**The status of the XBT network**
**July 16, 2008**

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**Summary**

The current XBT network has been diverging from the recommendations made during the OceanObs99 meeting. Here are selected issues concerning the operations of the XBT network that I would like to introduce to be evaluated and discussed by members of the scientific community.

**All XBT transects in general:**

- Is there a need for the re-evaluate these recommendations based on a) scientific requirements, and b) operational requirements?
- Since all high density transects have already a scientific justification, should this re-evaluation be done only for low density and frequently repeated transects?
- Discuss if there should be unified recommendations by all (OceanObs, NOAA, CLIVAR, etc) panels.
- Evaluate if there is a need for some transects to be carried together with other simultaneous observations, such as pCO2 and/or TSG (e.g. Oleander).
- Discuss if ocean models are ready to evaluate XBT transects or if the evaluation may need to be done using statistical approaches.
- There are no recommended transects at high latitudes in the North Atlantic. Would not be reasonable to have sustained XBT observations, given the importance of this region in water mass formation and the MOC?

**Low density and frequently repeated transects:**

- Is the difference between what was recommended and what is being done acceptable for the scientific and operational communities?
- Does the operational community (NCEP, MERCATOR) need data in low density and frequently repeated mode for more effective model initialization and forecast?
- Are observations made in frequently repeated mode being used by the scientific community?
- Would be acceptable for the scientific and operational communities to not have some lines that are extremely difficult to maintain because of logistics issues?
- Evaluate if after 10 years of Argo observations these profiling floats are reproducing the same type of signal that XBTs were showing in low density mode.

**High density transects:**

- Evaluate if some transects need to be sampled with XBTs going deeper than 800m.
- Is Argo producing salinity measurements with the appropriate sampling to be used together with these zonal transects for meridional heat transport computations? Evaluate if there is a need for XCTD sampling along some of the high density transects
- Is there a need for additional high density transects?

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This informal report is submitted only as my personal view and to raise questions and issues concerning the current XBT operations that I believe, if addressed, may help improve the contribution of XBT observations to science and operations. I am trying to present some issues that, if considered appropriate, may need to be discussed by several members of the community. I would prefer if you do not distribute this report.

**The OceanObs99 recommendations:**

Prior to the OceanObs99 meeting that was held in Saint Raphael (France) a white paper (The role of XBT sampling in the ocean thermal network", by Neville Smith, D. Harrison, R. Bailey, O. Alves, T. Delcroix, K. Hanawa, B. Keeley, G. Meyers, R. Molinari, and D. Roemmich) was written to examine the status of XBT observations and to provide recommendations on how to proceed with XBT observations. Additionally, some CLIVAR panels routinely provide their own recommendations when they make an assessment of the observing system in their corresponding basins. Since the recommendations provided by OceanObs99 and by the individual CLIVAR panels do not always coincide and the goals are different, the analysis of the status of the XBT network may lead to diverging conclusions. In general and from the information that I have gathered:

- The CLIVAR Indian Ocean panel has provided fairly concise XBT recommendations that sometimes do not overlap with OceanObs99,
- The CLIVAR Atlantic Ocean panel has very briefly reported on the current XBT network and was recommended to keep the network as it is, and
- I have no information on the CLIVAR Pacific Ocean panel regarding their view on the current XBT network

During the last 10 years there have been changes in the global ocean observing system, as for example the full implementation of Argo profiling float and surface drifters. Additionally, operational altimetry has contributed with added observations and the advancement of numerical models has helped with the improvement of data analysis.

Given the above, the main questions that I post here are:

- Are these OceanObs99 recommendations, done 10 years ago, still valid today?, and
- Is there a need to re-evaluate these recommendations?

**The Ship Of Opportunity Program (SOOP):**

The XBT project addresses both scientific and operational goals of NOAA for building a sustained ocean observing system. The purpose of the XBT operations and in particular of the role of NOAA in the SOOP is to coordinate the activities, carry out XBT deployments, and provide oceanographic data needed to initialize the operational seasonal-to-interannual (SI) climate forecasts prepared by NCEP. These subsurface data have been shown to be necessary for successful SI predictions. Other key uses of these data are to increase understanding of the dynamics of the SI and decadal time scale variability, to perform model validation studies, and to investigate meridional heat advection at the basin scale. Specifically, NOAA manages a global XBT network that provides subsurface temperature data. SOOP is also an international WMO-IOC program whose primary objective is to fulfill the upper ocean data requirements.

