conducted in HD mode and XBT profiles collected constitute an important data set in an area of intense ocean variability as the ship crosses the Gulf Stream. NOAA/AOML is also responsible for XBT and TSG data management including scientific quality control and data distribution through the GTS and data archiving at NOAA/NCEI. University of Rhode Island, Stony Brook University, Woods Hole Oceanographic Institution, and the Bermuda Institute for Ocean Sciences are responsible for the logistics and deployments.

***Figure 2***. *(top) Location of the NOAA/AOML XBT deployments and NOAA/AOML-supported XBT deployments and transmissions during FY2023 carried out by NOAA/AOML or in partnership with national and international collaborators. (bottom) Detail of the Atlantic basin deployments by NOAA/AOML and partners.*

2.2.3. XBT observations and Atlantic hurricanes

An enhanced partnership with cargo vessels was started in June 2021 to begin conducting measurements of temperature profiles using XBTs along the continental shelf between the northeast US and Florida. These XBT deployments are performed by the crew of cargo vessels approximately every 130 km, and following logistics already available through regularly operated XBT transects. The ships and crew currently contributing to this effort are the Hapag Lloyd vessels *Chicago Express* and *Bremen Express* and Maersk vessels *Vilnius* and *Visby*, which are used for the AX07 (Miami to Gibraltar) and AX08 (Cape Town to New York) XBT transects. Data is transmitted in real-time onto the GTS and provides temperature observations in regions that are known to contribute to hurricane intensity changes (Figure 3). XBT observations often provided more than 50% of non-glider temperature profiles over the shelf of the US east coast. These observations are assimilated into NOAA experimental and operational ocean models to better characterize the upper ocean thermal structure in the shelf waters by providing continuous profile observations in areas that are otherwise undersampled. Similar to work done with profile observations from other observing platforms, they will be evaluated for their impact to better represent the ocean water mass properties that are linked to hurricane weakening or intensification.  These observations complement observations from Argo floats, which provide broader scale sampling but often miss boundary currents, and of gliders, whose sampling is geared towards carrying out observations with high horizontal spatial resolution along lines.  A total of 155 XBTs were deployed off the US East Coast with the goal of deploying 200 during each Atlantic hurricane season starting in 2024.  XBTs are now providing one of the most extensive sampling  of temperature profiles across the Gulf Stream and on the east US shelf waters ahead of this hurricane and during the full hurricane season.

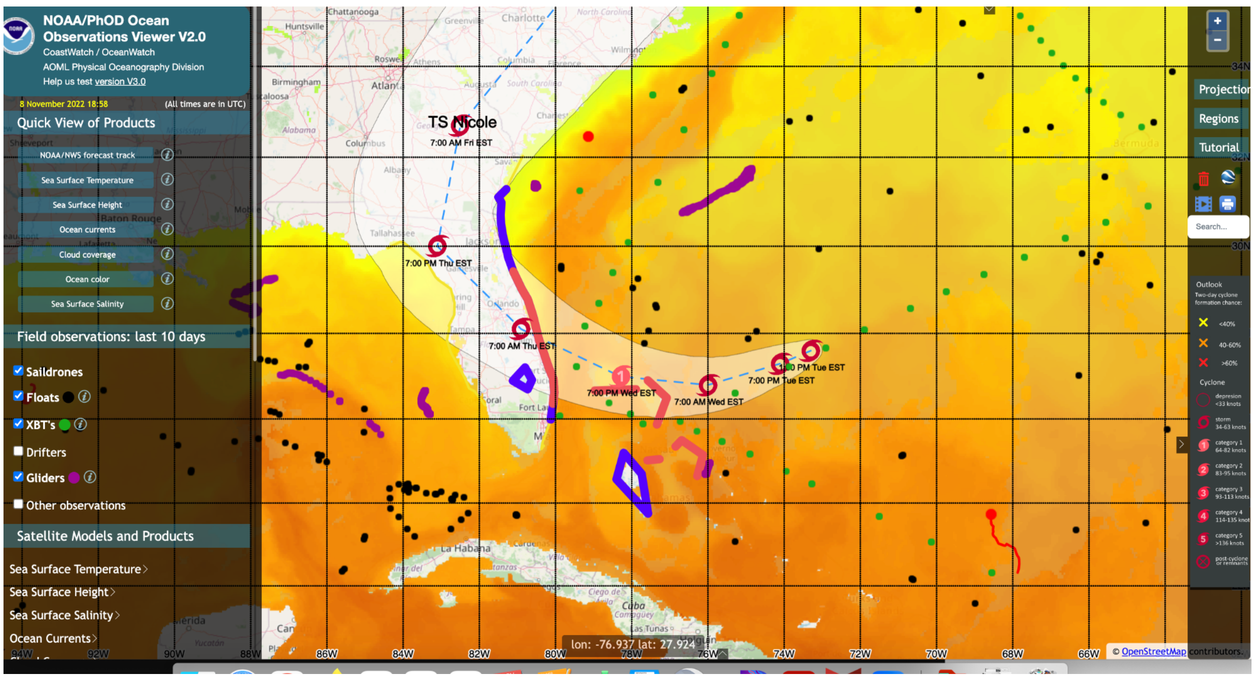


***Figure 3.***  Location of observations obtained from XBTs (in green), Argo floats (black), gliders (purple) up to 9 days ahead of the passage of Hurricane Nicole in November of 2022. XBT data in this example includes observations from AX04, AX07, AX08, AX32, and AXCOAST.

2.2.4 International Collaboration

The collaboration between NOAA/AOML and its international partners include the sharing of resources, such as XBT probes, ship recruitment and logistics, equipment, scientific riders, and data management. NOAA/AOML contributes with XBT probes to oceanographic institutions in which AOML is a partner in the project.  Some of these partnerships during FY2023 included:

- **IRD, Brest,** (AX01), collaborators: Denis Diverres and Gilles Reverdin;