Please note that the SOOP deals with ocean observations while the VOS (Voluntary Observing Ship) Program deals with meteorological observations. However, in some occasions the activities of these two programs slightly overlap.

Besides carrying out the deployment of XBTs, the ships of the SOOP are used to deploy Argo profiling floats and surface drifters, and a few of them have TSG installed. Therefore, the operations from the SOOP are sometimes considered to be the backbone of a large part of the current ocean observing system.

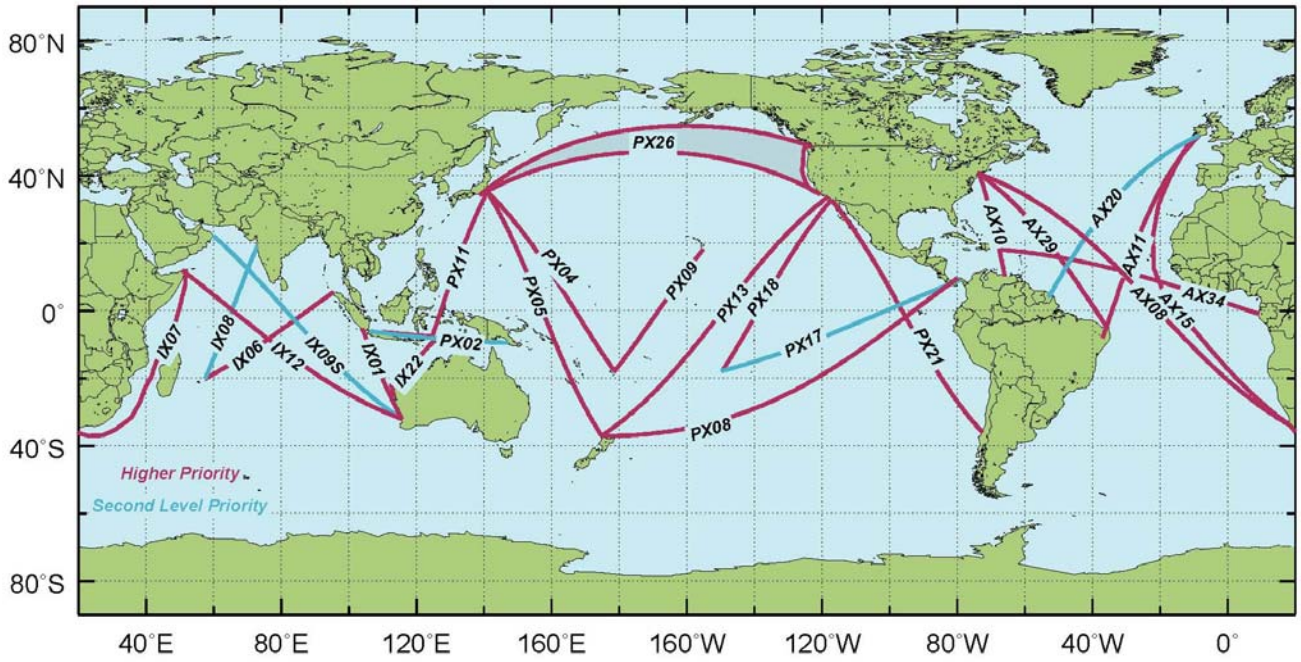
The same software (SEAS) that is used to acquire and transmit XBT observations is also used by ships of the VOS to transmit more than 200K meteorological bulletins from 350+ ships every year. Therefore NOAA/AOML SEAS provides the largest contribution of marine meteorological observations. Additionally, the headers are forwarded to the US Coast Guard as part of the Amver SEAS Program and have been successfully used several times for search and rescue operations.

**XBT transects:**

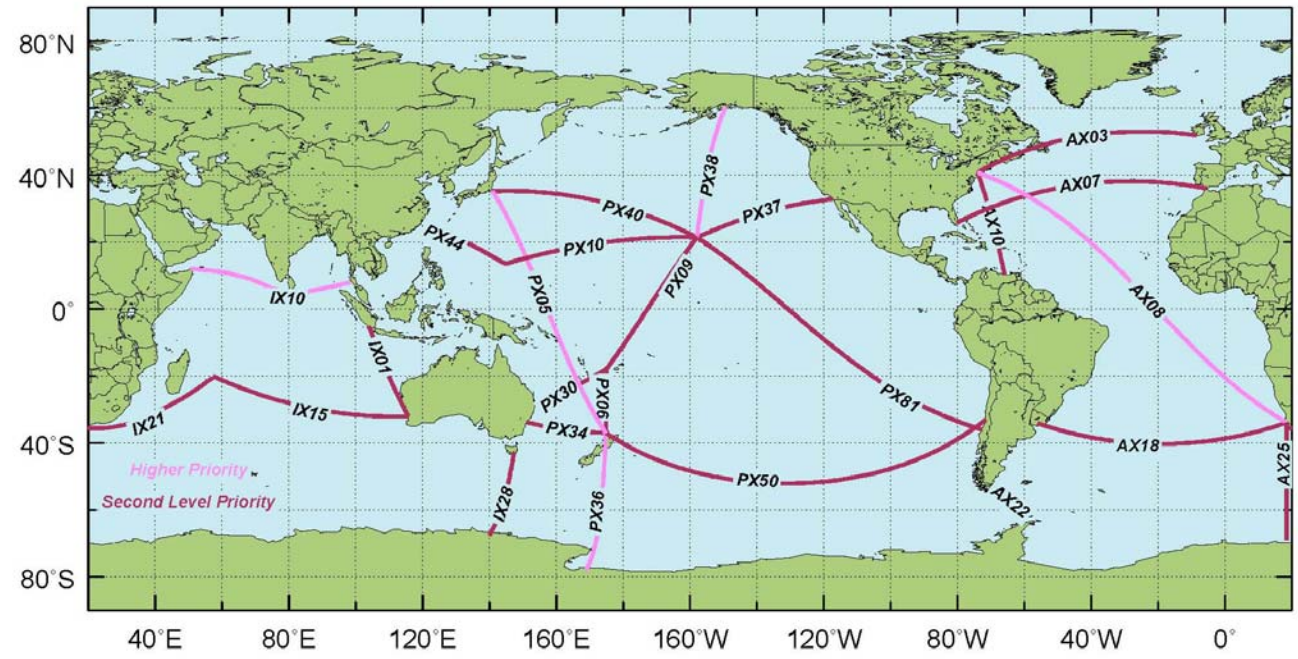
The maps below show the recommendations made by OceanObs99 for the two modes of deployment: high density (HD) and low density (LD)/frequently repeated (FRX) transects. The XBT deployments from ships of the SOOP are done in three different modes:

1. **Low density**: 12 transects per year, 4 XBT deployments per day
2. **Frequently repeated**: 18 transects per year, 6 XBT deployments per day
3. **High density**: 4 transects per year, 1 XBT deployment every approximately 25 km (35 XBT deployments per day with a ship speed of 20kts).