- **UFRJ and FURG, Brazil,** (AX97), collaborators: Mauro Cirano and Mauricio Mata;
- **University of Cape Town**, (AX25), collaborator: Isabelle Ansorge; and
- **Bermuda Institute of Ocean Sciences, University of Rhode Island, Woods Hole Oceanographic Institution, and State University of New York at Stony Brook**, (AX32), collaborators: Ruth Curry, Thomas Rossby, Kathleen Donohue, Charles Flagg, and Magdalena Andres

| Transect | No. of Realizations | No. of XBTs | Avg. No. of XBTs per Transect | Spatial Resolution (km) | Argo Floats Deployments Since 2000 | Drifter Deployments Since 2000 |
|---|---|---|---|---|---|---|
| **AX01** | 1 | 54 | 54 | 35 | 0 | 0 |
| **AX04** | 19 | 685 | 36 | 60 | 0 | 0 |
| **AX07** | 16 | 1801 | 113 | 25/55 | 113 | 224 |
| **AX08** | 23 | 1,510 | 66 | 90 | 309 | 491 |
| **AX10** | 6 | 567 | 95 | 20 | 34 | 19 |
| **AX18** | 1 | 226 | 226 | 25 | 92 | 40 |
| **AX25** | 2 | 329 | 165 | 35 | 176 | 84 |
| **AX32** | 10 | 450 | 45 | 25 | 0 | 0 |
| **AX97** | 6 | 331 | 55 | 25 | 0 | 0 |
| **AXCOAST** | 15 | 155 | 10 | 95 | 0 | 0 |
| **Total** | 99 | 6108 | | | 724 | 828 |

***Table II.*** *Summary of the number of cruises and XBT deployments along the transects operated by NOAA/AOML or with direct NOAA/AOML participation during FY2023. Number of surface drifters and Argo float deployments carried out during XBT cruises and done by the XBT riders since 2000 are also included (see figures A1 and A2).*

2.2.5 Meridional Heat Transport

Changes in the Atlantic Meridional Overturning Circulation (AMOC) and associated Meridional Heat Transport (MHT) can affect climate and weather patterns, regional sea levels, and ecosystems. Direct observations of the AMOC are still limited, particularly in the South Atlantic. A new optimal mapping method was developed recently to estimate the AMOC/MHT at 22.5°S based only on sustained ocean observations. This method minimizes the difference between surface in-situ dynamic height and satellite altimetry to retrieve monthly temperature and salinity profiles from Argo and XBT data along the 22.5°S section. With the help of high-density XBT transect (AX97) and altimeter data, this method resolves the energetic Brazil Current near the western boundary, westward propagating signals, and coastal sea level variability. The results (i) suggest a greater influence of the western boundary dynamics on the AMOC variability at 22.5ºS, (ii) highlight the importance of high-density in situ data for AMOC estimates, and (iii) contribute to a better understanding of the AMOC/MHT variability and water masses distribution in the South Atlantic. A paper describing and assessing this method was recently accepted for publication. This method is currently being applied at 34.5°S to derive AMOC/MHT and freshwater estimates taking advantage of XBT transects AX18 and AX08, which allow resolving the strong currents on both the western (Brazil Current) and eastern (Benguela Current) boundaries.

2.2.6 Machine Learning

A deep learning model was used to estimate salinity directly from XBTs temperature measurements. The model was trained and evaluated with two different datasets: i) temperature and the associated salinity, from XBT data archives; ii) temperature and salinity data sampled by CTD profilers. Then, the fitted model was applied to estimate the salinity for independent XBT datasets. When the longitude, latitude, depth and month of the samplings are considered, in addition to temperature, the predictions show a sharp decrease in the mean salinity absolute error. Longitude and latitude are the major contributors to the augmentation of the model's skill. In general, the results are highly accurate, with mean absolute percentage error in the order of 5% (~0.02 psu).

A deep learning method is also being applied on the mapping of temperature and salinity along cross-basins transects such as 22°S and 34.5°S, and this methodology will aid the estimates of boundary current and meridional heat transports. Some of the results will be shown during the Ocean Sciences meeting in February 2024.

2.2.7 Automatic Weather Station

The weather stations installed in the MV Chicago Express in 2020 and in the Bremen Express in 2021 continue collecting meteorological data continuously along the AX04 and AX07 XBT transects. The data are currently being transmitted in real-time to AOML and work is currently underway to implement real-time transmission of these meteorological data into the GTS. These data are being analyzed and compared with reanalysis products (NCEP2 and ERA5) for surface turbulent heat flux calculation. Our analyses show that mean biases of reanalysis products are not statistically significant for all variables but the biases for individual events can be large. The correlation between the shipboard measurements and the reanalyses are high ($r>0.9$) for all variables (surface air temperature, SST, sea level pressure) except for RH, which is slightly lower between shipboard and ERA5 data ($r=0.84$), and much smaller between shipboard and NCEP2 data ($r=0.42$). The derived turbulent fluxes suggest that ERA5-based fluxes agree better with the shipboard estimates than NCEP2-based fluxes. A manuscript is prepared for submission to a scientific journal.

2.2.8 Boundary Currents and Large-Scale Ocean Circulation

A significant fraction of large-scale and slow sea surface temperature and height changes in the North Atlantic exhibit a tripolar pattern. In the recent decade, the tripolar pattern has been linked to increased nuisance flooding along the United States southeast coast. Despite its extensive impacts on the low-lying coastal lands, many properties of the pattern remain unaccounted for, particularly the vertical structure. The XBT transects AX07, AX08, AX10, and AX32 transects in the North Atlantic, together with reanalysis data, were used to describe the tripole's characteristics across the continental shelf and slope and in the open ocean. The results indicate that the tripole-associated temperature and sea level signatures are most pronounced in the Slope water between the Gulf Stream and the Mid-Atlantic Bight shelf break, concomitant with notable changes in the stream strength and position, but they rapidly decay within the shelf. The tripole temperatures in the ocean interior are apparent in the upper 300 m in the subtropics but to a shallower extent in the tropics. The tripole attains its maximum during summer, following the North Atlantic Oscillation's winter maximum.

XBT measurements from AX10, AX32, and AXWBTS were also used to examine the Gulf Stream variability, including its path meridional shifts, transport, and velocity vertical structure. Preliminary results indicate that the Gulf Stream near 70°W shifted shoreward and its transport increased after 2015. Accompanied with the strengthening of the Gulf Stream, the temperature to the south of the Gulf Stream increased with maximum warming occurring between 600 m and 800 m depth.

2.2.9 Software and Engineering Developments

During FY2023, our engineering team has made a number of developments to make the XBT operation more efficient.

- **Development of an innovative communications interface:** Incorporating iridium, autolauncher, and GPS technologies. The redesigned interface streamlines functionality by seamlessly integrating multiple components, reduces clutter and enhances user experience through increased intuitiveness. A singular USB cable facilitates communication with all serial devices, eliminating the necessity for multiple DB9 serial ports.
- **Development of a wireless access point:** Based on Raspberry Pi technology to enable wireless utilization of the XBT system. Housed within a waterproof enclosure, the device operates efficiently through Power over Ethernet (PoE), capitalizing on existing Ethernet infrastructure. This design has undergone successful testing on AX10.
- **Development of Implementation enhancements to the Java-based XBT binary library**: This critical component is utilized in various XBT-related software applications.

These improvements contribute to the overall robustness and functionality of the library, ensuring optimal performance across multiple software interfaces.

- **XBT cruise help planner program**: developed to help XBT riders plan cruise operations, such as autolauncher reload times, distance, and times to a given location and no. of XBTs that will be deployed.
- **Autolauncher controller board prototype**: the unavailability of many electronic components used in the current version of the autolauncher board required the design of a new printed circuit board. The new version will have a lower cost than legacy components, a smaller footprint, and greater availability. With most of the electronics being surface mount technology, it will allow the PCB manufacturers to mount many of the components in their factories, delivering a product that can be used by non-technical personnel. The board will also include an additional serial port that allows the connection of a GPS directly to the autolauncher, without the need for a separate antenna connected to a computer. It will also be prepared to include a small LCD screen with a menu browser to control the unit and the XBT recorder from the autolauncher, which is convenient for situations where the data acquisition computer is far from the autolauncher. A future release will include a serial communication port to communicate with the new AXR (replacement of the Lockheed Martin MK21 - data acquisition system-) that will be mounted on the autolauncher board.
- **XBT map and profile plotter:** a new graphical user interface was developed in order to display XBT profiles and locations on an interactive map with different available types such as topographic, streets, satellite, etc. The data can be downloaded from an FTP server or a local directory and filtered by ship call signs and dates.

In addition, we continue the in-house refurbishment and maintenance of the expensive instruments to save money for the project. These instruments are needed to maintain a mixed FR/HD operation. Specifically, the following work has been done during FY2023,

- Refurbishment of 4 AutoLaunchers and one Iridium Transmitter
- Refurbishment of 6 Hand-Held Launchers
- Refurbishment and testing of two Iridium Transmitter with AOML-designed custom electronics, housing & wiring
- Fabrication and assembly of 3 AutoLauncher main boards used to control the operations of the AutoLaunchers

We also continue the ongoing testing of prototype proof of concept self-contained microcontroller-based board for recording and transmitting meteorological data in real-time. This work is performed to produce a next generation (new version) of these key components to be able to maintain the operations as the components from previous models are not available anymore and, therefore, most components [e.g., autolauncher, meteorological station, antennas] needs to be re-designed.

2.2.10 XBT Project Collaborations and Partnerships with other Projects

***a. Meridional Heat Transport***

XBT observations in the Atlantic Ocean obtained from the HD transects AX07 and AX18 are used to monitor the Meridional Heat Transport in the Atlantic basin on a quarterly basis (Project PI: Shenfu Dong). Time series of these estimates can be found at: *www.aoml.noaa.gov/phod/goos/xbtscience/mht_products.php*. Results from those transects have been used to assist MOC-related studies combining different data sets and investigate the impact of the MOC in the South Atlantic on climate and extreme weather events. The XBT transects also aided a development of synthesis method to combine satellite and in situ data to derive real-time MOC and MHT at various latitudes (26.5°N, 20°S, 25°S, 30°S, and 34.5°S) in the Atlantic Oceans on a monthly basis. This method relies on the relationships between sea height and depth of isotherms. In FY2023, we updated those relationships with additional hydrographic data collected in the past 10 years, and recomputed the real-time MOC and MHT at the four latitudes in the South Atlantic. Updating the MOC and MHT for the North Atlantic is ongoing.

***b. NWS Marine Meteorological Observations***

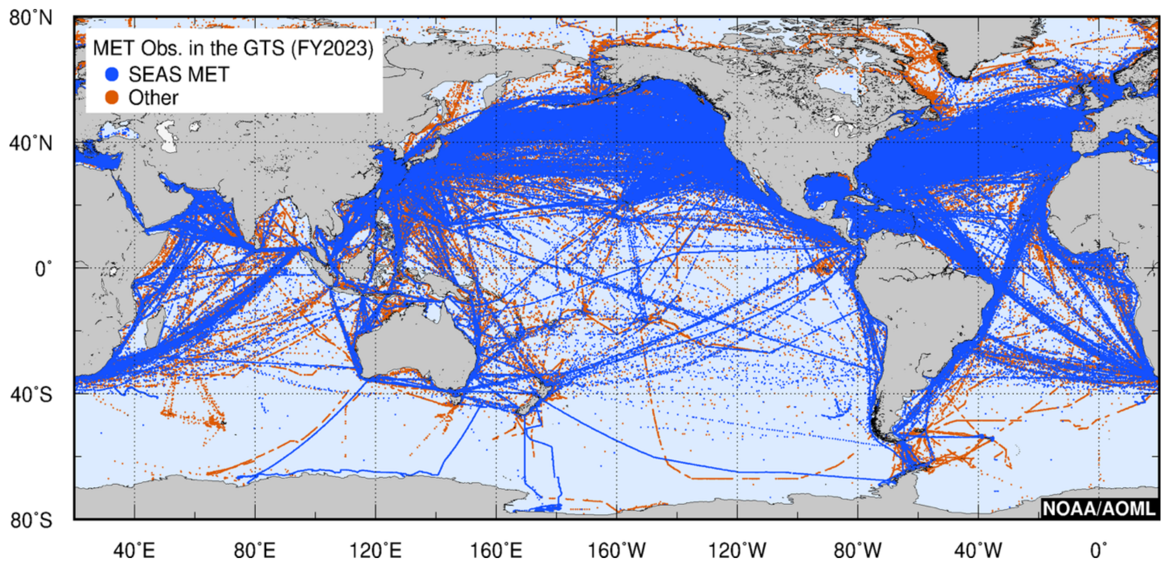


***Figure 4.*** *Locations of more than 1,407,000 marine weather observations obtained from 1,800 ships of the US-VOS distributed through the GTS using SEAS software during FY2023.*

The SEAS software, which is supported by this project, is also used by the NOAA National Weather Service Voluntary Observing Ships (VOS) program. Using the SEAS system, NOAA/AOML transmitted and distributed through the GTS more than 1,407,000 meteorological bulletins (which represent a 48% increase with respect to FY2022 and account for 60% of all global marine meteorological observations in the GTS) from approximately 1,800 participating vessels during FY2023 (Figure 4), constituting the largest source of marine meteorological bulletins. These observations are used in weather forecast prediction models and analysis by universities and government laboratories, such as the Tropical Analysis and Forecasting Branch of the National Hurricane Center.