Frequently Repeated (FR) XBT Network, OceanObs99 Recommendations



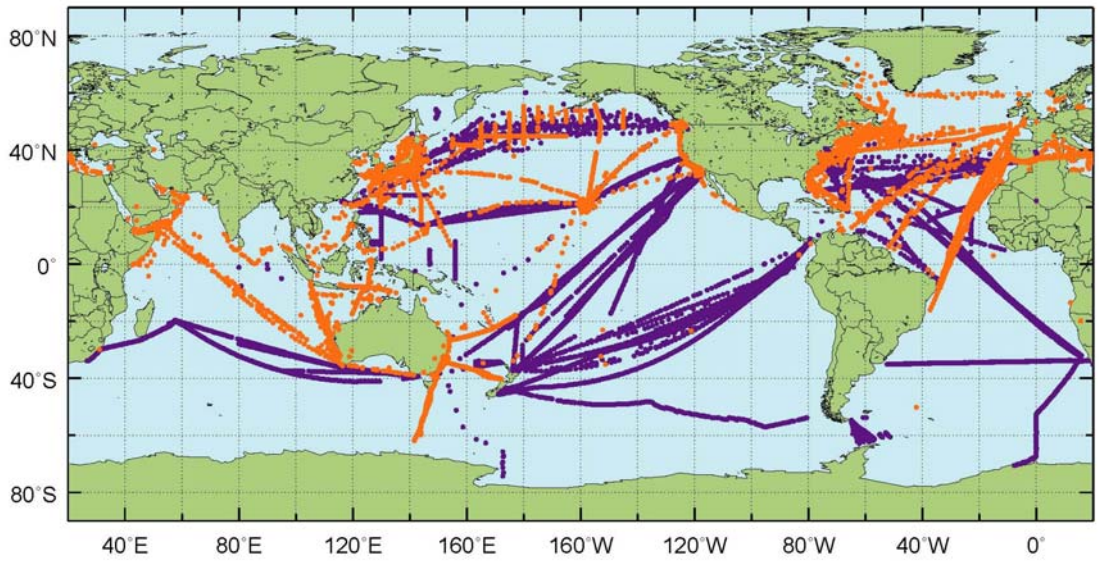

High Density (HD) XBT Network, OceanObs99 Recommendations



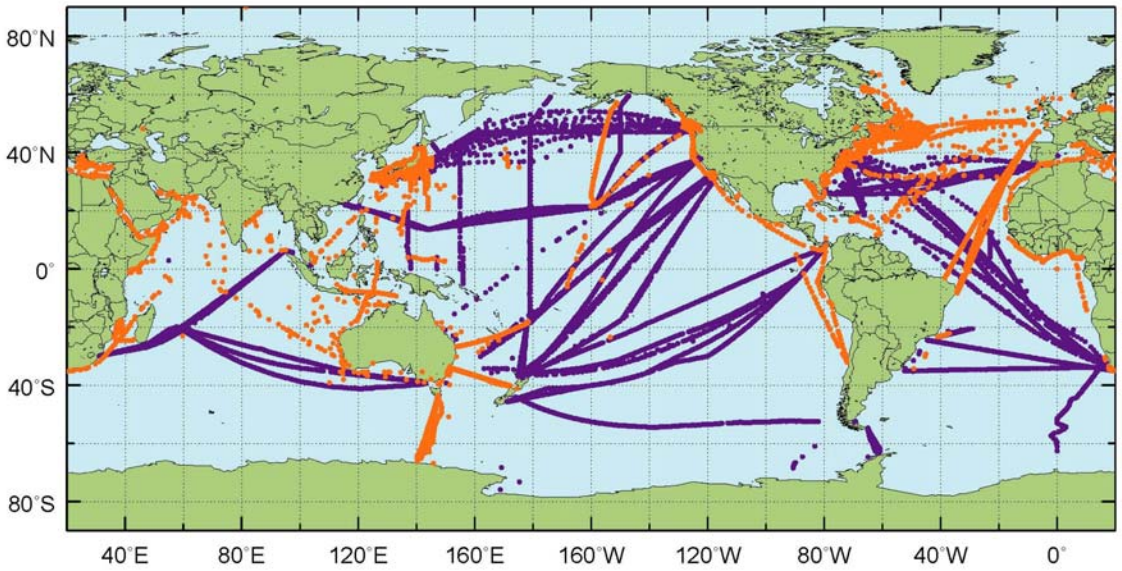
**Actual XBT deployments:**

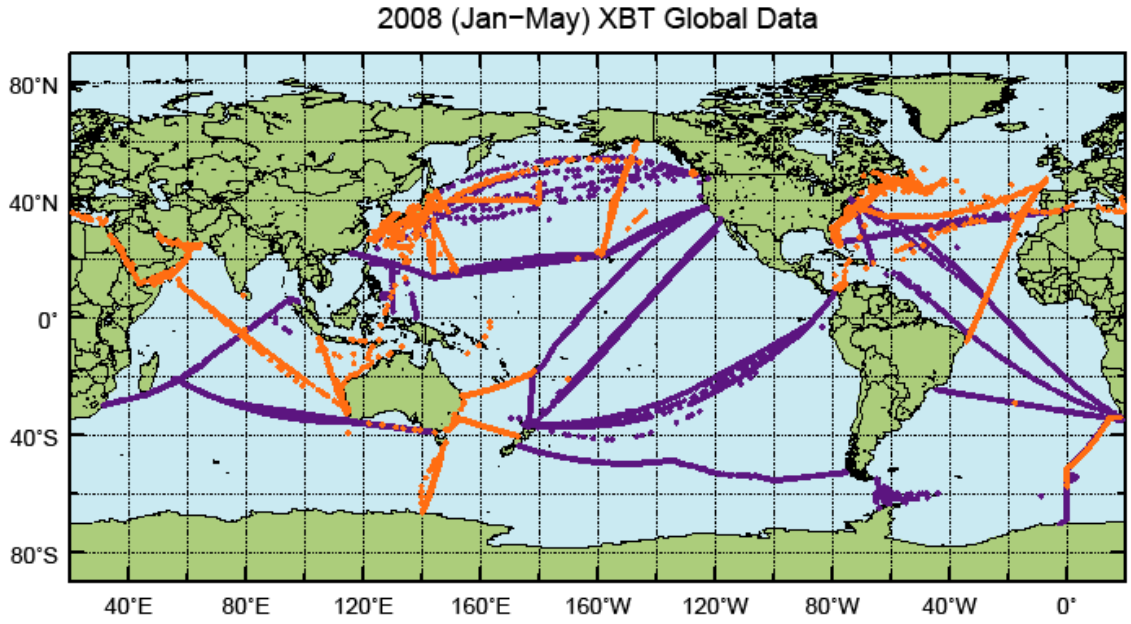
The maps bellow show the XBT observations done during 2006, 2007 and during January-June 2008 (blue are SEAS data, orange are non-SEAS data). Note that the observations from a few hundred XBT deployments are not transmitted to the GTS because some non-NOAA supported ships of the SOOP do not have real-time transmission capabilities and they are not included in this report. SEAS observations are those acquired and transmitted using NOAA/AOML SEAS software and include all AOML and SIO deployments.