### *c. TSG Operations*

During FY2023 NOAA/AOML continued the thermosalinograph (TSG) operation, a component of its Ship Of Opportunity Program (SOOP), in support of the $pCO_2$ operations. During this period, NOAA/AOML received, processed and distributed TSG data from 12 ships of the NOAA fleet (*RV Bell M. Shimada, RV Fairweather, RV Gordon Gunter, RV Henry Bigelow, RV Okeanos Explorer, RV Oregon II, RV Oscar Dyson, RV Oscar Elton Sette, RV Pisces, RV Reuben Lasker, RV Ronald H. Brown, RV Thomas Jefferson*), including 3 (*RV Henry Bigelow, RV Ronald Brown, and RV Gordon Gunter*) with operational pCO2 systems. Although the new *MV Oleander* was delivered before the pandemic, because of the interruption of the pandemic and errors made by the shipyard, the observing systems (including TSG component) are not fully online yet. It is expected that all systems will be operational in early 2024. From the ships of the NOAA fleet collecting TSG data during FY2023, 25% also collected pCO2 observations.

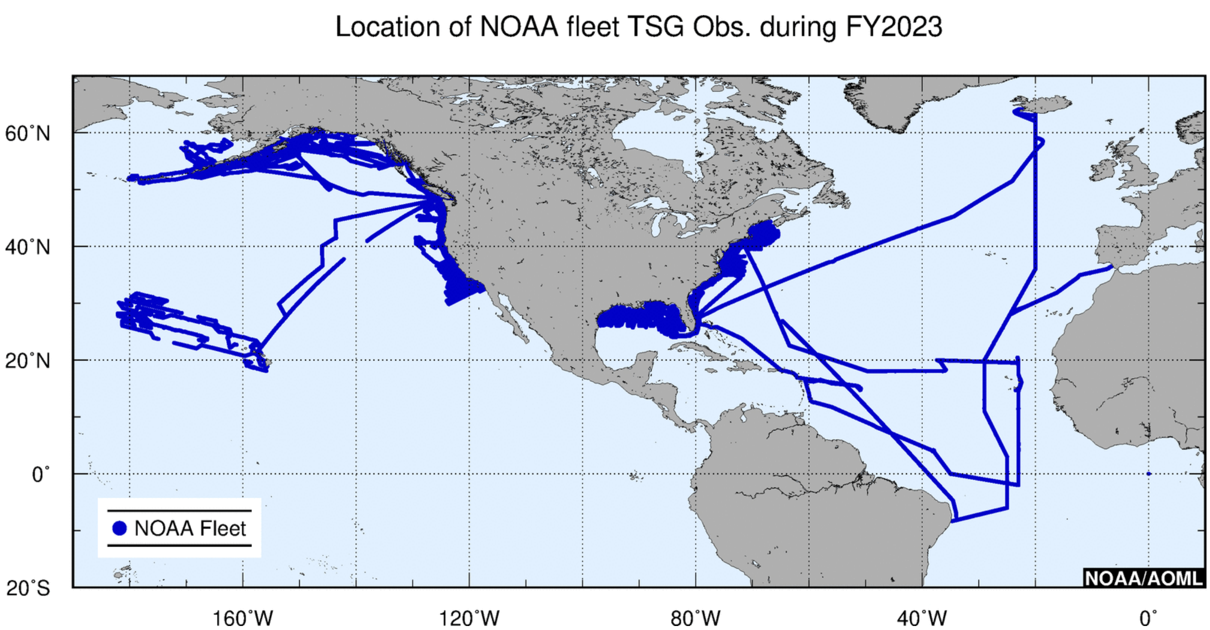


***Figure 5.*** *Location of approximately 345,000 TSG observations (3-min. resolution) received and processed by NOAA/AOML during FY2023 from 12 ships of the NOAA fleet.*

More than 1 million TSG records from ships of the NOAA fleet (corresponding to approximately 345,000 records with 3-minute temporal resolution) were processed at NOAA/AOML during FY2023 (Figure 1), and distributed through several data centers including NOAA's National

Centers for Environmental Information (NCEI) and Global Ocean Surface Underway Data (GOSUD).

### *d. Argo Program*

Riders from ships performing XBT deployments also deploy Argo floats at no cost to the Argo program. A total of 634 Argo floats were deployed by NOAA/AOML XBT ship riders along 5 XBT transects in the Atlantic Ocean (AX07, AX08, AX10, AX18, and AX25) since 2000 (Figure A1).

### *e. Global Drifter Program*

The XBT network contributes, at no cost, to the Surface Drifter Program to maintain its drifter array by having the XBT ship riders deploy surface drifters. A total of 818 surface drifters have been deployed by NOAA/AOML XBT ship riders along 5 XBT transects in the Atlantic Ocean (AX07, AX08, AX10, AX18, and AX25) since 2000 (Figure A2).

### *f. Western Boundary Time Series Project (WBTS)*

XBT observations collected along the repeat transects AX07 (Miami to Gibraltar) and AXWBTS (West Palm Beach to Bahamas) are often coordinated with hydrographic surveys carried out at 27°N in the Florida Straits that aim at calibrating a continuous record of the Florida Current flow derived from telephone cables voltage measurements. The coordination includes conducting XBT transects around the same time as the WBTS cruises, which allow us to combine these data to investigate the vertical structure of the Florida Current transport and temperature, and more importantly, for better understanding of oceanic changes and impacts. The WBTS has not been able to conduct cruises during FY2023 because of the permission issues, however, the WBTS cruises are expected to restart in late 2023.

### *g. Other collaborations*

Other domestic collaborations in which the NOAA/AOML XBT Project are also actively involved include:

- Support of the NOAA-funded "Surface $pCO_2$ Measurements from Ships" (PIs: Drs. Rik Wanninkhof, Richard Feely), for which NOAA/AOML provided 1 pallet of XBTs (324 probes) to BIOS (Bermuda) and University of Rhode Island to be deployed along the $pCO_2$ transects AX32.
- NOAA/AOML provides equipment (for example, Iridium antennas) and support to ships of SIO HD XBT operations;
- NOAA/AOML provided the software to SIO for XBT data acquisition and transmission and carries out the real-time quality control and GTS data distribution of all SIO HD XBT data;
- NOAA/AOML collaborates with the National Weather Service to provide GTS distribution in real-time of marine meteorological observations using the SEAS system.

- Through an agreement with the U.S. Coast Guard, NOAA/AOML provides real-time information about the location of ships with the SEAS software installed, which is used for search and rescue operations.

### *2.3. Deliverables Contributing to Societal Needs*

NOAA's Climate Goal is focusing on an initial set of societal challenges:
- Reduce vulnerability to extreme weather (extremes);
- Prepare for drought and water resource challenges (drought);
- Manage risks to coastlines and coastal infrastructure (coastal inundation); and
- Sustainably manage marine ecosystems (marine ecosystems).

Observations from the XBT network and the analysis carried out with its data provide an indirect contribution to these societal challenges. XBT observations represent approximately 10-15% of all ocean temperature profile data and, consequently, they are key for assessments of upper ocean heat content and sea level variability studies. In addition, this project provides direct estimates of the boundary current transports that could affect coastal sea level and marine heatwaves, and whose variability may be linked to changing weather and climate patterns. Similarly, changes in the net meridional overturning circulation can influence long-term sea level. Extreme weather (e.g., hurricanes) and drought (or rainfalls) have been linked to the strength of the meridional overturning circulation. Continued analysis of boundary currents and the meridional overturning circulation and heat transport may improve forecasts of coastal inundation, seasonal forecasts of hurricanes, etc.

#### 2.3.1. Essential Ocean and Climate Variables and products

The XBT network provides critical data to monitor the following Essential Ocean and Climate Variables:
- Sea surface and subsurface temperature
- Sea surface and subsurface currents
- Sea surface salinity

In addition, NOAA/AOML maintains a set of online products to monitor the state and variability of the ocean:
- Ocean currents and variability (*www.aoml.noaa.gov/phod/research/po/currents*)
- North Atlantic Meridional Overturning Circulation (*www.aoml.noaa.gov/phod/research/moc/namoc*)
- South Atlantic Meridional Overturning Circulation (*www.aoml.noaa.gov/phod/research/moc/samoc*)
- Meridional Heat Transport (*www.aoml.noaa.gov/phod/indexes/samoc_alt.php*)
- Ocean indexes and indicators, including ocean current indicators (*www.aoml.noaa.gov/phod/indexes/index.php#currents*), and South Atlantic meridional

overturning circulation and meridional heat transport at 34.5ºS (*www.aoml.noaa.gov/phod/indexes/index.php#samoc*)
- Atlantic heat transport quarterly reports (*www.aoml.noaa.gov/phod/soto/mht/reports*)

### *2.4. Issues related to funding that affect progress*

In the past, years of level funded budgets have reduced the salary support for data processing, equipment calibrations and maintenance, equipment spares and travel to scientific meetings. The project, therefore, increasingly relied on contractor riders to support the data collection efforts. However, due to the pandemic, we did not have this issue in FY2023 as work by contractors was limited and their effort replaced by redesigning sampling along the transects. It is expected that the support for contractor riders will resume starting FY2024 as we attempt to conduct AX18 transect in a similar frequency as before the pandemic and to conduct AX08 in HD mode. The weather station installment in the AX97 transect has been delayed because of the pandemic, and later due to the restrictions of civil personnel on the Brazilian Navy ships. This issue has been recently resolved.

### *2.5. Web Pages*

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*, or directly through the NOAA/AOML XBT Network web page *www.aoml.noaa.gov/phod/goos/xbt_network/*.

| | |
|---|---|
| XBT Network: | *www.aoml.noaa.gov/phod/goos/xbt_network* |
| XBT HD: | *www.aoml.noaa.gov/phod/hdenxbt* |
| XBT Science | *www.aoml.noaa.gov/phod/goos/xbtscience* |

The latest information on operational XBT transects along with specific web pages showing the latest XBT, meteorological, and TSG observations are available online at: *www.aoml.noaa.gov/phod/goos/seas/latest/***.** The GOOS website also features a Google Earth layer displaying Global Marine and Meteorological Observations available online at *www.aoml.noaa.gov/phod/VOS/GE/GE_AOML_DT.kmz***.** This application is a powerful tool to visualize the global extent of ocean and meteorological observations interactively and in real time.

The AOML XBT website (*www.aoml.noaa.gov/phod/goos/xbt_network/*) was created to provide easy access to XBTs operations, data, XBT-derived products, and other XBT-related information. Information related to AOML XBT operations and research are posted through the XBT Science website (*www.aoml.noaa.gov/phod/goos/xbtscience*). Derived products and indicators are provided through our web pages, including estimates of velocity and transports for various ocean currents systems, such as the Gulf Stream, Florida Current, Brazil Current, and Kuroshio Current, (*www.aoml.noaa.gov/phod/goos/xbtscience/oc_currents.php*), and indicators for the main current systems in the Atlantic Ocean (Brazil Current, Benguela Current, Tropical Atlantic Current System, etc.), and the meridional overturning circulation (MOC) and meridional heat transport (MHT) in both the North and South Atlantic Oceans (*www.aoml.noaa.gov/phod/indexes/index.php*). Maintenance and updates of these web pages have been delayed due to personnel changes, but expected to resume in the following years with new personnel.

**3. Outreach and Education**

- Gustavo Goni and Francis Bringas continue work to improve project web pages.
- S. Dong works with women scientists to increase retention in the field (MPOWIR).
- S. Dong co-mentored four postdocs working on variations of marine heat waves and cold spells along US east coast and Gulf of Mexico (Filippos Tagklis), impact of spatio-temporal variations in Antarctic meltwater fluxes on Antarctic Bottom Water (Wilton Aguiar), sea level variations along the United States East Coast (Lei Huang), and warming in the Southern Ocean south of South Africa (Xiaoyue Hu).
- S. Dong co-mentored (with M. Goes and A. Vaz) two undergraduate students: Samantha Donner from Rutgers University as an undergraduate student Lapenta intern (during summer 2023) on a project focused on water mass transformations in the North Atlantic by tropical cyclones, Rebecca Foody from Cornell University who continued the project started in summer 2022 in evaluating turbulent fluxes from reanalysis products using concurrent shipboard measurements.
- S. Dong co-mentored two graduate Ph.D. students, V. Cainzos Dias and C. Arumi Planas, from the University of Las Palmas de Gran Canaria from September-November 2022. During their internships, they compared model zonal current transports with observations from the Spanish South Atlantic GAteway (SAGA) project along 10°W, and model and observational estimates of the meridional overturning circulation transports along 34.5°S.
- Gustavo Goni and Shenfu Dong are mentoring Dr. Kandaga Puijana, an early career scientist at CIMAS, who is conducting research about the three-dimensional thermal structure of the North Atlantic tripole.
- On Oct 19, 2023 M. Goes gave a class for 5th graders of Sunset Park Elementary school about Earth's hydrological cycle.
- M. Goes mentors the PhD student Ivenis Pita on the use of Argo and XBT to monitor the AMOC and MHT in the South Atlantic.
- On April 27, 2023 M Goes was a presenter at the “Take Your Child to Work Day” sponsored by AOML, the Southeast Fisheries Science Center, and the Girl Scouts of Miami.
- M. Goes participated in several interviews for media outlets (including CBS, NBC, the Wired, Outer Banks Milepost) about the potential collapse of the AMOC.