2006 XBT Global Data




2007 XBT Global Data






A visual comparison between the recommendations and the actual observations, along with a more detail analysis of the lines, will lead that:

a) Many of the OceanObs99 recommended lines are being properly done,
b) Some observations are being done along lines that were not recommended. There were approximately 10 of these lines during 2007 in which some 700 XBTs were deployed.
c) Some observations are not done along lines that were recommended. There are approximately 15 of these lines.
d) Only a few recommended lines are being partly done.

I have the draft of a table with the statistics and full information for the four cases above, but going into the details is probably beyond the scope of this report.

Because of the difference between OceanObs99 and the CLIVAR panel recommendations, logistic and funding issues, etc, the actual observations have been slowly diverging from the OceanObs99 recommendations. The question remains on if there is any impact on science and operations because of these differences.

**Low density and frequently repeated lines:**

A detail of the goals of the XBT transects are clearly provided in the Smith et al white paper. The main objectives of the LD and FRX lines are to:

- Investigate intraseasonal to Interannual variability in the tropical oceans

- Measure temporal variability of boundary currents
- Characterize mesoscale baroclinic eddies

In view of the implementation of the Argo Program and, to some extend, of the availability of satellite altimetry data, the international SOOP community decided in 1999 to gradually phase out the transects made in LD mode but maintain the transects in HD and FRX modes. The actual reduction in low density sampling started in FY2006. In practice, several low density lines were dropped and others were converted to frequently repeated lines. The reasoning behind these selections was two fold:1) keep the lines that had been operated the longest, and 2) in view of the SI emphasis for the use of the XBT observations, transects (mostly zonal) that cross the Equator and are located in the subtropics were, in principle, maintained.

It is important to notice that some LD transects were dropped before Argo was fully implemented. Some may argue that there should have been an overlap period between LD XBT deployments and fully implemented Argo to investigate if Argo could/can reproduce the same type of signals that XBTs do (in low density mode). However, this was not done before the LD lines were discontinued.

In a typical year, 2500 probes are deployed in LD and FRX modes.

***Issues:***

- Is the difference between what was recommended and what is being done acceptable for the scientific and operational communities?

- Some lines (for example, PX18) in FRX mode are extremely difficult to maintain, mainly because several ships are needed to perform the18 transects per year. Most ships do not stay in the same line for a long time. Would be fine for the scientific and operational communities to not have these lines and we concentrate efforts instead in the rest of the lines?

- LD and FRX transects that have been maintained for a long time should be kept until it is demonstrated that Argo can produce the same ocean signals. Evaluate if after 10 years of Argo observations these profiling floats are reproducing the same type of signal that XBTs were showing in LD mode. If the answer is no: Should we reinstitute the LD lines that have been dropped? If the answer is yes: Is there a need to maintain LD transects?

- Does the operational community (NCEP, MERCATOR,…) need data in frequently repeated mode for more effective model initialization and forecast? In particular, it will be interesting to know if there are any studies done concerning the effect that data from LD/FRX XBT transects have on forecast models.

- Besides the data being used by these forecast centers, who else is using the XBT data in FRX mode?