## 3.1. Panel Memberships

*Ship Of Opportunity Programme Implementation Panel (SOOPIP).* The NOAA/AOML SOOP Program is a participating member of OceanOps. The NOAA/AOML SOOP XBT program is represented bi-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. Francis Bringas is the Co-Chair of the WMO/IOC Ship Of Opportunity Program Implementation Panel (SOOPIP), Dr. Gustavo Goni is a member of the SOOPIP Panel, Dr. Joaquin Trinanes is a member of the Meta-T panel and the SOT Data Management Programme Area (DMPA) Task Team on Table Driven Code Forms, and Dr. Francis Bringas is a member of the SOT DMPA Task Team on Table Driven Code Forms, the SOT Task Team on Instrument Standards, and the SOT Task Team on Training.

*XBT Science Team*. Dr. Goni is an active member of the XBT Science Steering Team. For over 10 years, together with Dr. Janet Sprintall (SIO, for science) and Ms Cowley (CSIRO, for data management), Gustavo Goni has been the co-Chair of the XBT Science team, a position that passed to Shenfu Dong this year. Drs. Goes and Bringas are members of the XBT Science Team.

S. Dong is a member of the SAMOC science team, the SAMOC Executive Committee, NOAA Coastal Inundation Task Force, and North Atlantic Regional Team. S. Dong is working with women scientists to increase retention in the field (MPOWIR). G. Goni is a member of the GOMO Extreme Events Ocean Observations Task Team and the IQUOD Steering Team. H. Lopez is a member of the CPC seasonal hurricane outlook team, NOAA/OAR Societal Challenges Working Group, and NOAA MAPP's CMIP6 Task Force, and co-chairs NOAA's Marine Heatwaves group and NOAA's Severe Weather Weeks 2-4 Tiger Team.

## 3.2. XBT Meetings and Workshops organized or attended by XBT PIs

***NOAA/AOML Annual XBT Meeting***

The annual NOAA/AOML XBT/TSG Operations Virtual Meeting was held on April 6, 2023. The main goal of this meeting was to bring together the main participants of the NOAA/AOML XBT Network, SEAS, and TSG project, and to discuss progress, current status, and plans for the upcoming year. This workshop was attended by more than 30 participants from NOAA/AOML, CIMAS, and the University of Miami.

***7th XBT Science Team Meeting (May 11-12, 2023)***

Francis Bringas, Shenfu Dong, Marlos Goes, Gustavo Goni (virtual participation), Ivenis Pita, and Kandaga Pujiana (virtual participation) attended and made presentations at the 7th Session of the XBT Science Team (XBTS-7) meeting in Melbourne, Australia. The meeting featured discussions of the latest scientific results, data management developments, and plans using data collected from the global XBT network.

***12th Session of Ship Observations Team (SOT) Meeting (May 15-18, 2023)***
Zach Barton, Francis Bringas, Shenfu Dong, Marlos Goes, Gustavo Goni (virtual), Ivenis Pita, and Joaquin Trinanes attended the 12th Session of the Ship Observations Team (SOT) in Melbourne, Australia. All AOML participants gave presentations and/or led sessions. The SOT was sponsored by the World Meteorological Organization and tasked with the implementation and maintenance of global networks dedicated to collecting environmental observations from ships of opportunity.

***28th IAPSO/IUGG (July 10-17, 2023)***
Shenfu Dong and Marlos Goes attended the International Association for the Physical Sciences of the Oceans (IAPSO) Conference during the 28th General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Berlin, Germany. Dong gave an invited talk on the South Atlantic MOC and Goes gave a talk on marine heatwaves in the western subtropical South Atlantic.

***AMOC observation workshop (July 18-20, 2023)***
Shenfu Dong and Marlos Goes attended the AMOC observation workshop in Hamburg and gave presentations on the South Atlantic MOC (Dong) and marine heat waves (Goes).

***GOMO Community Workshop (July 25-27, 2023)***
Ivenis Pita, Shenfu Dong (remotely), and Gustavo Goni (remotely) attended the Hybrid NOAA/Global Ocean Monitoring and Observing (GOMO) Community Workshop, Silver Spring, MD.

## 4. Publications and Reports

AOML adheres to the NOAA's Public Access to Research Results (PARR) requirements for publications. This includes submitting a digital copy of final pre-publication manuscripts to the NOAA Institutional Repository once accepted for publication and the final pre-publication copy is available (*www.glerl.noaa.gov/review2016/reviewer_docs/NOAA_PARR_Plan_v5.04.pdf*).

### 4.1. Relevant Publications by Principal Investigators and other scientists

Baker, J.A., R. Renshaw, L.C. Jackson, C. Dubois, D. Iovino, H. Zuo, R.C. Perez, S. Dong, M. Kersalé, M. Mayer, J. Mayer, S. Speich, and T. Lamon, 2023: South Atlantic overturning and heat transport variations in ocean reanalyses and observation-based estimates. In *7th edition of the Copernicus Ocean State Report (OSR7)*, K. Schuckmann et al. (eds.). State of the Planet, 1-osr7, 15 pp., https://doi.org/10.5194/sp-1-osr7-4-2023

Balaguru, K., G. Foltz, L. Leung, W. Xu, D. Kim, H. Lopez, and R. West, 2022: Increasing hurricane intensification rate near the US Atlantic coast. Geophysical Research Letters, 49(20):e2022GL099793, http://doi.org/10.1029/2022GL099793

Boyer, T., H.M. Zhang , K. O’Brien, J. Reagan , S. Diggs, E. Freeman, H. Garcia, E. Heslop, P. Hogan, B. Huang, L.-Q. Jiang, A. Kozyr, C. Liu, R. Locarnini, A.V. Mishonov, C. Paver, Z. Wang, M. Zweng, S. Alin, L. Barbero, J.A. Barth, M. Belbeoch, J. Cebrian, K.J. Connell, R. Cowley, D. Dukhovskoy, N.R. Galbraith, G. Goni, F. Katz, M. Kramp, A. Kumar, D.M. Legler, R. Lumpkin, C.R. McMahon, D. Pierrot, A.J. Plueddemann, E.A. Smith, A. Sutton, V. Turpin, L. Jiang, V. Suneel, R. Wanninkhof, R.A. Weller, and A.P.S. Wong, 2023: Effects of the pandemic on observing the global ocean. Bulletin of the American Meteorological Society, 104(2):E389-E410, https://doi.org/10.1175/BAMS-D-21-0210.1

Chidichimo, M.P., R.C. Perez, S. Speich, M. Kersalé, J. Sprintall, S. Dong, T. Lamont, O.T. Sato, T.K. Chereskin, R. Hummels, and C. Schmid, 2023: Energetic overturning flows, dynamic interocean exchanges, and ocean warming observed in the South Atlantic. Communications Earth & Environment, 4:10, https://doi.org/10.1038/s43247-022-00644-x

Good, S., B. Mills, T. Boyer, F. Bringas, G. Castelão, R. Cowley, G. Goni, V. Gouretski, and C.M. Domingues, 2023: Benchmarking of automatic quality control checks for ocean temperature profiles and recommendations for optimal sets. Frontiers in Marine Science, 9:1075510, https://doi.org/10.3389/fmars.2022.1075510

Holbach, H.M., O. Bousquet, L. Bucci, P. Chang, J. Cione, S. Ditchek, J. Doyle, J.-P. Duvel, J. Elston, G. Goni, K.K. Hon, K. Ito, Z. Jelenak, X. Lei, R. Lumpkin, C.R. McMahon, C. Reason, E. Sanabia, L.K. Shay, J.A. Sippel, A. Sushko, J. Tang, K. Tsuboki, H. Yamada, J. Zawislak, and J.A. Zhang, 2023: Recent advancements in aircraft and in situ observations of tropical cyclones. Tropical Cyclone Research and Review, 12(2):81-99, https://doi.org/10.1016/j.tcrr.2023.06.001

Kim, D., S.-K. Lee, H. Lopez, G.R. Foltz, C. Wen, R. West, and J. Dunion, 2023: Increase in Cape Verde hurricanes during Atlantic Niño. Nature Communications, 14:3704, https://doi.org/10.1038/s41467-023-39467-5

Lee, S.-K., H. Lopez, F.P. Tuchen, D. Kim, G.R. Foltz, and A.T. Wittenberg, 2023: On the genesis of the 2021 Atlantic Niño. Geophysical Research Letters, 50(16):e2023GL04452, https://doi.org/10.1029/2023GL104452

Lumpkin, R., F. Bringas, G. Goni, and B. Qiu, 2023: Surface currents. In Chapter 3, *State of the Climate in 2022*. Bulletin of the American Meteorological Society, 104(9):S177-S180, https://doi.org/10.1175/BAMS-D-23-0076.2

Parks, J., F. Bringas, R. Cowley, C.P. Hanstein, L. Krummel, J. Sprintall, L. Cheng, M. Cirano, S. Cruz, M.P. Goes, S. Kizu, and F. Reseghetti, 2022: XBT operational best practices for quality assurance. Frontiers in Marine Science, 9:991760, https://doi.org/10.3389/fmars.2022.991760

Pujiana, K., D.L. Volkov, S. Dong, G. Goni, M. Baringer, R.H. Smith, and R. Garcia, 2023: Genesis of the Gulf Stream subseasonal variability in the Florida Straits. Journal of Geophysical Research-Oceans, 128(2):e2022JC018555, https://doi.org/10.1029/2022JC018555

Volkov, D.L., C. Schmid, L. Chomiak, C. Germineaud, S. Dong, and M. Goes, 2022: Interannual to decadal sea level variability in the subpolar North Atlantic: The role of propagating signals. Ocean Science, 18(6):1741-1762, https://doi.org/10.5194/os-18-1741-2022

Volkov, D.L., R.H. Smith, C.S. Meinen, R. Garcia, M. Baringer, and G. Goni, 2023: The skill of measuring the Florida Current volume transport from space. *Proceedings, 5th Oceans from Space Symposium,* Venice, Italy, October 24-28, 2022. European Commission, 238-239.

Volkov, D.L., D.A. Smeed, M. Lankhorst, S. Dong, B.I. Moat, J. Willis, W. Hobbs, T. Bilo, W. Johns, and L. Chomiak, 2023: Meridional overturning circulation and heat transport in the Atlantic Ocean. In Chapter 3, *State of the Climate in 2022*. Bulletin of the American Meteorological Society, 104(9):S181-S184, https://doi.org/10.1175/BAMS-D-23-0076.2

### 4.2. Other Relevant Publications

XBT publications in refereed journals since 2000 total approximately 2100. There were approximately 24 peer-reviewed XBT publications that used NOAA XBT data during FY2023. For a complete list of XBT-related publications please visit our XBT bibliography page at: *www.aoml.noaa.gov/phod/goos/xbtscience/bibliography.php*

## 5. Data and Publication Sharing

AOML adheres to the NOAA's Public Access to Research Results (PARR) requirements for data. This includes assuming that data are well documented, publicly accessible, and preserved. See the following link for details on PARR requirements: (*www.glerl.noaa.gov/review2016/reviewer_docs/NOAA_PARR_Plan_v5.04.pdf*).

### 5.1. Data Flow

XBT profiles are acquired and transmitted in real-time using Iridium modems. NOAA/AOML also uses Iridium transmission on all TSG operations. The ratio of XBTs deployed to real time data transmitted is essentially 100% in ships with XBT transects directly implemented and maintained by NOAA/AOML.

### 5.2 Data quality control and distribution

NOAA/AOML and Scripps XBT profiles undergo near-real time automatic quality control (AQC) procedures at NOAA/AOML. The profiles that fail the AQC are submitted to visual quality control (VQC) using a code developed at NOAA/AOML, in which a trained operator decides whether or not to send the data to the GTS. Probe failure (as measured by the AQC) remains consistently between 5% and 10% with higher failure rates at higher latitudes during winter months. Approximately 95% of the profiles that fail the AQC were approved during the VQC. Typically, about 95% of all profiles are approved during the QC process and submitted to the GTS. In addition, all the XBT data obtained are submitted to NOAA/NCEI for archival and distribution. All requirements are followed for data transmissions into the GTS, including the use of BUFR format for XBT profiles.

5.3 Data quality control and distribution to NCEI

All Atlantic Ocean High Density XBT data collected by NOAA/AOML and NOAA/AOML partners undergo delayed mode quality control. For this expert quality control, bad profiles are identified, spikes are removed and profiles are evaluated for representativeness of the surrounding physical oceanography features known for the region. Similar procedures are employed as other delayed mode quality control such as Scripps and CSIRO. For example, subsurface temperature inversions found near the high salinity/higher temperature Mediterranean outflow might fail automatic quality control procedures, but are perfectly acceptable, expected oceanographic profiles. Occasionally, some data are filtered to remove the small-scale unphysical electrical noise that can occur in the profiles. All modifications to the XBT profiles are logged and available via the NOAA/AOML web site. Final quality-controlled profiles are delivered to NOAA/NCEI for archival and replacement into the "Best Quality" GTSPP and WOD data sets, typically within one-two months of the data being collected.

5.4 VOS data distribution

NOAA/AOML, through the SEAS system supported by this program, distributed approximately 1,407,000 meteorological bulletins from 1,800 vessels participating in the US-VOS program (Figure 4). This volume of meteorological bulletins accounts for approximately 60% of all global marine meteorological observations during FY2023.