- There are no recommended transects at high latitudes in the North Atlantic. Would not be reasonable, given the importance of this region in water mass formation and the MOC, to have sustained XBT observations? Note that IRD(France) sometimes uses the XBT they obtained from the international collaboration in a line that goes to Iceland. However, as this line is not recommended, it is difficult to justify its support.

**High density lines:**

The main objectives of the HD lines are to investigate:

1) Seasonal and interannual variability in the meridional transport of mass, heat and freshwater.
2) Variability of geostrophic fields
3) Variability of transports of boundary currents and ACC
4) Variability of eddy fields

- Some of the key objectives of HD transects overlap with those of FRX transects, as in the case of detecting mesoscale features, and monitoring geostrophic currents. Current HD transects have very detailed and specific scientific justifications and their data are frequently used for research purposes, therefore they should be maintained. For instance:
- Data from the zonal HD transects AX07 and AX18 have been used to monitor meridional heat transport in the Atlantic basin,
- Meridional HD transects (AX25 and AX22) across the ACC allow to study the seasonal variability and long-term change of the upper ocean structure of the Drake Passage (SIO) and south of South Africa (AOML and UCT),
- The above transects together with AX18 form a closed box allows investigating and monitoring the heat budget at high latitudes in the South Atlantic,
- Meridional transect AX08 allows to monitor zonal surface and subsurface currents and undercurrents in the tropical Atlantic, where the sea height signal is weak and, therefore, the subsurface currents are usually not detected by altimetry.

France carries one XBT transect in HD mode done under the ARAMIS project (tropical Atlantic), but it will be soon discontinued.

In a typical year, 3500 probes are deployed by NOAA/AOML in the Atlantic Ocean and 5400 are deployed by SIO in the Pacific Ocean.

***Issues:***

- Evaluate if some transects need to be sampled with XBTs going deeper than 800m. This could be very important for those transects used to compute meridional heat transport, for example AX07 and AX18.

- Is there a need for XCTD sampling along some of the HD transects? For example, the difference between monthly (Levitus) climatology and observed salinity along one AX08 transect is shown bellow. Transects such as AX08 are used to monitor mass and heat transport. It will be useful to know if these differences in salinity have any impact on the transport estimates. If so, deployments of XCTDs may be needed.

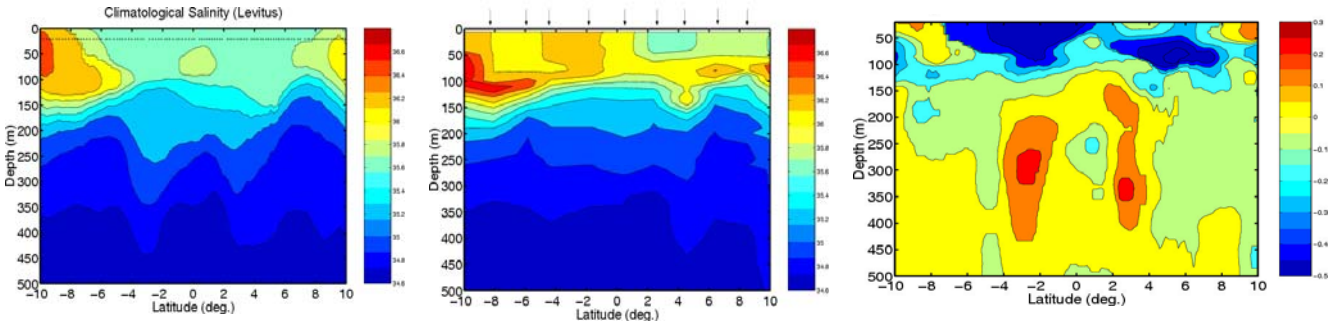



**Figure.** (right) monthly December climatological salinity along AX08, (center) actual observations made with Argo floats (December 2000), and (right) their differences.

- Is Argo producing salinity measurements with the appropriate sampling to be used together with these zonal transects for meridional heat transport computations?

- Does the operational community (NCEP, MERCATOR,…) need data in high density mode for more effective model initialization and forecast?

Altimetry can provide a good signal for surface currents, but there are subsurface currents (Atlantic NEUC for example) that may have a very weak or non existent surface (height) signal. In these cases XBT observations in HD (or even FRX) mode could be used to monitor these currents.