5.6 International Quality-controlled Ocean Database

The IQuOD (International Quality-controlled Ocean Database) effort is a recently started initiative by the oceanographic community that aims to produce and freely distribute a high quality ocean data set with assigned uncertainties for use in ocean and climate research applications. Scientists from the NOAA/AOML XBT Network participate in this effort. During FY2023, NOAA/AOML continued its participation in the test and development of automatic quality control procedures. A manuscript with results about tests for an optimized automatic quality control procedure was submitted and accepted for publication. For more information, please visit: *www.iquod.org.*

## 6. Project Highlight Slides

Emailed separately.

## 7. Appendix

**Argo floats and surface drifters deployed by riders from XBT transects since 2000.**

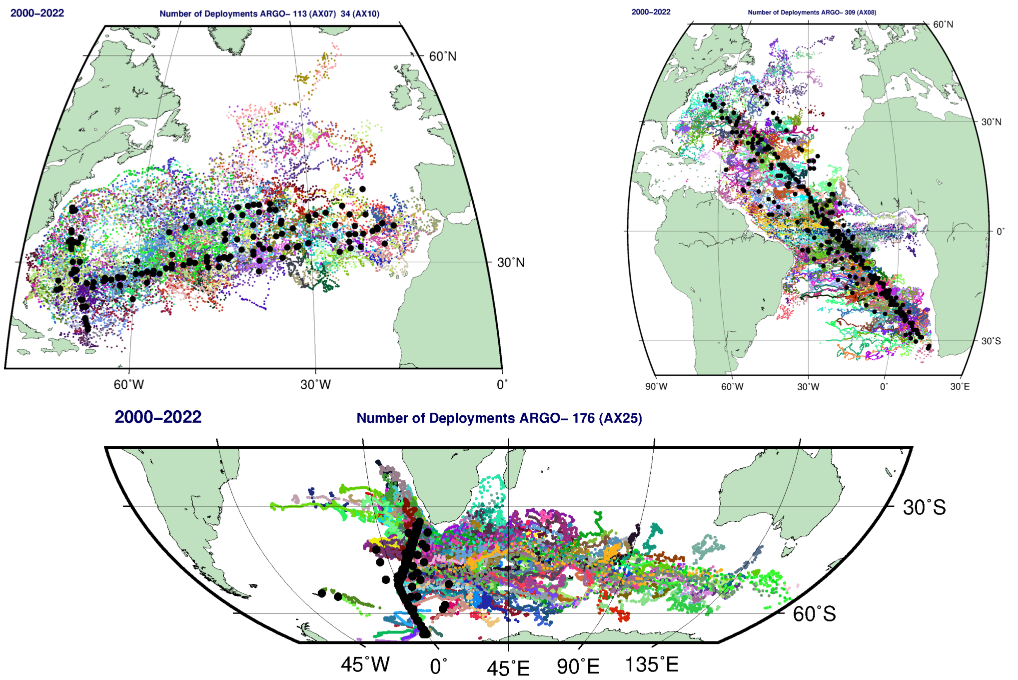


**Figure A1.** Location of deployments (black circles) of profiling floats carried out by XBT ship riders since 2000 (113 from AX07, 309 from AX08, 34 from AX10, and 176 from AX25). Locations of observations from these floats are indicated by color dots.

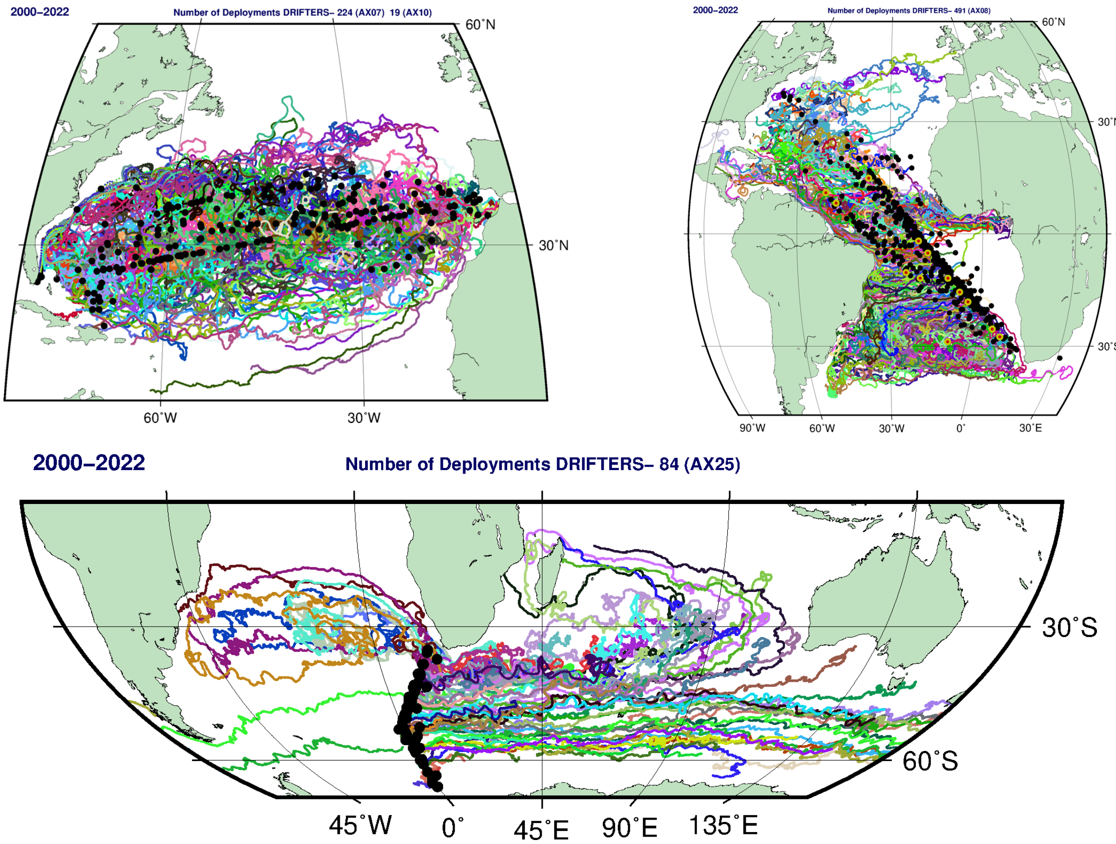


**Figure A2.** Location of deployments (black circles) of surface drifters carried out by XBT ship riders since 2000 (224 from AX07, 477 from AX08, 19 from AX10, and 84 from AX25). Trajectories of these drifters are color lines.