**International Collaboration:**

Although most LD and FRX transects are maintained exclusively by NOAA/AOML, in some cases international partners deploy NOAA/AOML probes to save the cost of ship recruiting and greeting for lines that would be difficult to maintain from the US. These partners are:

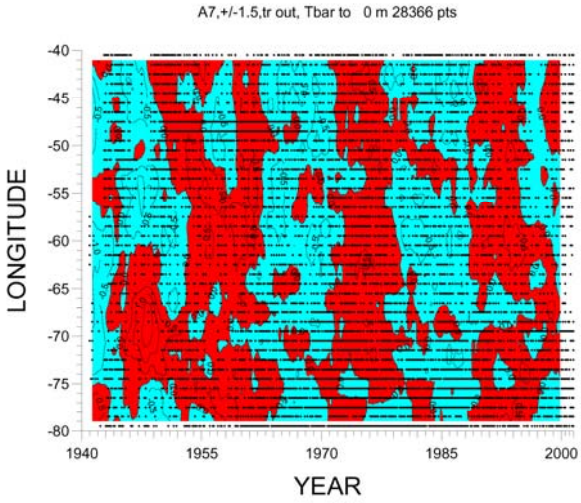
- IRD, Brest (1.5), in the Atlantic Ocean
- IRD, Noumea (1.0), in the Pacific Ocean
- BOM/CSIRO, Australia (2), in the Indian and Pacific oceans
- FURG, Brazil (1, HD only), across the Brazil Current

The contribution (in number of pallets, 1 pallet=324 XBT probes) to each of these international partners is in parenthesis.

India has started an effort to monitor IX08 with XBTs and XCTDs (Gopalakrishna Vissa, lead PI). NOAA/AOML has provided equipment and training to start carrying real-time transmission of data.

Although there are informal written agreements with these institutions on where to deploy the XBTs and on having the data transmitted in real-time, the whole operation is not always successful. We are doing our best to get these institution committed to fully comply with the agreements and we are making progress on this respect. In summary: IRD (Brest) deploys XBTs where they promised and they also transmit in real-time, IRD (Noumea) has problems with ship recruitment and data transmission in real-time, BOM/CSIRO have problems to transmit in real-time, and FURG does not transmit in real-time but forwards the data to us upon arrival of the cruise and we insert the data into the GTS.

The figure bellow (courtesy of Bob Molinari) is a space-time diagram showing a signal of long period (~10 years) found in XBT-derived SST observations along AX07 (Gibraltar-Miami). A similar figure with the space time diagram but with temperatures at 100m deep does not show this same periodicity. Models may need to be evaluated to examine if they properly reproduce this type of observed signal.




**General XBT Issues:**

- Is there a need for the revision of XBT deployments based on a) scientific requirements, and b) operational requirements?

- Since all HD transects have scientific justifications, the evaluation could be done for LD and FRX transects only,

- Discuss if there should be unified recommendations by all (OceanObs, NOAA, CLIVAR, etc) panels,
- Are observations made in FRX mode being used by the scientific community?

- Evaluate if there is a need for some transects to be carried together with other simultaneous observations, such as pCO2 and/or TSG. One excellent example of concurrent measurements is a line that transects between NYC and Bermuda and done by the Oleander. This ship has been surveying the Gulf Stream since 1992, making measurements from XBTs, ADCP, CPR (Constant Plankton Recorder), and TSG (http://www.po.gso.uri.edu/rafos/research/ole/index.html). NOAA provides the XBTs to this operation. Although this is not recognized in their web page, we are working to correct this. Please notice that the Oleander transect is not recommended,

- Discuss if ocean models are ready to evaluate XBT transects or if the evaluation may need to be done using statistical approaches,

- The cost to maintain LD/FRX should be partly taken into consideration, particularly because it sometimes involves high logistical expenses (hiring of contractors, storage places, travel). In some cases, funds could be better use to perhaps maintain additional HD transects.

An assessment of the XBT operations is always done by NOAA/AOML for the US operations and by the SOOP Implementation Panel for the international operations. A re-evaluation of the XBT transects is probably overdue in order to make these operations more efficient and to better serve the scientific and operational communities.

**Data distribution:**

- XBT data is distributed in (near) real-time through the GTS.
- NOAA/NODC archives the raw data.
- The XBT GTSPP (Global Temperature-Salinity Profile Program) had three components (NOAA/AOML for the Atlantic data, SIO for the Pacific data and CSIRO for the Indian Ocean data) to provide delayed-time quality controlled data. This program was discontinued.
- The Coriolis site provides data in (near) real-time. These data go through a quick quality control.
- NOAA/AOML posts information and raw data on their HD transects at: http://www.aoml.noaa.gov/phod/hdenxbt/high_density_home.html
- SIO posts information and raw data on their HD transects at:
- http://www-hrx.ucsd.edu/index.html
- A Google Earth (GE) kmz file can be downloaded daily from: ftp://ftp.aoml.noaa.gov/pub/phod/goni/GE. If GE is installed properly, it will show an animation of the ocean observations done during the last 30 days, separated by platform (XBTs, TSGs, Argo, moorings, etc). This file is updated daily.

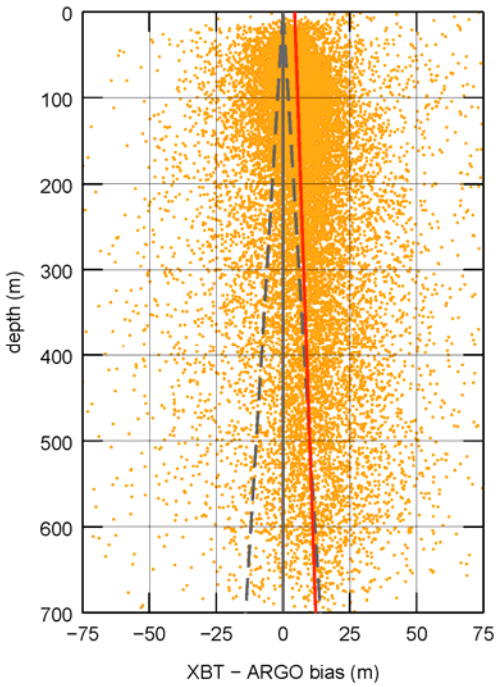
Additional questions such as where and how XBTs could better serve to study and monitor, for example, the upper ocean heat content, surface current transports, meridional heat advection, and the gyres need probably to be also addressed with particular emphasis on XBT transects.

**XBT fall rate:**

An XBT fall rate workshop took place in AOML on March 10-12, 2008, organized by Gustavo Goni and Molly Baringer of the Physical Oceanography Division at AOML. This workshop was supported by NOAA's Climate Program Office and endorsed by the World Meteorological Organization's Ship Observations Team. The workshop brought together an international group of participants, from the US, France, Australia, Italy, Switzerland, India, and Germany; to analyze small but systematic discrepancies in ocean temperature profile observations between expendable bathythermographs (XBTs) with other observing platforms, such as CTDs and Argo floats. These studies are very important when estimating long term upper ocean heat storage, since discrepancies coming from different platforms may introduce spurious climatic signals.

The ability of XBTs to collect observations with the precision required for climate studies leads to further calibration with more precise observations from CTDs or Argo floats. During the workshop experts on this issue met for the first time to exchange their knowledge, share their expertise and coordinate actions to be performed by observational centers across the world.

Throughout the workshop, a wide range of methodologies comparing XBT estimates of thermal structure with estimates obtained with Argo floats and CTDs showed positive biases that result in deeper isotherm depths for the period 2000–2007. For instance, results presented of time–mean isotherm depth differences between XBT and Argo observations as a function of depth (Figure bellow) indicate that the 2% error bounds specified by the XBT manufacturer (dash line), are different than those corresponding to the least-squares fit of these differences (red line). These results are also being compared with those obtained from experiments using side-by-side XBT and CTD casts. This field work is being carried out by scientists from NOAA and other institutions. Ultimately, these analyses resulting from the realization of this workshop will help scientists to develop a revised unified methodology to process XBT data for climate studies.




Additionally, in this workshop the metadata needs to fully identify, characterize and control the XBT data flow was discussed. This will provide useful information to establish a framework for data and metadata exchange, allowing defining different levels of metadata processing, roles and responsibilities, and setting metadata standards for current and future operational missions. Particularly and during the workshop, a new BUFR template for XBT distribution through the GTS system was outlined. This new template will serve as a basis for migrating the XBT near real time distribution scheme from the current FM 63 XI Ext. BATHY form to a table-driven code representation for data and metadata.

More information about the workshop is at:
http://www.aoml.noaa.gov/phod/goos/meetings/2008/XBT

***Issues:***

- How to proceed?
- Pending: Workshop report to be ready by mid September